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Development and application of
stressor – response relationships of
nutrients

Ligia B. Azevedo

Azevedo, LB (2014) . Developed and application of stressor – response relationships of nutrients. PhD thesis, Radboud University Nijmegen, the Netherlands.

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ISBN: 978-94-6259-231-5.

Development and application of
stressor – response relationships of
nutrients

Proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. mr. S.C.J.J. Kortmann,
volgens besluit van het college van decanen
in het openbaar te verdedigen op vrijdag 12 september 2014
om 10:30 uur precies

door

Ligia Bacchereti Azevedo
Geboren op 28 april 1983
te São Paulo, Brazilië

Promotoren:

Prof. dr. M.A.J. Huijbregts
Prof. dr. ir. A.J. Hendriks

Copromotoren:

Dr. ir. R. van Zelm
Dr. R.S.E.W. Leuven

Manuscriptcommissie:

Prof. dr. A.M. Breure
Prof. dr. L.P.M. Lamers
Prof. dr. ir. A.F. Bouwman
(Universiteit Utrecht)

Development and application of
stressor – response relationships of
nutrients

Doctoral Thesis

to obtain the degree of doctor
from Radboud University Nijmegen
on the authority of the Rector Magnificus prof. dr. S.C.J.J.
Kortmann,
according to the decision of the Council of Deans
to be defended in public on Friday, September 12, 2014
at 10.30 hours

by

Ligia Bacchereti Azevedo
Born on April 28, 1983
in São Paulo, Brazil

Supervisors:

Prof. dr. M.A.J. Huijbregts
Prof. dr. ir. A.J. Hendriks

Co-supervisors:

Dr. ir. R. van Zelm
Dr. R.S.E.W. Leuven

Doctoral Thesis Committee:

Prof. dr. A.M. Breure
Prof. dr. L.P.M. Lamers
Prof. dr. ir. A.F. Bouwman
(Universiteit Utrecht)

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Chapter 1

General introduction

General introduction

1.1 Background

1.1.1 Abiotic and biotic effects of nutrient pollution

Among the chemical elements in the periodic table, nutrients are essential to the maintenance of living cells, as they constitute organic molecules such as nucleic acids, chlorophyll, and phospholipids. Some of these nutrients are required in high concentrations and are thereby named macronutrients, e.g. carbon, nitrogen, hydrogen, phosphorus, and sulfur (Millenium Ecosystem Assessment, 2005). Historical events, such as the industrial revolution, the intensification of agricultural production, and the increase in the population and resource consumption, have led to an unprecedented increase in the flows of carbon (IPCC, 1990), phosphorus (Cordell *et al.*, 2009), sulfur (Kuylenstierna *et al.*, 2001), and nitrogen (Bouwman *et al.*, 2009). Ultimately, the excess in nutrient availability has led to impacts on biodiversity.

Anthropogenic emissions of macronutrients cause increasing stressor levels in different environmental compartments. As a result of increasing fossil fuel combustion and land use change (IPCC, 1990), the surplus of carbon dioxide in the atmosphere and its subsequent deposition into oceans lead to increasing hydrogen ion concentrations and calcium carbonate dissolution in marine water (Feely *et al.*, 2009). Phosphorus and nitrogen emissions to freshwater, originating from wastewater (Van Drecht *et al.*, 2009a), agricultural runoff, and, in the case of nitrogen, atmospheric deposition (Bouwman *et al.*, 2009), lead to increasing net primary productivity and depletion of dissolved oxygen (Carpenter *et al.*, 1998). Likewise, nitrogen and sulfur compounds emitted to the atmosphere are deposited on land afterwards (Dentener *et al.*, 2006a) and, ultimately, they lead to increasing levels of hydrogen and aluminum ions and leaching of base cations in the soil (Warfvinge & Sverdrup, 1992).

The biogeochemical processes leading to the abiotic changes described above can be estimated on a global scale with spatially explicitly models, such as with Global NEWS or GEOS Chem (Bey *et al.*, 2001, Bouwman *et al.*, 2009). Nutrient pollution may trigger biotic effects, such as declines of growth and reproduction rates (Falkengren-Grerup, 1986, Zvereva *et al.*, 2010), increases in mortality rates (Kurihara *et al.*, 2004b), and changes in species composition (Carpenter *et al.*, 1998) and richness (Zvereva *et al.*, 2008). The mechanisms by which the surplus in stressor levels affects species are numerous. In the case of ocean acidification, calcifying organisms are subjected to declines in their calcareous body mass

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as a result of calcium carbonate dissolution (Feely *et al.*, 2009), thereby affecting their growth, reproduction and survival (Kurihara *et al.*, 2004b). On land, soil pH decreases affect the reproduction and growth of plants (Falkengren-Grerup, 1986, Zvereva *et al.*, 2010) and their richness (Zvereva *et al.*, 2008). In aquatic systems, increasing primary productivity can lead to the release of allelochemicals by competing phytoplankton and decreasing supply of oxygen, both of which may be harmful to freshwater species (Leflaive & Ten-Hage, 2007, Verberk *et al.*, 2011).

1.1.2 Life cycle assessment and risk assessment

The assessment of abiotic and biotic impacts of nutrient pollution can be performed by combining existing models on the transport of pollutants with quantitative relationships of their effects on species. Two possible methods by which this can be attained are life cycle impact assessment (LCIA) and environmental risk assessment (ERA). These are described below.

In order to evaluate the environmental impact of a given product or service, a life cycle assessment (LCA) can be performed (Udo de Haes *et al.*, 2002a). In the impact assessment phase of LCA, the impact of the emission of a pollutant on the ecosystem is described with a characterization factor (CF). The CF is composed of a fate factor, whereby the transport of the pollutant of concern from its emission to its receiving location is estimated, e.g. Helmes *et al.* (2012), Roy *et al.* (2012b), and an effect factor, which describes the increase in ecosystem damage resulting from an increase in the concentration of the pollutant of concern in its receiving ecosystem. Recently, nutrient transport models were also developed within the context of life cycle assessment (LCA) on a global scale for phosphorus in inland waters (Helmes *et al.*, 2012) and nitrogen and sulfur in the atmospheric and soil compartments (Roy *et al.*, 2012a, Roy *et al.*, 2012b).

One approach for estimating the biotic effects of environmental pollution is with estimations of the ecological risk of a pollutant or group of pollutants (Fedorenkova *et al.*, 2012, van Straalen, 2002). These consist of the estimation of the risk that species are impacted as a result of exposure to a certain pollutant concentration in the environment. This risk takes into account the inherent range in tolerance of a species assemblage to the pollutant and the actual levels of the pollutant in the environment.

Unlike the CF, which estimates the environmental burden of an emission, the ecological risk approach estimates the ecological impact of a certain stressor in the environment (namely, its concentration). However,

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LCIA and ERA both employ stressor – response functions describing the impact of the concentration of a pollutant to a species group representative of a species assemblage in the environment.

1.1.3 Stressor – response functions and their underlying data

The cumulative effect of increasing nutrient pollution on an assemblage of species can be illustrated with a stressor – response function (Figure 1.1). This probabilistic model framework can be built from species sensitivity distributions of ecotoxicology (Posthuma *et al.*, 2002) and was extended to include ecological impacts due to nutrient pollution. The function may represent, for example, the increase in the fraction of species potentially affected (PAF) due to the increase of a stressor level. Likewise, the function can illustrate the decrease in the relative species richness (RSR) expected with increasing stressor levels.

Stressor – response functions can be derived using data collected in laboratory, under highly controlled conditions (Krewski *et al.*, 2009), as well as using data collected in the field, where variability in environmental conditions is more significant. Similarly to laboratory experiments, field experiments may be set up in order to test a specific hypothesis and hence their environmental variable of interest is manipulated. A famous example is nutrient addition experiments, which test if the excess of a nutrient enhances primary productivity (Schindler, 1977). These manipulated field experiments differ from observational field experiments as the latter often does not purposely modify the environmental variable of interest so as to test a hypothesis. The environmental variables, as well as the biotic response of interest, are thereby simply surveyed (Struijs *et al.*, 2011b).

Observational field experiments can be conducted at fairly lower costs compared with manipulated experiments. Besides this practical motivation, observational field experiments may more efficiently record the species in the field because they often do not specifically focus on a species or group of species beforehand and, accordingly, the inventoried species assemblage may be more representative than that of manipulated experiments. Finally, since manipulated experiments are perturbations of environmental variables so as to test a possible cause – effect relationship, they may overlook ecological processes which may begin long after the experiment has been terminated, thereby leading to misleading results or failure to detect differences among treatments (Tilman, 1987). For example, lakes may be subjected to long-term processes such as the uplift of

phosphorus from sediments into the water column (Holtan *et al.*, 1988), which may not be detected if the experiment is short.

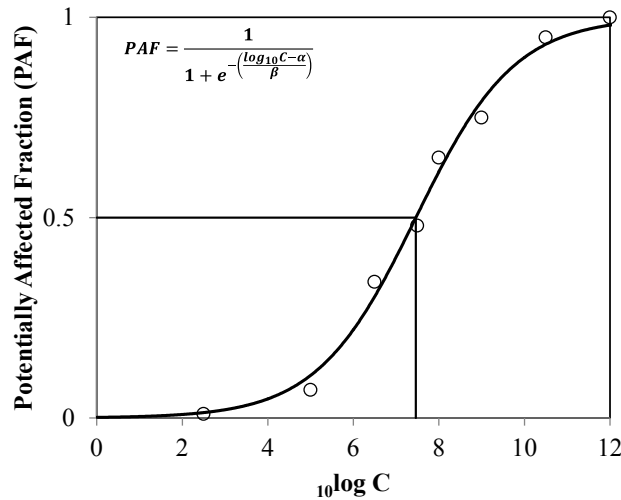


Figure 1.1 Example of a logistic function describing the potentially affected fraction (PAF) of species as a function of concentration C (e.g., $\text{mg}\cdot\text{L}^{-1}$) of stressor. The coefficients α and β of the PAF as a function of C represent the $10 \log$ concentration of C that prompts the PAF to equal 0.5 (in this case, $\alpha = 7.5$) and the slope of the log-logistic function, respectively.

1.2 Problem statement

Ecosystem-specific impact assessments of the biotic effects of nutrient pollution are common, e.g. Kozlov & Zvereva (2011), Bobbink *et al.* (2010), De Schrijver *et al.* (2011), particularly in temperate systems (Dodd *et al.*, 1994, Harpole & Tilman, 2007). Assessments of nutrient pollution impacts which are not differentiated across ecosystems have also been performed, e.g. for phosphorus eutrophication (Weijters *et al.*, 2009). Impact assessments with a focus on specific life processes as growth or mortality are relatively common (Elser *et al.*, 1996, Kurihara *et al.*, 2004b). Besides life processes, ecosystem-specific assessments based on species diversity losses following increasing levels of stressors such as eutrophication are also available on a global scale (Alkemade *et al.*, 2009, Bobbink *et al.*, 2010, Schuurkes *et al.*, 1986).

Nevertheless, large-scale assessments covering multiple ecosystems prompted by terrestrial and marine acidification or freshwater eutrophication are rare. This deficiency is also reflected in LCA and ERA, where the effects of pollutants on species diversity are available for a specific European

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ecosystems, e.g. forests (van Zelm *et al.*, 2007) or streams (Struijs *et al.*, 2011b). Furthermore, within the context of ERA, the impacts of nitrogen and phosphorus are generally performed for a single pollutant only. Additionally, in the case of nitrogen and phosphorus, assessments are either site-specific (Schindler, 2012, Schindler *et al.*, 2008) or they are performed on a global scale but without differentiation between world's regions (Weijters *et al.*, 2009). For ocean acidification, the impact of pH declines on species life processes have generally been conducted in laboratories, mesocosms and for a limited number of species only, e.g. Kurihara & Shirayama (2004) and Thomsen *et al.* (2013).

1.3 Thesis goal and outline

The goal of this thesis is to develop stressor – response relationships that allow for (1) comparisons of the relative impact of nutrient pollution across different regions, environmental compartments, or species groups, and (2) implementation into the context of LCA or ERA. To achieve this goal, relationships were developed for three categories of impact, i.e., terrestrial acidification, marine acidification, and freshwater eutrophication. Common features of these relationships were their large spatial coverages (i.e. continental or global) and the large numbers of species included in the relationships. An overview of the chapters of the thesis is given in Table 1.1.

Chapters 2 and 3 assess the impact of terrestrial acidification on vascular plant species based on observational field data. In chapter 2, the stressor – response relationships describe the changes in the relative species richness (RSR) following the changes in soil pH in multiple biogeographic regions (i.e. terrestrial biomes). In this chapter, the pH at which species richness is maximized and the coefficients of the stressor – response curves describing the effect of pH on RSR are compared across the biomes.

In chapter 3, the stressor – response curves are applied into the context of LCIA in order to estimate the relative impact of acidifying emissions on the potentially not occurring fraction (PNOF) of vascular plants. Here, the impact is calculated for individual grids (spatial resolution: 2.0 ° x 2.5°) and it integrates the atmospheric fate of acidifying pollutants and the subsequent decrease in soil pH with the relationships between pH and PNOF.

In chapter 4, the stressor – response curves describe the changes in the potentially affected fraction (PAF) of calcifying species due to changes

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in marine water pH. Here, the relationships are developed on a global scale (thus, no spatial specificity) and for three life processes (i.e. mortality, reproduction, and growth) using data from controlled experiments. The relationships are then employed into the context of ERA in order to estimate the PAF and the increases in PAF with two different climate change scenarios for individual grids (spatial resolution: $4.0^\circ \times 5.0^\circ$).

Chapters 5, 6, and 7 assess the impact of freshwater eutrophication on different species groups based on observational field data. In chapter 5, the stressor – response relationships describe the changes in the RSR of autotrophs and heterotrophs following the changes in total phosphorus (TP) in multiple biogeographic regions (i.e. freshwater habitats) and in two freshwater types (i.e. lakes and streams). Similarly to chapter 1, the TP level that maximizes species richness and the coefficients of the stressor – response curves describing the effect of TP on RSR are compared across habitats or freshwater types.

In chapter 6, the stressor – response curves are applied into the context of LCIA in order to estimate the relative impact of phosphorus emissions to water on PNOF of heterotrophs. Here, the impact is calculated for individual grids (spatial resolution: $0.5^\circ \times 0.5^\circ$) and it is estimated with a transport model of TP in freshwaters and with an effect model of the increase in PNOF following an increase in TP levels. In this chapter, the impact of TP emissions occurring in temperate European river basins is compared across lakes and streams and across three effect model types that are available for LCIA.

In chapter 7, stressor – response curves are applied into the context of ERA in order to estimate the risk that increasing TP and NO_3 cause species to become absent. Here, the risk is calculated for individual river basins of Europe and it integrates monitored environmental concentrations of N and P of the last twenty-five years and stressor – response curves describing the additive effect of TP and NO_3 on the PNOF of invertebrates.

Table 1.1 Overview of the stressor – response curved developed in each chapter

Chapter	Compartment	Category of impact	Stressor	Experiment type	Species group	Response type	Spatial coverage	Spatial resolution	Application
2	Terrestrial	Acidification	pH	Observational	Vascular plants	Occurrence change	Global	Biome	Assessment of differences in ecosystem sensitivity LCIA
3	Terrestrial	Acidification	pH	Observational	Vascular plants	Occurrence decrease	Global	Biome	LCIA
4	Marine water	Acidification	pH	Controlled	Calcifying species	Growth, mortality, and decrease in reproduction	Global	Global	ERA
5	Freshwater	Eutrophication	TP	Observational	Heterotrophs and autotrophs	Occurrence change	Global	Biome	Assessment of differences in ecosystem sensitivity LCIA
6	Freshwater	Eutrophication	TP	Observational	Heterotrophs	Occurrence decrease	Temperate Europe	River basin	LCIA
7	Freshwater	Eutrophication	TP and NO ₃	Observational	Invertebrates	Occurrence decrease	Temperate Europe	River basin	ERA

TP: total phosphorus; H: hydrogen ion; LCIA: Life Cycle Impact Assessment; ERA: Environmental Risk Assessment

Chapter 2

Global assessment of the effects of terrestrial acidification on plant species richness

Ligia B. Azevedo
Rosalie van Zelm
A. Jan Hendriks
Roland Bobbink
Mark A. J. Huijbregts

Modified version of manuscript published in *Environmental Pollution* (2013)
174: 10 – 15

Soil pH – relative species richness

MODIFICATIONS FROM PUBLISHED VERSION

- 1- The dependent variable of the logistic regression is relative species richness (RSR), not potentially occurring fraction of species (PNOF);
- 2- Figures 2.1 and 2.2 are shown in grey scale, not in color;
- 3- The projection of the map of Figure 2.1 is Gall-Peters not Plate Carée;
- 4- The symbols if Figure 2.1 represent locations of studies, not individual study sites;
- 5- Figure S2.2.2 illustrate pH in soil profile for the four biomes of focus, not all.

ABSTRACT

This study estimates the potential losses of vascular plant species richness due to terrestrial acidification for different world's biomes. We used empirical occurrence data of 2409 species from 140 studies and estimated the relative species richness – pH response curves using logistic regressions. The regressions were then used to quantify the fraction of species that are potentially lost due to soil pH changes. Although we found considerable variability within biomes, our results show that the pH at which species richness was maximized was found to be the lowest in (sub)tropical forests (pH = 4.1) and the highest in deserts (pH = 7.4). We also found that (sub)tropical moist forests are highly sensitive to decreases of in soil pH below 4.1. This study can be coupled with existing atmospheric deposition models to quantify the risk of species richness loss following soil acidification.

2.1 Introduction

Terrestrial acidification is a global threat to plant diversity and is mainly caused by atmospheric deposition of acidifying compounds (Dentener *et al.*, 2006a). Soils of low pH or with low acid neutralizing capacity are generally characterized by increased mobilization and toxicity of aluminum and other metals, leaching of base cations, and decreased nitrification and organic matter decomposition rates (Bobbink *et al.*, 2010, Knoepp & Swank, 1994, Matson *et al.*, 1999).

As a result of changes in nutrient regulation, plants may suffer from a decrease in phosphorus and magnesium content in tissue, an increase in tissue yellowing, a reduction in biomass, coverage, and root growth, unsuccessful germination and regeneration, and competitive exclusion by acid-tolerant species (Falkengren-Grerup, 1986, Roem & Berendse, 2000,

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Zvereva *et al.*, 2008). Consequently, decreased occurrence of plants in unsuitable, acidified soils has been reported in areas subjected to soil pH reductions in the past (Falkengren-Grerup, 1986, Roem & Berendse, 2000).

Here we focus on soil pH as an indicator of soil acidity since it is an important predictor of plant occurrence and it is correlated to many soil nutrients, e.g. base cations, and acidifying pollutants, e.g. aluminum and sulfur (Kozlov & Zvereva, 2011, Pepler-Lisbach & Kleyer, 2009, van Zelm *et al.*, 2007).

Up to now, studies that relate soil pH with species richness have included only a limited number of ecosystems, most of which are in middle to high latitudes (Chytrý *et al.*, 2010, Olsson *et al.*, 2009). Recently, climate has been shown to be an important predictor of the sensitivity of vascular plants to various pollutants (Kozlov & Zvereva, 2011). In warmer climates, for example, higher temperatures may increase the mobility of toxicants and the year-round production of tissue may enhance sensitivity to pollutants (Zvereva *et al.*, 2008). In addition, larger plants or plants consisting of woody tissue appear to be more sensitive to acidifying pollution than small, soft tissue ones (Zvereva *et al.*, 2010, Zvereva *et al.*, 2008).

To identify large regions according to their climate and ecological interactions and similarities (Orians, 1993), this study categorized the world into terrestrial biomes delineated by Olson *et al.* (2001). Classification on a biome level highlights the influence of soil pH while accounting for main climatic differences such as temperature, precipitation, or sunlight.

The objective of our work is to develop response relationships of vascular species richness along the pH gradient for different world's biomes. The response relationships were attained for the acidic pH gradient, up to levels where vascular species richness is maximized. Here we define species richness as the total number of vascular species (trees, herbs, shrubs, etc.) occurring on a soil of a given soil pH. Vascular plants are important not only because they comprise a vast number of species of plants but also due to their contribution to a considerable portion of primary production in the terrestrial system. Response relationships of species richness and pH can be used for predictions of the potential reductions of biodiversity due to soil property changes (van Zelm *et al.*, 2007). Connecting pH response curves to pollutant transport models, including their impacts on soil properties, may give insight into the impact of acidifying pollution at large spatial scales, help identify sensitive areas, and indicate where acidifying pollution

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reduction efforts should be concentrated (Mac Nally & Fleishman, 2004, van Zelm *et al.*, 2007).

2.2 Material and methods

In order to estimate the relative vascular plant species richness – pH patterns, we first gathered field observational data from the literature relating individual species occurrence and soil pH to derive empirical relationships of species richness along the soil pH gradient. Second, we performed a logistic regression analysis to arrive at pH – response functions for the different biomes. The steps of gathering literature data to finally determining response functions are described below and illustrated in appendix S2.1 of the Supporting Information.

2.2.1 Data gathering

We collected peer-reviewed studies available up to September 2010 consulting Web of Science with the following keywords: (1) pH; and (2) either soil, ground, land, or terrestrial; and (3) either cover, abundance, species richness, species frequency, extinction, presence, absence, diversity, biodiversity, community, occurrence, or biomass; and (4) either plantation, plant, plants, vegetation, vegetative, flora, forest, tree, or trees. This keyword combination allowed the retrieval of approximately 4000 peer-reviewed studies that were considered for our data inventory. We then manually selected the studies that fulfilled the following criteria.

We excluded croplands or urban studies as they do not reflect the natural vegetation of the area and included studies based on abandoned, restored, re-vegetated areas, and semi-natural grasslands since they are also subjected to biodiversity losses due to terrestrial acidification. Additionally, we only included exploratory, survey studies that reported a specific quantitative relationship between pH and vascular plant species. We only considered species and not higher taxonomic groups (e.g. family, class, etc.). An exception was made for genus-level records when those did not accompany any other species belonging to that genus. Lower taxonomic level records (i.e. subspecies, variety) were also included and were considered equal to a species record.

2.2.2 Data handling

First, pH values were standardized to a representative soil depth and to water extracted pH (pH-H₂O). When more than one pH was reported for a given soil (e.g. multiple horizons), we used the value that was closest to

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either the B horizon or to 50cm of soil depth. This is the soil horizon where there is accumulation of clay minerals such as iron and aluminum and the approximate depth at which roots are present in all biomes (Canadell *et al.*, 1996). For the studies reporting soil pH by KCl or CaCl₂ and not by H₂O extraction (fifteen in total), we converted pH – KCl and pH – CaCl₂ values to pH-H₂O using data from the ISRIC-World Soil Information database (Batjes, 2009), appendix S2.2.

Second, we standardized the species name records using The Plant List (2010) so as to correct for synonyms. Since species occurrence was reported in different ways (i.e. biomass, percent cover, abundance) we adapted the data to a presence or absence format by transforming any number higher than zero to species presence and any zero value to species absence.

Subsequently, we allocated each of the selected studies to one of the biomes based on the vegetation coverage described by their authors. Studies describing a vegetation pattern that either did not fit the biome classification system described by Olson *et al.* (2001) or that were described as a transition zone between two biomes were excluded.

Following this, we derived the pH range at which each plant species can occur within the biome. We considered a species to be absent at pH values outside its reported pH range. The soil pH range obtained from each study was set equal to the mean pH \pm 1.645 times the reported standard deviation (i.e. 90% of sample population) following Latour *et al.* (1994). For forty studies that did not report mean and standard deviation values, but the minimum – maximum pH ranges were used instead, e.g. Karim & Mallik (2008). Finally, we determined the range between the minimum and maximum pH of each specific plant species per biome as the pH occurrence range for that species. If a species was reported in more than one study within the same biome, we used the lower and upper pH boundaries as the overall species occurrence range. From the pH occurrence ranges of the species within each biome, we excluded the species that were reported at a single mean pH value (273 of 3311 species – biome combinations) because these data are not representative of the tolerance pH range where a species is found in the environment.

2.2.3 Response curves

We computed the species richness (SR) as the sum of present species at each 0.1 pH unit i value within each biome j as

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$$SR_{i,j} = \sum_{i,j} pH_{i,j} O_{i,j} \quad (2.1)$$

where O is the occurrence of each species at pH i in biome j . O is 0 when the species was reported absent and 1 if the species was reported present.

In a subsequent step, so as to compare biomes with dissimilar species richness, e.g. temperate vs. (sub)tropical forest, the species richness results in each biome were transformed into a zero-to-one measure described as the empirical relative species richness (eRSR) as

$$eRSR_{i,j} = 1 - \frac{SR_{i,j}}{SR_{opt,j}}, \text{ for } pH_{i,j} \leq pH_{opt,j} \quad (2.2)$$

where $SR_{i,j}$ is the number of species present at pH i and $S_{opt,j}$ is the highest species richness along the pH gradient of biome j . An eRSR of one represents the optimum pH condition ($pH_{opt,j}$) or optimum pH conditions (range of pH_{opt}), where species richness equals $SR_{opt,j}$; while an eRSR of one represents the complete absence of species.

We calculated logistic functions of RSR (cRSR) by fitting them to the empirical eRSR data. The use of logistic functions follows the calculation procedure commonly adopted in ecotoxicology to arrive at species sensitivity distributions for toxic chemicals and population modeling studies (De Zwart, 2001). They are represented as

$$eRSR_{i,j} = \frac{1}{1 + e^{-\frac{(pH_{i,j} - \alpha_j)}{\beta_j}}}, \text{ for } pH_{i,j} \leq pH_{opt,j} \quad (2.3)$$

where cRSR_{*i,j*} is the calculated RSR at pH i of biome j below or equal to $pH_{opt,j}$ (equation 2.3). At pH levels above pH_{opt} , species richness is not affected by acidic soil conditions but by other stressors, which we do not account in this study, such as sodium toxicity, etc. Coefficient α represents the pH at which the relative species richness is 0.5 and β represents the relative change in species richness with pH. Biomes with low β values comprise the ecosystems with the steepest slope in the logistic function. We fitted α and β coefficients using logistic regression in SAS 9.2. The sample size for cRSR is given by the number of cRSR – pH data points (with a 0.1 pH interval) observed from the lower end of the pH gradient up until the pH optimum. The confidence intervals were reported at a 95% confidence level.

2.2.4 Sensitivity analysis

In order to evaluate the uncertainty in the pH-response curves within biomes, we performed a sensitivity analysis for two additional levels of spatial aggregation: Ecoregion and individual sites (study) within each biome. That was attained by allocating the studies to ecoregions instead of biomes (Olson *et al.*, 2001). Ecoregions are biogeographical subunits of specific biomes thus they offer a higher resolution of the existing vegetation. We then used the same methodology as described above and derived ecoregion-specific and site-specific logistic functions.

2.3 Results

A total of 140 studies fulfilled our selection criteria (appendix S2.3) which, in total, comprised 2409 vascular plant species (see Table S2.4.2., appendix S2.4, for their respective pH range within each biome). The number of studies within biomes varied from 2 (i.e. flooded grasslands and savanna, mangrove, and montane grassland and shrubland) to 55 (temperate broadleaf mixed forest), Table 2.1. The location of each study is shown in Figure 2.1.

In (sub)tropical moist broadleaf forests, the optimum pH was the lowest (4.1) while in desert and xeric shrublands and mediterranean forests, woodland and scrub, the optimum pH was the highest (7.4 to 7.8). Biomes within the temperate zone have rather similar optimum pHs, i.e. broadleaf mixed and coniferous forests, and grassland, savanna, and shrubland (4.7 to 5.1). The logistic regressions for all biomes indicate an association between decreasing RSR and pH decreasing (Figure 2.2).

Our results show that (sub)tropical moist broadleaf forest have steep cRSR slopes ($\beta = 0.18$ to 0.25 , Table 2.2). This indicates that terrestrial acidification could cause the highest decreases in RSR (thus the steepest species loss) in that biome.

Studies were available for a total of fifty-six ecoregions distributed across the thirteen biomes for comparisons of different spatial aggregation levels, (Table S2.5.1, appendix S2.5) and we were able to derive logistic functions for nineteen of them (Table S2.5.2, appendix S2.5). At a site (i.e. study) spatial resolution, we were able to derive logistic functions for thirty-three out of 140 individual studies (Table S2.5.3, appendix S2.5). We found higher optimum pHs for ecoregions (from 7.0 to 7.5) and sites (from 7.0 to 8.3) within desert and xeric shrubland compared to temperate broadleaf mixed

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forest and (sub)tropical moist broadleaf forests, which varied from 4.0 to 7.2 at the ecoregion level and 4.0 to 7.5 at the site level. Likewise, α

coefficients were consistently higher in desert and xeric shrublands (from 6.2 to 8.3) compared to temperate broadleaf mixed forest and (sub)tropical moist broadleaf forest (from 3.1 to 6.1). However, no difference was observed in β results across biomes at the ecoregion and site spatial resolution level.

Table 2.1 Total numbers of studies and species per biome, the total number of species in the optimum pH, the pH range of species occurrence and the (range of) optimum pH.

Biome	Studies	Species	Species in the optimum pH ($SR_{opt,i}$)	pH range	(Range of) pH optimum
(Sub)tropical Moist Broadleaf Forest	17	533	358	3 to 8.2	4.1
(Sub)tropical grassland, savanna, and shrubland	3	131	107	4.5 to 6.1	4.9
Mangrove	2	25	25	3.4 to 7.2	4.3 to 6.0
(Sub)tropical dry broadleaf forest	3	139	65	5.5 to 8.5	7
Flooded grassland and savanna	2	18	18	5.3 to 6.9	5.9 to 6.6
Desert and xeric shrubland	17	350	293	5.1 to 10.5	7.4
Mediterranean Forest, Woodland, and Shrubland	4	31	13	4.9 to 8.6	7.8
Temperate Broadleaf Mixed Forest	55	682	473	2.4 to 9.4	4.7 to 5.1
Temperate Grassland, Savanna, and Shrubland	17	422	325	2.6 to 9.1	5.1 to 5.7
Temperate Coniferous Forest	8	230	191	3.1 to 8.3	4.7 to 4.8
Montane grassland and shrubland	2	138	138	5.5 to 7	6.0 to 7.0
Boreal Forest / Taiga	4	90	77	3.2 to 7.7	5.3
Tundra and alpine	6	171	111	4 to 7.9	7.0 to 7.3

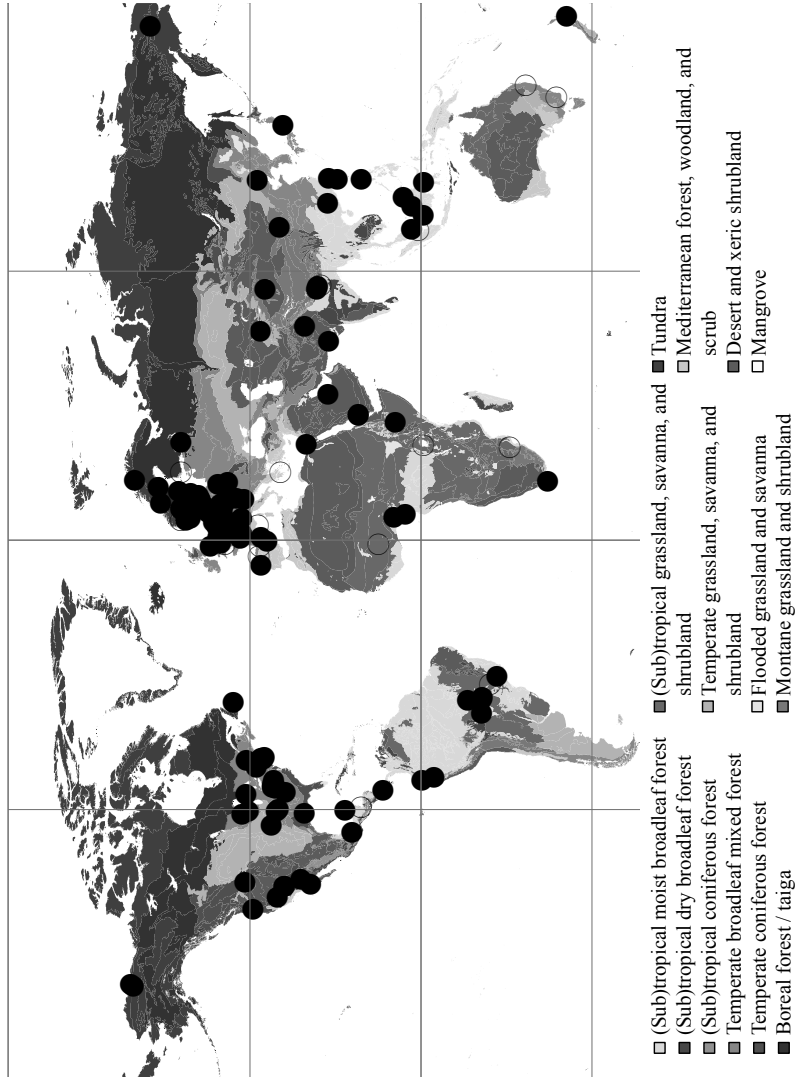


Figure 2.1 Biomes delineated by Olson et al. (2001) and the location of the 136 studies included in our paper. The sites where the described vegetation in each study corresponds to the biome where it is located (total of 118) and where the described vegetation is outside the boundaries of the corresponding biome (total of 16) are represented by closed and open circles, respectively.

Soil pH – relative species richness

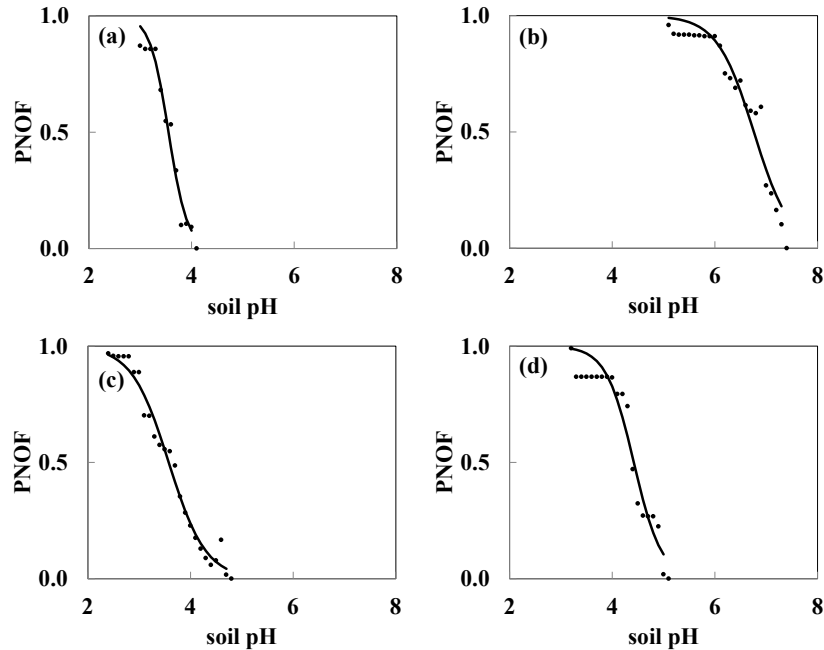


Figure 2.2 Examples of response curves for the relative species richness (RSR) of plants along the soil pH range shown for (a) (sub)tropical moist broadleaf forest, (b) desert and xeric shrubland, (c) temperate broadleaf mixed forest, and (d) temperate grassland, savanna, and shrubland. Dots and lines represent, respectively, the empirical (eRSR) and the calculated (cRSR).

2.4 Discussion

We predicted the relative vascular plant species richness – soil pH patterns, expressed as RSR, aggregated at the ecosystem (biome) level. In the following, we discuss the sources of uncertainty involved in our study. Furthermore, we assess the validity of our results by suggesting ecological arguments for the differences in the PNOF – pH relationships across ecosystems.

2.4.1 Uncertainty

First, it should be stressed that the RSR reveals relative changes in overall vascular plants richness but not in individual species. Also, we do not analyze differentiated responses of specific functional traits, of specific native plants, or taxonomic groups. Hence, designating an optimum (or range of optimum) pH based on the maximized number of species may not necessarily associate with the least modified, most “pristine” soil condition.

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Our results should thus be interpreted at the community level instead of at the species level.

Secondly, the number of studies differed considerably across biomes, which affected the number of species available in each biome (Table 2.1). For example, despite the high biodiversity in (sub)tropical biomes, we found more species reported in the temperate broadleaf mixed forest biome (Table 2.1). Given the low number of species available to derive logistic regressions in poorly covered biomes (e.g. mangroves, mediterranean forest, woodland, and scrub, and flooded grassland and savanna), the results for these biomes should be interpreted with caution. Therefore, interpretation is focused on biomes which are better covered by a number of studies and species.

Thirdly, for the temperate broadleaf mixed forest biome especially, there were a large number of European studies found. Given that we clustered all the studies into the same biogeographical region, there may be an over-representation of European species in this biome.

A fourth source of uncertainty is that our regressions were based on empirical data reporting the occurrence of plant species at a particular pH range. Our assumption is that, outside that range, the species was not observed thus it may have become absent.. Within the pH occurrence range, the species is always considered to be present. Ultimately, in our field-based study, species absence could have been due to an unreported species occurrence outside the pH boundaries. Our approach differs from controlled, laboratory-based standard species sensitivity distributions, where the environmental conditions and the species of interest are deliberately chosen (Posthuma *et al.*, 2002, Tilman, 1987). In controlled studies, conditions that determine species presence can be ascertained with a higher level of certainty. If the ranges of species occurrence were broader than what we were able to determine, the species richness would be maintained at lower pH conditions. Accordingly, the pH level where RSR is 0.5 would be lower than those currently reported.

Fifth, the conversion of pH-KCl and pH-CaCl₂ to pH-H₂O could have introduced uncertainty to the range of pH occurrence of each species. The conversion from CaCl₂ and KCl to H₂O extracted pH varied up to 1 and 2 pH units, respectively (appendix S2.2). This uncertainty may have been larger in temperate grassland, savanna, and shrubland and temperate broadleaf mixed forest biomes, where 17 to 20% of studies required conversion. Desert and xeric shrublands required no conversion to H₂O-extraction.

Table 2.2 Logistic regressions coefficients α and β (95% confidence interval) for the RSR curves.

Biome	α	β	R^2 [#]
(Sub)Tropical Moist Broadleaf Forest	3.55 (3.51 to 3.6)	0.18 (0.14 to 0.22)	0.97
(Sub)tropical grassland, savanna, and shrubland [#]	4.55 (4.40 to 4.70)	0.16 (NS)	
Mangrove	3.72 (3.67 to 3.77)	0.25 (0.20 to 0.30)	0.95
(Sub)tropical dry broadleaf forest	Model did not fit the empirical data		
Flooded grassland and savanna	5.31 (5.10 to 5.51)	0.33 (0.14 to 0.53)	0.73
Desert and xeric shrubland	6.76 (6.68 to 6.83)	0.36 (0.28 to 0.36)	0.94
Mediterranean Forest, Woodland, and Shrubland	6.64 (6.21 to 7.08)	1.18 (0.54 to 1.83)	0.42
Temperate Broadleaf Mixed Forest	3.57 (3.53 to 3.61)	0.36 (0.32 to 0.40)	0.98
Temperate Grassland, Savanna, and Shrubland	4.42 (4.37 to 4.47)	0.26 (0.22 to 0.31)	0.95
Temperate Coniferous Forest	3.33 (3.17 to 3.50)	0.28 (0.11 to 0.44)	0.65
Montane grassland and shrubland [#]	5.92 (NS)	0.01 (NS)	
Boreal Forest / Taiga	4.21 (4.09 to 4.32)	0.69 (0.55 to 0.84)	0.89
Tundra and alpine	4.76 (4.62 to 4.90)	0.47 (0.33 to 0.61)	0.86

[#] One (or both) logistic coefficients are non-significant at a 95% confidence level

[#] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{corrected}}$, as defined by Schabenberger & Pierce (2001)

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Our data set encompasses present-time, exploratory species occurrence studies of the last 20 years. Since acidifying pollution began much earlier than this, we cannot account for potential adaptation strategies that plants may have developed prior to the modification of the environment, e.g. increase in β -diversity, even though such adaptations are known to exist (Kozlov & Zvereva, 2011, Trubina & Vorobeichik, 2012). Also, a biome located in an area that has been exposed to intense air pollution, e.g. temperate broadleaf mixed forests, may have species that are less representative of their original assemblage or may have optimum pH lower than prior to air pollution compared to biomes which were subjected to acid deposition. Availability of nutrients such as nitrogen and phosphorus, which also relates to soil pH, may explain part of the remaining co-variance (Roem & Berendse, 2000).

Finally, the log-logistic results at the ecoregion and site spatial resolutions showed that there can be major differences between the logistic regression results representing plant communities of a biome. This may be remedied by applying more spatial to derive the regressions. However, this approach would include considerably fewer species per spatial unit and a reduced range of pH where species occur. Consequently, the logistic regression we proposed often did not fit the empirical data at an increasing level of spatial resolution. This inherent spatial variability may also be explained by the existence of ecoregions transitioning between two ecosystems, e.g. the Central forest-grassland transition ecoregion, or of studies corresponding to a certain biome but that are located within the boundaries of another biome (open circles in Figure 2.1). In these cases, the studies were allocated to biomes based on their vegetation description, not their position in the map.

2.4.2 Response curves

The differences in the pH optima and the response curves across biomes may be explained by intrinsic differences across biomes. Soil pH follows a latitudinal gradient in which the highest pH values occur at mid-latitudes (approximately 30° distant from the Equator line) while the lowest pH values occur in tropical regions (Pärtel, 2002), Figure S2.2.2. This trend is similar for the optimum pH of biomes found in this study (Table 2.1). For example, the highest optimum pH is observed in soils of deserts and xeric shrublands, which are subjected to low precipitation and cation accumulation combined with high soil evaporation (Smith *et al.*, 2002). Intermediately, mid to high latitude biomes, located in the temperate zone, are subjected to continuous sediment deposition from glaciations, e.g. temperate grassland,

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savanna, and shrubland (Pärtel, 2002). Conversely, (sub)tropical moist forests, generally comprising “ancient” soils, have low soil pH because they are subjected to strong long-term weathering of base cations without additional input of nutrient-rich sediments, in addition to increased solubility of ammonium, aluminum and manganese (Matson *et al.*, 1999).

The adaptation of plants to specific environmental conditions for which they have been subjected is explained by the species pool hypothesis (Hajek *et al.*, 2007, Pärtel, 2002). Species richness is maximized at low pH values in traditionally low soil pH biomes and at high pH values in traditionally high soil pH biomes (Chytrý *et al.*, 2010, Pärtel, 2002). For example, in southwestern African desert, the highest number of species was found between pH levels of 7.0 to 7.5 (Medinski *et al.*, 2010) while in the Appalachian Mountains, comprising temperate broadleaf mixed forests, maximum species richness is found at a pH of 4.0 to 5.0 (Peet *et al.*, 2003). The high tolerance to acidic conditions in (sub)tropical moist broadleaf forests is also reflected by the high incidence of species belonging to families that are known to comprise a large number of aluminum-tolerant plants, i.e. Melastomataceae, Theaceae, and Symplocaceae (Hayde Gonzalez-Santana *et al.*, 2012).

Species richness – soil pH relationships are often reported as linear (Schuster & Diekmann, 2003). However, even though there is an increasing fraction of species that perish with decreasing pH, this rate is reduced at increasingly acidic conditions, suggesting that the species richness – pH relationship is non-linear. While species that cannot sustain acidic conditions are reduced, the total number of species is still maintained by a few ‘specialist’ species that are able to sustain (or exist exclusively) at acidic conditions or that are able to adapt to new conditions, such as grasses (Falkengren-Grerup, 1986, Kozlov & Zvereva, 2011).

Although we found that (sub)tropical moist forests hold the highest number of species at acidic conditions, they are also highly sensitive to further increases in acidity compared to other biomes. This is illustrated by the steeper slope (lower β coefficient) of the log-logistic function, which represents the change in sensitivity associated with variation in soil pH.

Two aspects (the size and the physiology of plants) may help to explain the difference in the sensitivity of biomes to acidifying conditions. Previous studies report that grasses and smaller plants (herbaceous) are less sensitive to pollutants (e.g. aluminum or SO₂) than larger plants (Zvereva *et al.*, 2010, Zvereva *et al.*, 2008). Broadleaf mixed forests and grassland,

savanna, and shrublands in the temperate zone were comprised of a high number of grasses and sedges (species of the Cyperaceae, Juncaceae, and Poaceae families). Small size plants, which are adapted to lessen evapotranspiration, dominated the desert and xeric shrubland biome, e.g. species of the Amaranthaceae and Cactaceae families. (Sub)tropical moist forests, on the other hand, encompassed large evergreen trees, e.g. Lauraceae, Myrtaceae species.

Toxic levels triggered by acidic conditions are particularly harmful to young roots (Zvereva *et al.*, 2008). In addition, roots tend to grow to deeper layers in arid soils (Wilcox *et al.*, 2004), which may become less exposed to the deposition of acidifying compounds. In opposition to colder (higher latitude) biomes, the high rate and year-round production of plant tissue in (sub)tropical moist forests may increase tissue exposure to acidic conditions and increase their sensitivity to low pH conditions. Mangroves, likewise, may be exposed to heavy metals following oxygenation of iron sulfide-rich soils (Amaral *et al.*, 2011). The decreasing sensitivity to pollution with increasing latitude and decreasing temperature and precipitation has been observed in previous meta-analysis studies (Zvereva *et al.*, 2010, Zvereva *et al.*, 2008).

2.5 Conclusion

The results of this study describe general patterns that illustrate the increase in the fraction of species that may disappear with acidifying conditions at a spatial resolution equivalent to biomes. When a sensitivity analysis at higher spatial resolutions was performed (ecoregions and individual sites), we identified a considerable spatial variability within biomes, especially in the slope (β) of the logistic regressions, β . Furthermore, the results relating to many biomes were based on a small number of available species due to the low availability of studies performed in these regions. In this study, we used biomes as the spatial resolution since enhancing geographical coverage can increase the explanatory power of biogeographical patterns such as species richness – pH relationships (Field *et al.*, 2009).

Our results suggest that regions within the (sub)tropical moist broadleaf forest may suffer great changes in species richness following a soil acidification. This is an alarming situation given that soils in the (sub)tropical climate zone have very low acid neutralizing capacity (Dentener *et al.*, 2006b, Kuylenstierna *et al.*, 2001). The results of our study

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can be used with atmospheric pollutant transport and soil fate models so as to link acidifying air emissions to their ultimate biodiversity risk.

ACKNOWLEDGMENTS

This research was funded by the European Commission under the 7th framework program on environment; ENV.2009.3.3.2.1: LC-IMPACT – Improved Life Cycle Impact Assessment methods (LCIA) for better sustainability assessment of technologies, grant agreement number 243827. We thank the three reviewers for comments on the previous version of the manuscript, Pierre-Olivier Roy for his advice on data compilation, Joop J.H. Schaminée for his advice on plant taxonomy, Rob S. E. W. Leuven for methodological insights, and Jon Matthews for proofreading the text.

Chapter 3

Characterization factors for terrestrial acidification: a systematic analysis of spatial variability and uncertainty on a global scale

Pierre-Olivier Roy
Ligia B. Azevedo
Manuele Margni
Rosalie van Zelm
Louise Deschênes
Mark A. J. Huijbregts

Submitted

Characterization factors for terrestrial acidification

ABSTRACT

Characterization factors (CFs) that quantify the impact of acidifying emissions on the richness of terrestrial plant species in life cycle assessment (LCA) are currently available on a European continental level only. This paper provides $2^{\circ} \times 2.5^{\circ}$ spatially-explicit CFs for terrestrial acidification by emissions of nitrogen oxides (NO_x), ammonia (NH_3) and sulphur dioxide (SO_2) at the global scale. The CF quantifies the change in relative loss of terrestrial plant species due to acidic pH due to an acidifying emission change. The CF considers the change in atmospheric acid deposition due to an emission change (atmospheric fate factor) which, according to the soil buffer capacity, increase the soil solution H^+ concentration (soil sensitivity factor) which, in turn, may lead to a loss in relative vascular plant species richness (effect factor). Emission locations in central Asia, central Africa and Canada were shown to have the highest consequences on terrestrial acidification. We found that the soil sensitivity factor is the dominant contributor to spatial variability in the CFs and that is over six orders of magnitude. The CFs provided in our study allows the worldwide spatially explicit evaluation of impacts related to acidifying emissions on the relative loss of vascular terrestrial plant species for a LCIA purposes. This opens the door to evaluating the regional life cycle emissions of different products in a global economy.

3.1 Introduction

Terrestrial acidification is the result of atmospheric acidifying emissions such as nitrogen oxides (NO_x), ammonia (NH_3) and sulphur dioxide (SO_2) and their subsequent deposition on soils, which may in turn decrease the soil's solution pH. A large pH deviation will impact the relative loss of plant species of terrestrial ecosystems (Thomsen *et al.*, 2013).

Global scale terrestrial acidification impact evaluation has thus far focused on a receptor's framework by evaluating the level of acid deposits (Volkoff, 1998), the receptor sensitivity with a critical load approach (Bouwman *et al.*, 2002, Kuylenstierna *et al.*, 2001) or, more recently, by quantifying an increase of H^+ ions in the soil solution, on a specific surface, following acid deposition (Roy *et al.*, 2012a). This paper integrates atmospheric source-receptor relationships (shifting the perspective from receptor to source location), subsequent proton soil solution increases, and finally changes in relative species richness due to acidifying effects.

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Life cycle assessment (LCA) evaluates the potential impacts of a product or service throughout its life cycle (Udo de Haes *et al.*, 2002a). The potential environmental impacts of a given life cycle emission inventory are assessed using characterization factors (CFs). Endpoint level CFs are a mathematical representation of the cause-effect chain that links an emission to the ultimate impact of a given area of protection, e.g. human health, biodiversity loss (Udo de Haes *et al.*, 2002a). Historically, LCA evaluated potential impacts in a standardized or generic *unit world* and with simplified modeling of a typical pollutant's fate, exposure, and effect pattern (Chan & Connolly, 2013). However, Potting *et al.* (1998a) showed that source location and surrounding conditions strongly influenced CFs. Therefore, developments shifted to country- or continent-dependent CFs representative of certain regions, such as Europe, the United States or Japan (Bare, 2002, Goedkoop & Spriensma, 2001, Hayashi *et al.*, 2004, Huijbregts *et al.*, 2000, Potting *et al.*, 1998b, Seppälä *et al.*, 2006, van Zelm *et al.*, 2007). Yet, applying existing CFs implicitly assumes that every emission in the life cycle inventory of a product occurs in the specified region, which is not the case in our global market economy. Up to now, there is no spatially-explicit CFs for terrestrial acidification at the global scale.

Furthermore, current CFs do not account for the transport and sensitivity of acidifying emissions outside the considered geographical context. Neglecting transboundary transport to areas with limited buffer capacity (i.e. sensitive areas) may result in a large underestimation of CFs. Finally, while the spatial variability of CFs in many impact categories, including acidification, has been evaluated (Orr *et al.*, 2005), uncertainties, arising from not knowing exact model input parameters, are seldom considered in CF calculations. It has, however, been recognized that uncertainty evaluation is required in order to support LCA results interpretation (Finnveden *et al.*, 2009).

The objective of this paper is to develop spatially-explicit CFs for NO_x, NH₃ and SO₂ at the global scale with a spatial resolution of 2° x 2.5° (latitude x longitude) that includes atmospheric fate, soil sensitivity, and relative loss of plant species. In this context, we evaluate the importance of transboundary transport to the CFs and the contribution of atmospheric fate, soil sensitivity, and ecological effects to the spatial variability and parameter uncertainty of CFs.

Characterization factors for terrestrial acidification

3.2 Material and methods

3.2.1 Characterization factor

Building on the work of van Zelm *et al.* (2007), CFs for terrestrial acidification were defined as a change in the potentially not occurring fraction of vascular plant species (PNOF) summed over the receiving areas j , due to a marginal change in the emission of acidifying substance p at the source location i . The mathematical expression to convert atmospheric emissions of acidifying substances into a relative species loss indicator is presented in Equation 3.1. The CF can be subdivided into an atmospheric fate factor (FF), a soil sensitivity factor (SF) and a marginal effect factor (MEF). CFs ($\text{m}^2 \cdot \text{yr} \cdot \text{kg}^{-1}$) and were calculated for 13,104 emission source grids ($2^\circ \times 2.5^\circ$ spatial resolution) as

$$CF_{i,p} = \sum_j (FF_{i,j,p} \cdot SF_{j,p} \cdot MEF_j) \quad (3.1)$$

3.2.2 Atmospheric and soil sensitivity fate factor

The atmospheric fate factor (FF, $\text{kg} \cdot \text{yr}^{-1}$) describes the change in pollutant emission ($\text{kg} \cdot \text{yr}^{-1}$) in source grid cell i of acidifying pollutant p (i.e., NO_x , NH_3 , or SO_2) and the change in acid deposition on soil j ($\text{keq} \cdot \text{yr}^{-1}$) in the receptor grid cell [see Roy *et al.* (2012b) for a detailed description of FFs], a spatial resolution of $2.0 \times 2.5^\circ$. The atmospheric transport is based on the 3-dimension GEOS-Chem global tropospheric chemistry model (Bey *et al.*, 2001), fed by meteorological observations from the Goddard Earth Observing System (GEOS) of the NASA Data Assimilation Office (Bey *et al.*, 2001). The yearly averaged results of GEOS-Chem for 2005 were used (2005 being representative of meteorology of the average from 1961 to 1990).

3.2.3 Soil sensitivity factor

The soil sensitivity factor (SF, $\text{mol H} \cdot \text{L}^{-1} \cdot \text{m}^2 \cdot \text{keq}^{-1} \cdot \text{yr}$) describes the change in soil solution hydrogen ion concentration ($\text{mol H} \cdot \text{L}^{-1}$) due to a change in the atmospheric deposits of pollutant p on soil j ($\text{m}^2 \cdot \text{keq}^{-1} \cdot \text{yr}$) in the receptor grid cell [see Roy *et al.* (2012a) for a detailed description of SFs]. We introduced changes in pollutant deposition from a 10% increase in emissions-depositions, which is commonly used to calculate CFs for acidification (Huijbregts *et al.*, 2000, Krewitt *et al.*, 2001, Potting *et al.*, 1998b). The SFs were determined with the steady-state PROFILE soil model.

3.2.4 Marginal effect factor

The effect factor was calculated by using biome-specific stressor – response relationships of the potentially not occurring fraction (PNOF) of vascular plant species and soil pH. To attain that, first, we considered the minimum pH value at which each species was confirmed to occur per biome (according to biome classification of Olson *et al.* (2001). Second, the empirical PNOF (ePNOF) was defined as the rank of the species divided by the maximum rank of the species within the biome. Third, we fitted the ePNOF as

$$PNOF_{j,b} = \frac{1_j}{1 + e^{-\frac{\log_{10} C_j - \alpha_j}{\beta_b}}} \quad (3.2)$$

where $PNOF_{j,b}$ is the potentially not occurring fraction of vascular plant species of biome b associated with soil j , C_j the soil H concentration, α_b represents the soil solution pH at which 50% of vascular plant species potentially do not occur in biome b , and β_b is the slope of the logistic function of relative species richness along a soil pH gradient in biome b . The minimum pH level for each species in each biome was reported by Azevedo *et al.* (2013b) (data available in appendix S2.4.2 of chapter 2 of this thesis).

Fourth, we determined the effect factor (MEF, mol H⁻¹L) as the marginal increase of the PNOF (dimensionless) following an increase in hydrogen ion concentration (C_j , mol H L⁻¹) at the receiving environment j location as

$$MEF_j = \frac{dPNOF_j}{dC_j} = PNOF^2 \cdot e^{\frac{\alpha_b - \log_{10} C_j}{\beta_b}} \cdot \frac{1}{\beta_b \cdot C_j \cdot \ln(10)} \quad (3.3)$$

where C_j is the hydrogen ion concentration determined as output of the PROFILE model and the biome-specific log-logistic coefficients α and β were determined with each receiving soil compartment j was allocated to its respective biome b using the map by Olson *et al.* (2001). For the (sub)tropical dry broadleaf and coniferous forests, for which regression coefficients were unavailable, we employed the coefficients for (sub)tropical moist broadleaf forest as they encompass fairly similar climate conditions according to the Köppen-Geiger classification (Schiel, 1985). The biome-specific coefficients are presented in appendix S3.1 of the Supporting Information.

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3.2.5 Region-specific characterization factors

Since the specific source locations of the input and output processes compiled in the LCI phase are seldom known (Finnveden *et al.*, 2009), LCA practitioners often require coarser resolutions to assess the potential impacts of compiled emission inventories. We calculated CFs for larger spatial units (i.e., world, continent, and country) as the average of CFs of grids located within each unit. As a measure of the spatial variability within each of the three units, we calculated the spread in grid-specific CFs within each unit as

$$R = \log_{10} \left(\frac{CF_{i,p}}{CF_{U,p}} \right) \quad (3.4)$$

where R is the ratio between grid-specific CF in grid i and CF_U is the CF of the larger spatial unit U (i.e., world, continent, or country) for pollutant p .

3.2.6 Significance of transboundary transport

To estimate the importance of emission impacts occurring to continents other than to that where the emission originated from, we calculated the intercontinental transboundary transport (CTT, %) as

$$CTT = 1 - \frac{CF_{U,p}}{CF_{i,p}} \quad (3.5)$$

where CTT is the fraction of emission impacts of grid i taking place in elsewhere continents and $CF_{U,p}$ is the continent-specific CF in which grid i is located in.

3.2.7 Contribution of fate and effect factors

The influence of the FFs, SFs, and EFs on the spatial variability of the CFs was evaluated for each emitting grid using a linear regression analysis. To attain that, we calculated grid-specific CFs whereby the variability was solely due to the atmospheric fate factor (thus, no soil sensitivity or effect factor influence) and due to the atmospheric and soil fate factors (thus, no effect factor influence). This exercise was done for the three pollutants separately.

3.3 Results

3.3.1 Characterization factors

Highest CFs were found at emission locations situated in central Asia, central Africa and Canada (Figure 3.1). CFs are largest for emission locations with dominant transport to areas with low buffering capabilities (indicated by high pH change) and a working point of the pH-PNOF relationship curve associated with a steep slope value.

The median CF of SO_2 ($4.5 \text{ m}^2 \cdot \text{yr} \cdot \text{kg}^{-1}$) is higher than the median CF of NH_3 ($4.3 \text{ m}^2 \cdot \text{yr} \cdot \text{kg}^{-1}$) and NO_x ($2.1 \text{ m}^2 \cdot \text{yr} \cdot \text{kg}^{-1}$), Figure 3.1(d). CFs range over four (for NO_x), five (for SO_2) and six (for NH_3) orders of magnitude. The spatial variability of the CFs of a given pollutant is orders of magnitude larger than the variability between pollutants.

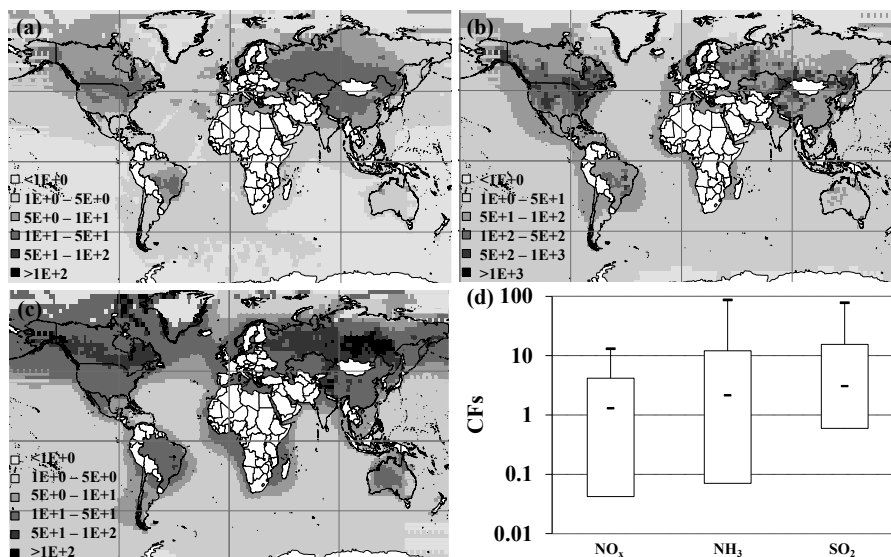


Figure 3.1 Grid-specific characterization factors ($\text{m}^2 \cdot \text{yr} \cdot \text{kg}^{-1}$) for (a) NO_x , (b) NH_3 and (c) SO_2 emissions. Boxplot of CFs is shown in (d).

3.3.2 Region-specific characterization factors

Global, continental, and country averaged CFs are available in appendix S3.2. Figure 3.2 shows that respectively 41 – 54%, 4 – 12% and 3 – 10% of the grid-specific CFs within the global, continental, and country spatial resolutions, are more than one order of magnitude higher or lower compared to the specified coarser spatial resolution CFs.

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3.3.3 Significance of intercontinental transboundary transport

Figure 3.3 shows the CTT occurring outside the continental scale for continental emissions of NO_x , NH_3 , and SO_2 . For example, depending on the emitted pollutant, between 60 and 70% of continental $2^\circ \times 2.5^\circ$ grids have less than 10% of their total potential impact associated with transboundary transport. On average, 15%, 12% and 13% of the NO_x , NH_3 and SO_2 impacts from continental emissions occur outside the continental scale, respectively. Grid-specific CTTs are shown in Figure S3.3.1.

3.3.4 Regression analysis

Table 3.1 presents the results of the regression analysis. Results showed an explained variance of less than 0.07 for $\sum FF$ towards CF. The explained variance of $\sum FF \cdot SF$ towards CF results is an explained variance between 0.95 and 0.97 with slopes of the linear regression that approximate 1. The stronger correlation between $\sum FF \cdot SF$ and CFs is also confirmed by the relatively low standard error and residual sum of squares of the regressions.

3.4 Discussion

3.4.1 Spatial variation

Relatively high CFs are obtained for emissions locations with depositions in areas with high SFs and EFs. Roy *et al.* (2012b) showed that highest sensitivity factors occurred in the Canadian shield region, the Scandinavian region, the Amazon basin, central Africa and parts of east and southeast Asia. EFs are highest in the “desert and xeric shrubland biome” and in the “tundra biome”. The soil sensitivity factor contributes most to spatial variability in the CFs, as shown by the regression analysis.

Application of the spatial explicit CFs in a full LCA would require regional life cycle emissions databases. Recently database providers such as ecoinvent (v3) (Godbold & Calosi, 2013) developed regional modules that cover different regions of the world and address the geographical locations of emission flows. Spatial explicit CFs still provide relevant information for situations when regional life cycle inventory is not or only partially available. CFs calculated at different level of aggregation (country, continent or world) with the associated information on spatial variability allows LCA practitioners to assess the uncertainty inherited from the lack of spatial information.

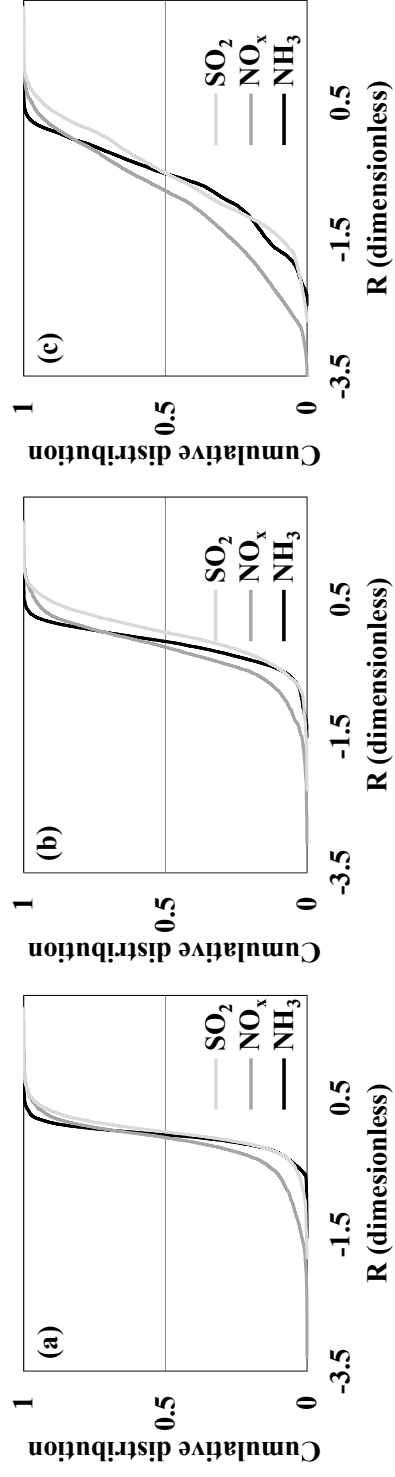


Figure 3.2 Cumulative distribution of the ratio $R = \log_{10} \left(\frac{CF_{i,p}}{CF_{U,p}} \right)$ between grid-specific and the (a) country, (b) continent, and (c) global CFs.

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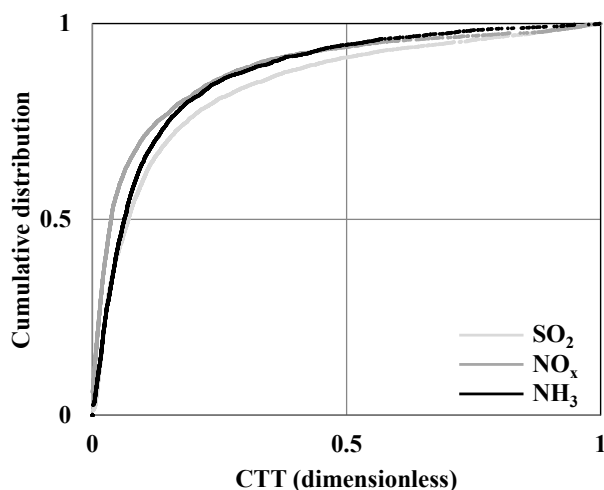


Figure 3.3 Contribution of intercontinental transboundary transport $CTT = 1 - \frac{CF_{U,p}}{CF_{i,p}}$ to the grid-specific CF.

Table 3.1 Linear regression analysis of the spatial variability between characterization factors and (a) atmospheric fate and (b) atmospheric fate and soil sensitivity factors.

	Regression	R ²	Standard error	Residual sum of squares
(a) Atmospheric fate				
NO _x	$\log(CF) = 0.2 \log(\sum FF) + 1.9$	0.00	0.63	3923
NH ₃	$\log(CF) = -2.1 \log(\sum FF) - 16.4$	0.07	0.88	8031
SO ₂	$\log(CF) = 0.2 \log(\sum FF) + 2.7$	0.00	0.73	5861
(b) Atmospheric fate and soil sensitivity				
NO _x	$\log(CF) = 1.0 \log(\sum FF \times SF) + 3.7$	0.96	0.12	140
NH ₃	$\log(CF) = 1.0 \log(\sum FF \times SF) + 3.8$	0.97	0.16	255
SO ₂	$\log(CF) = 1.0 \log(\sum FF \times SF) + 3.9$	0.94	0.17	324

3.4.2 Uncertainty

There are also assumptions in the modeling that can influence the CF results. First, deposition was considered evenly distributed within a 2°x2.5° grid, neglecting local factors favoring deposition (e.g. mountains) in certain regions within the grid. Without higher resolved global atmospheric models, this situation cannot be averted.

Second, terrestrial acidification can be caused via various cause-effect pathways, including nutrient depletion and an increase in soil solution H⁺ concentration (or decrease of pH) and aluminum toxicity (Jeffries &

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Ouimet, 2004). By using soil solution H^+ concentration as the soil sensitivity indicator, we evaluated the direct harm to the vegetation. The increase in soil solution H^+ concentration was chosen over the other types of indicators because it is recognized as a successful predictor of species richness and a primary indicator of soil acidity (Pepler-Lisbach & Kleyer, 2009, Whittaker, 1972). Furthermore, Roy *et al.* (2012b) showed that other soil sensitivity indicators, such as aluminum concentration or nutrient concentration (in the form of base cations), were more sensitive to soil input parameters uncertainties as compared to soil solution pH.

Third, biomes comprising soils that are inherently less acidic (e.g., deserts and mediterranean), encompass a PNOF at a pH level higher than other biomes (high α values, Table S3.1.1). This occurs because, in the past, the species which were able to subsist in basic soils were favored while others perished (Azevedo *et al.*, 2013b). The opposite took place in acidic soils, e.g. temperate conifer and tropical moist forests, and tropical grasslands. This reflects in the sensitivity of species to pH declines (represented by the effect factor). In more alkaline soils, the increase in PNOF with pH declines is more pronounced than in soils where the species fraction reaches a reduction to 50% at acidic conditions.

Fourth, our approach based on marginal change, as used by many authors, may still raise concerns. Firstly, the quantification of a marginal change is still under discussion as several authors (Huijbregts *et al.*, 2000, Krewitt *et al.*, 2001, Potting *et al.*, 1998b) used a +10% variation, while others tried a combination of different values with a maximum of 50% (Seppälä *et al.*, 2006, van Zelm *et al.*, 2007). We deemed a 10% variation as satisfactory since Roy *et al.* (2012b) tested the variations of the receiving environment sensitivity factor over 100 randomly chosen receiving environments with increments of deposition of 1%, 5% and 10% and found a quasi-linear relation between the registered pH at 5% and 10% increment. Secondly, other approaches such as the *average* (Huijbregts *et al.*, 2011) or *linear* (Amores *et al.*, 2013, Gandhi *et al.*, 2010, Rosenbaum *et al.*, 2008) approaches could have been used instead. However, selection of any of these approaches should not modify significantly the obtained results since, on average, the effect factor equaled $1.9E-6$, $1.3E-6$ and $1.7E-6 \cdot 10^5 \text{ mol } H^{-1} \cdot L$ for the marginal, average and linear approach, respectively.

Finally, missing model regression parameters impaired the effect assessment in Central America, India and the mountain regions of Asia. These territories were approximated with parameters from other

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environments. The lack of data for these regions hinders the accurate interpretation of the potential impacts.

3.4.3 Comparison with other studies

We compared our European CFs with the CFs from Goedkoop & Spriensma (2001) and van Zelm *et al.* (2007). Results are presented in Table 3.2. While our CFs are higher than the ones previously obtained, they are of similar orders of magnitude; which tend to make them acceptable. The elaborated differences below may explain the discrepancies in obtained results.

This study and the study of van Zelm *et al.* (2007) showed a similar relative importance of NO_x, NH₃, and SO₂ per unit emission. However, van Zelm *et al.* (2007) derived, systematically lower CFs. This may be explained by the fact that van Zelm *et al.* (2007) i) used the EUTREND (Beaufort *et al.*, 2011) atmospheric model, which does not include transboundary emission and related impacts outside of Europe (an average difference of 15%); ii) used the dynamic soil model SMART (Benner *et al.*, 2013), whose steady-state version showed a 25 to 65% difference with PROFILE when calculating critical loads (Nakamura *et al.*, 2011); iii) assessed changes in soil base saturation instead of H⁺ concentration; iv) used a base saturation – PNOF dose-response curve that yielded a gentler slope than the H⁺ concentration – PNOF dose-response, thus resulting in lower EFs in Europe (0.26 per base saturation comparatively to, on average, 1.9E-6 mol H⁺·L); v) had EFs that equaled 0 for forest whose base saturation values were lower than 0.15 while our EFs were always greater than 0; and vi) limited their assessment of potential impacts to European forest ecosystems, unlike our assessment, which included numerous types of ecosystems; forests were shown to have one of the species – pH shallowest slopes

This study and that of Goedkoop & Spriensma (2001) resulted in similar (in terms of order of magnitude) absolute CFs for NO_x and NH₃ and differ significantly for SO₂ results. However, there exists several discrepancies between both studies: Goedkoop & Spriensma (2001) i) modeled the impacts for the Netherlands and extrapolated their EF results to Europe; ii) did not rely on atmospheric fate modelling, preferring a 10 mole marginal change to mapped deposition levels; iii) used the SMART model to evaluate changes in many soil properties, iv) assessed the potential impacts of both acidification and eutrophication instead of soil acidity changes; and v) assessed the potentially

Table 3.2 Comparison of available endpoint CFs.

	This study		van Zelm <i>et al.</i> (2007)		Goedkoop & Spriensma (2001)	
	CFs (m ² ·yr·kg)	Contribution (%)	CFs (m ² ·yr·kg)	Contribution (%)	CFs (m ² ·yr·kg)	Contribution (%)
NO _x	9.8	11.4	0.4	15.6	5.7	25.6
NH ₃	46.9	54.5	1.5	62.9	15.6	69.7
SO ₂	29.4	34.1	0.5	21.5	1.0	4.66

disappeared fraction of species (PDF) for more than 900 Dutch plant species with the MOVE model (Latour & Reiling, 1993) contrarily to our biome approach.

3.4.4 Concluding remarks

This study determines spatially-explicit CFs for terrestrial acidification at the global scale. We showed the importance of including the potential impacts of intercontinental transboundary transport in CF calculations. Consequently, available LCIA methods underestimated the potential impacts of acidifying emissions. We revealed that spatial variability of a given pollutant is orders of magnitude larger than the variability between pollutants. Regardless of the remaining limitations, the proposed approach opens the door to evaluating the regional life cycle emissions of different products in a global economy.

ACKNOWLEDGMENTS

Special thanks to Cécile Bulle, Olivier Jolliet, Vahid Partovi Nia and Guillaume Bourgeault for their expertise regarding the evaluation of uncertainties. The CIRAIG would like to thank its industrial partners for their financial support: ArcelorMittal, Bombardier, Bell Canada, Cascades, Eco Entreprises Québec, RECYC-QUÉBEC, Groupe EDF, Gaz de France, Hydro-Québec, Johnson & Johnson, LVMH, Michelin, Mouvement des caisses Desjardins, Nestlé, Rio Tinto Alcan, RONA, SAQ, Solvay, Total, Umicore and Veolia Environment. The research was partly funded by the European Commission under the Seventh Framework Programme on environment (ENV.2009.3.3.2.1: LC-IMPACT - Improved Life Cycle Impact Assessment methods (LCIA) for better sustainability assessment of technologies).



Chapter 4

Calcifying species sensitivity distributions for ocean acidification

Ligia B. Azevedo
An M. De Schryver
A. Jan Hendriks
Mark A. J. Huijbregts

Submitted

Marine water pH – potentially affected fraction

ABSTRACT

Increasing global CO₂ atmospheric levels have led to increasing ocean acidification, thereby enhancing dissolution of calcium carbonate of marine calcifying organisms. In this study, we gathered peer-reviewed experimental data on the effects of acidified seawater on the growth, reproduction, and mortality of calcifying species. The experimental data were used to derive species-specific half maximum effective concentrations, i.e. EC₅₀, and 10% maximum effective concentrations, EC₁₀, and, subsequently, we developed a probabilistic model of the cumulative affected fraction of species exposed to ocean pH stress, known as species sensitivity distributions (SSDs). Our results show that species growth is most affected by pH declines (where average of EC₅₀ and EC₁₀ were 7.53 and 7.93, respectively) than reproduction or mortality (where average EC₅₀ and EC₁₀ ranged from 7.45 to 7.74 and 7.46 to 7.65, respectively). The constructed SSDs were then applied to two climate change scenarios in order to estimate the change in the potential fraction of species affected (Δ PAF) by future ocean acidification. EC₅₀-based and EC₁₀-based Δ PAF varied from 4 to 6% and 8 to 33% in a low emission climate change scenario, respectively. In a high emission scenario, Δ PAF ranged from 12 to 13% (for EC₅₀-based effects) and from 19 to 70% (for EC₁₀-based effects). This study provides the first SSDs developed for ocean pH and an application of SSDs towards estimating the potential effects of global climate change on calcifying marine species assemblages.

4.1 Introduction

Rises in atmospheric carbon levels have led to increasing uptake of CO₂ by oceans (IPCC, 1990). This process, characterized by enhancement of dissolved CO₂ levels and the decrease in ocean pH, leads also to amplification of carbonate dissolution in oceans (Feely *et al.*, 2009). As calcifying species depend on highly saturated carbonate conditions in oceans in order to guarantee the building of their shells and skeletons (Secretariat of the Convention on Biological Diversity, 2009), carbonate dissolution following ocean acidification may pose a particular threat to these species.

Since the process of calcification is observed in a wide variety of taxa (such as phytoplankton, corals, and arthropods), denigrating effects of ocean acidification may go beyond the disruption of the various ecosystem services those species provide, including nursery for fish and protection against erosion and storms by corals, fisheries of urchins and invertebrates, and food provisioning for predators (Secretariat of the Convention on Biological

Diversity, 2009). Some important life processes may also suffer impairment, such as species growth or reproduction (Kroeker *et al.*, 2010).

Many laboratory experiments have assessed the effects of ocean acidification on individual species, which allowed for various meta-analyses of the effects of acidification on marine species, i.e. Chan & Connolly (2013), Kroeker *et al.* (2010), and Hendriks *et al.* (2010). Those studies have shown that acidification effects on marine species, particularly on the calcifying ones, are mainly detrimental (Kroeker *et al.*, 2010), although the responses of individual species are far from uniform (Hendriks *et al.*, 2010).

In environmental risk assessments, species-specific responses to a certain environmental stressor can be incorporated with species sensitivity distributions (SSDs). SSDs are commonly used in the estimation of effects of toxicants on species, such as metals or pesticides. They are particularly useful for (1) the estimation of the overall response (and the variability in responses) of an assemblage of species representing the species found in the environment and (2) the estimation of acceptable or “safe” levels of a stressor for the protection of the environment (Posthuma *et al.*, 2002). SSDs of the effects of marine species to increasing CO₂ exposure have been developed by de Vries *et al.* (2013). However, probabilistic models of a subsequent acidification effect of CO₂ level rises on ocean chemistry, namely pH declines, have not yet been developed for calcifying species, which are species that are particularly sensitive to the acidification of oceans (Kroeker *et al.*, 2010).

Here, we developed species sensitivity distributions (SSDs) based on three life processes (i.e. growth, reproduction, and mortality) and apply the SSDs to two global climate change scenarios of the Intergovernmental Panel on Climate Change, IPCC (2000). Growth, reproduction, and mortality are often indicators of the maintenance of species populations in the environment as they reflect the performance of species at important life processes (Schiel, 1985). Additionally, we assess if species potentially benefited from pH declines and if other important factors influence species responses, namely duration of experiments and water temperature levels.

4.2 Material and methods

4.2.1 Data inventory

We considered laboratory experiments on calcifying species conducted by 98 studies previously assembled by Kroeker *et al.* (2010) and Hendriks *et al.* (2010). We categorized the effect measured in each

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experiment into one of three response types, i.e. mortality, reproduction, or growth. Effects allocated to mortality include mortality and malformed or incomplete single cell organism growth. Effects allocated to reproduction include gamete abnormality, number of eggs, and fertilization success. Effects allocated to growth include growth or calcification rate, calcium content, and organism length. We excluded experiments whereby the taxonomic level of the tested organism was not species and experiments where the reported effect was related to a metabolic change in the organism and, thus, could not be allocated to neither of the three responses, e.g. O₂ productivity, photosynthetic rate or amount of rubisco.

We also recorded the duration and the temperature at which each experiment was conducted. When a pre-specified number of generations was employed by the study to determine the duration of the experiment, we employed the number of generations times the approximate life cycle of the species. For example, for the experiments conducted with *Emiliania huxleyi* by Langer *et al.* (2009), we assumed the life cycle of the organism as of one day.

For each experiment, we recorded the ocean pH to which species were exposed and the effect of the species. In experiments where CO₂ partial pressure (pCO₂) was reported instead of water pH, we converted pCO₂ to pH using the procedure described in appendix S4.1 of the Supporting Information. The empirical data on the pH condition and its effect on species were then employed in the derivation of SSDs for each experiment. We did not include empirical data of a specific experiment where the tested pH levels were above 8.35 or where the highest tested pH was below 7.95 as those conditions do not represent contemporary levels of ocean pH but past or future estimations of pH levels instead (Feely *et al.*, 2009).

4.2.2 Derivation of EC₅₀ and EC₁₀

For each experiment, we first scaled the effect at each pH level between zero and one, where zero is the lowest and one is the highest relative effect reported for the tested species. Second, we fitted the empirical data to the logistic regression

$$Y_{t,s,e} = \frac{1}{1 + 10^{-\left(\frac{pH - EC_{50t,s,e}}{\beta_{t,s,e}}\right)}} \quad (4.1)$$

where EC_{50t,s,e} is the pH leading to an effect on the species equivalent to 50% and $\beta_{t,s,e}$ is the slope of the logistic function for life process t (i.e.,

mortality, reproduction, and growth) of species s in experiment e . Third, we recorded which experiments indicated a denigrating effect of pH (i.e., $\beta_{t,s,e} < 0$, at a 95% confidence level), a beneficial effect (i.e., $\beta_{t,s,e} > 0$, at a 95% confidence level), or undetermined effect (i.e., $\beta_{t,s,e}$ not significantly different than zero or p value of the logistic regression above 0.05). For denigrating effects, we proceeded by calculating the pH leading to an effect of 10% in experiment e as

$$EC_{10_{t,s,e}} = -\beta_{t,s,e} \cdot \log_{10}(9) + EC_{50_{t,s,e}} \quad (4.2)$$

If multiple multiple $EC_{50_{t,s,e}}$ values were available for a particular life process of a species, the highest $EC_{50_{t,s,e}}$ was employed for the derivation of the $EC_{10_{t,s,e}}$ and of the PAF functions. This is a conservative approach as the effect on a species is given at the highest reported pH value.

4.2.3 Species sensitivity distributions

For each life process t and effect concentration c (i.e., EC_{50} and EC_{10} , hereafter defined as severe and subtle effects, respectively), the cumulative potentially affected fraction of species (PAF) was calculated as

$$PAF_{pH,t,c} = \frac{1}{\sqrt{2\pi\sigma_{t,c}}} e^{-\frac{(pH-\mu_{t,c})^2}{2\sigma_{t,c}^2}} \quad (4.3)$$

where $\mu_{t,c}$ and $\sigma_{t,c}$ are the average and standard deviation of species-specific EC_{50} or EC_{10} value. We determined the statistical uncertainty around the PAF at each pH level using a Monte Carlo exercise (10,000 simulations). This was attained by first determining the uncertainty around μ and σ , which was executed following the procedure described by Roelofs *et al.* (2003). In this procedure, the uncertainty around the μ and σ coefficients is augmented for SSDs encompassing fewer species.

4.2.4 Influence of water temperature and experiment duration

For denigrating effects of pH declines, tested if the duration and the temperature at which experiments were conducted affected the $EC_{50_{t,s,e}}$. This step was conducted for each of the three life processes as

$$\omega = \theta + \gamma_T + \gamma_D + \epsilon \quad (4.4)$$

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where ω is the estimated EC_{50} for a given life process, θ is the intercept, γ_T and γ_D are the coefficients for the temperature T and duration D factors, and ε is the residual of the multiple linear regression.

4.2.5 Climate change scenarios

Two climate change scenarios proposed by the Special Report on Emissions Scenarios, SRES (2000) were employed in order to estimate the fraction of species potentially affected by future ocean acidification. The scenarios B1 and A2 describe, respectively, low and high greenhouse gas emission scenarios and differing with respect to social-economic and technological developments expected in the future (IPCC, 2000). In addition to the decline of 0.1 pH unit which has already occurred since the industrial revolution (Orr *et al.*, 2005), Joos *et al.* (2011) project global average pH at the ocean's surface to be 7.95 and 7.8 by 2100 under the B1 and A2 climate change scenarios.

The change in PAF was calculated for each life process t and effect concentration c for both future scenarios F as

$$\Delta PAF_{F,t,c} = PAF_{F,t,c} - PAF_P \quad (4.5)$$

where $PAF_{F,t,c}$ and PAF_P are the PAF as a function of future and present ocean pH levels, respectively.

4.3 Results

Ninety-eight studies testing the effects of ocean acidification on species mortality, reproduction, or growth were assembled by Kroeker *et al.* (2010) and Hendriks *et al.* (2010) and considered for our inventory of experiments. Thirty studies encompassed at least one experiment with 3 or more tested pH levels (i.e. the minimum necessary to fit a logistic regression described in equation 4.1) and organisms recorded at the species taxonomic level. A total of 174 experiments was tested for a logistic trend, of which 41 yielded a detrimental effect of pH decreases on species (i.e. negative relationship between pH and effect on species), Table 4.1. We also found a beneficial effect (positive relationship) of pH declines on the growth and reproduction of four species (Table S4.3.1).

The duration of experiments ranged from two hours to 60 days while ocean water temperatures ranged from 14 to 27°C (Table 4.1). Despite the wide ranges of temperature and experiment duration, these two factors generally had no influence on EC_{50} results (Table 4.2). However, for

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mortality, temperature was negatively correlated with EC_{50} (p value = 0.044).

The experiment-specific logistic regressions yielded EC_{50} for fifteen different species (listed in Table S4.2.1). The organisms belonged to the Mollusca, Haptophyta, Cnidaria, Echinodermata and Arthropoda phyla. The SSDs for the three life processes based on EC_{50} and EC_{10} are shown in Figure 4.1. The arthropods *Acartia erythraea* and *A. steueri* were among the least sensitive to low pH levels while the mortality of hapophytes *Emiliania huxleyi* and *Calcidiscus leptoporus* were among the most pH-sensitive species. Molluscs (i.e. *Saccostrea glomerata*, *Crassostrea virginica*, and *Mytilus edulis*) comprised the organisms most sensitive for pH decreases with respect to growth responses.

The number of species available for the development of the SSDs varied across life processes. For growth, eleven species were available while, for reproduction, SSDs comprised of five species. The average sensitivity of species to growth effects was higher than for reproduction or mortality for severe effects (EC_{50} -based $\mu_{\text{growth}} > \mu_{\text{mortality}} = \mu_{\text{reproduction}}$, Figure 4.1) and subtle effects (EC_{10} -based $\mu_{\text{growth}} > \mu_{\text{reproduction}} > \mu_{\text{mortality}}$). Additionally, we found a higher variability across mortality effects of species than for growth or reproduction (EC_{50} and EC_{10} -based $\sigma_{\text{mortality}} > \sigma_{\text{reproduction}} > \sigma_{\text{growth}}$).

In the low emission scenario, the increase in the PAF of subtle effects following a decrease in pH from 8.1 to 7.95 varied from 8% for mortality and 33% for growth (Figure 4.2). For severe effects, the same decrease in pH prompted an increase of 4% for growth to 6% for mortality in the PAF. In the high emission scenario, pH declines of 0.3 units prompted subtle effects ranging from 19% for mortality to 70% for growth and severe effects from 12% to reproduction to 14% for growth.

Table 4.1 Logistic regression coefficients, i.e. EC_{50} and slope (95% confidence interval) for detrimental effects of pH decreases on species (a) growth, (b) reproduction, and (c) mortality. Temperature T and duration D of experiment is also shown.

Species [#]	EC_{50}	Slope β	R^2 / p value	T (°C)	D (day)
(a) Growth					
Hem_pul ^{E,§}	7.05 (6.74 to 7.36)	-0.76 (-7.53 to -0.40)	0.88 / 0.01	14	3
Ech_mat ^{E,§}	7.06 (6.92 to 7.2)	-0.78 (-1.32 to -0.55)	0.97 / <0.01	24	3
Sty_pis ^M	7.40 (7.32 to 7.47)	-0.38 (-0.68 to -0.26)	0.98 / <0.01	27	20
Sac_glo ^{M,§}	7.48 (7.26 to 7.7)	-0.36 (-1.87 to -0.20)	0.97 / 0.01	18	2
Ocu_arb ^C	7.56 (7.54 to 7.58)	-0.24 (-0.29 to -0.21)	1.00 / <0.01	25	60
Arg_irr ^M	7.61 (7.43 to 7.79)	-0.46 (-1.71 to -0.26)	0.97 / 0.01	25	60
Cra_gig ^M	7.66 (7.58 to 7.75)	-0.45 (-0.82 to -0.31)	0.61 / <0.01	20	0.1
Emi_hux ^{H,§}	7.72 (7.67 to 7.77)	-0.21 (-0.52 to -0.13)	1.00 / 0.02	20	12
Cal_lep ^{H,¶}	7.74 (7.6 to 7.87)	-0.35 (-1.38 to -0.2)	0.98 / 0.01	20	10
Cra_vir ^M	7.76 (7.6 to 7.91)	-0.36 (-1.92 to -0.2)	0.98 / 0.01	25	60
Myt_edt ^M	7.76 (7.7 to 7.82)	-0.24 (-0.53 to -0.15)	0.66 / <0.01	20	0.1
(b) Reproduction					
Aca_ery ^A	6.94 (6.74 to 7.14)	-0.18 (-0.18 to -0.18)	1.00 / <0.01	27	8
Aca_ste ^A	7.29 (7.28 to 7.3)	-0.26 (-0.27 to -0.25)	1.00 / <0.01	27	6
Ech_mat ^E	7.50 (7.40 to 7.6)	-0.48 (-0.75 to -0.35)	0.98 / <0.01	24	0.1
Hem_pul ^{E,§}	7.59 (7.47 to 7.72)	-0.45 (-1.26 to -0.27)	0.95 / <0.01	14	0.1
Sac_glo ^{M,§}	7.92 (7.87 to 7.96)	-0.11 (-1.78 to -0.06)	0.99 / <0.01	18	2

Species [#]	EC ₅₀	Slope β	R ² / p value	T (°C)	D (day)
(c) Mortality					
Tri_gra ^E	6.78 (6.56 to 6.99)	-0.36 (-2.68 to -0.20)	0.96 / <0.01	26	4
Aca_ery ^A	6.85 (6.84 to 6.85)	-0.26 (-0.26 to -0.26)	1.00 / <0.01	27	8
Cra_vit ^M	7.49 (7.46 to 7.52)	-0.26 (-0.56 to -0.17)	1.00 / 0.01	24	20
Oph_fra ^E	7.80 (7.71 to 7.89)	-0.02 (-0.11 to -0.01)	1.00 / <0.01	14	8
Emi_hux ^H	7.85 (7.82 to 7.88)	-0.13 (-0.21 to -0.09)	1.00 / <0.01	19	12
Cal_lep ^{H,‡}	7.98 (7.94 to 8.03)	-0.20 (-0.37 to -0.14)	0.99 / <0.01	20	10

[#] Legend of abbreviations of species names can be found in Table S4.2.1.

^A Arthropoda, ^H Haptophyta, ^M Mollusca, ^E Echinodermata, ^C Cnidaria

[‡] Life cycle of organism assumed to be of 1 day

^{*} Species with more than one available EC₅₀ result. The highest EC₅₀ value was used and the others were discarded. These values are: (a) Growth: Ech_mat: 7.00; Emi_hux: 7.69 and 7.72; Hem_pul: 7.03; Sac_glo: 7.33, 7.35, 7.39, and 7.43 and (b) Reproduction: Ech_mat: 6.83, 6.97, 7.18, and 7.40; Hem_pul: 6.91, 7.22, and 7.39; Sac_glo: 7.66, 7.78, 7.82, and 7.90.

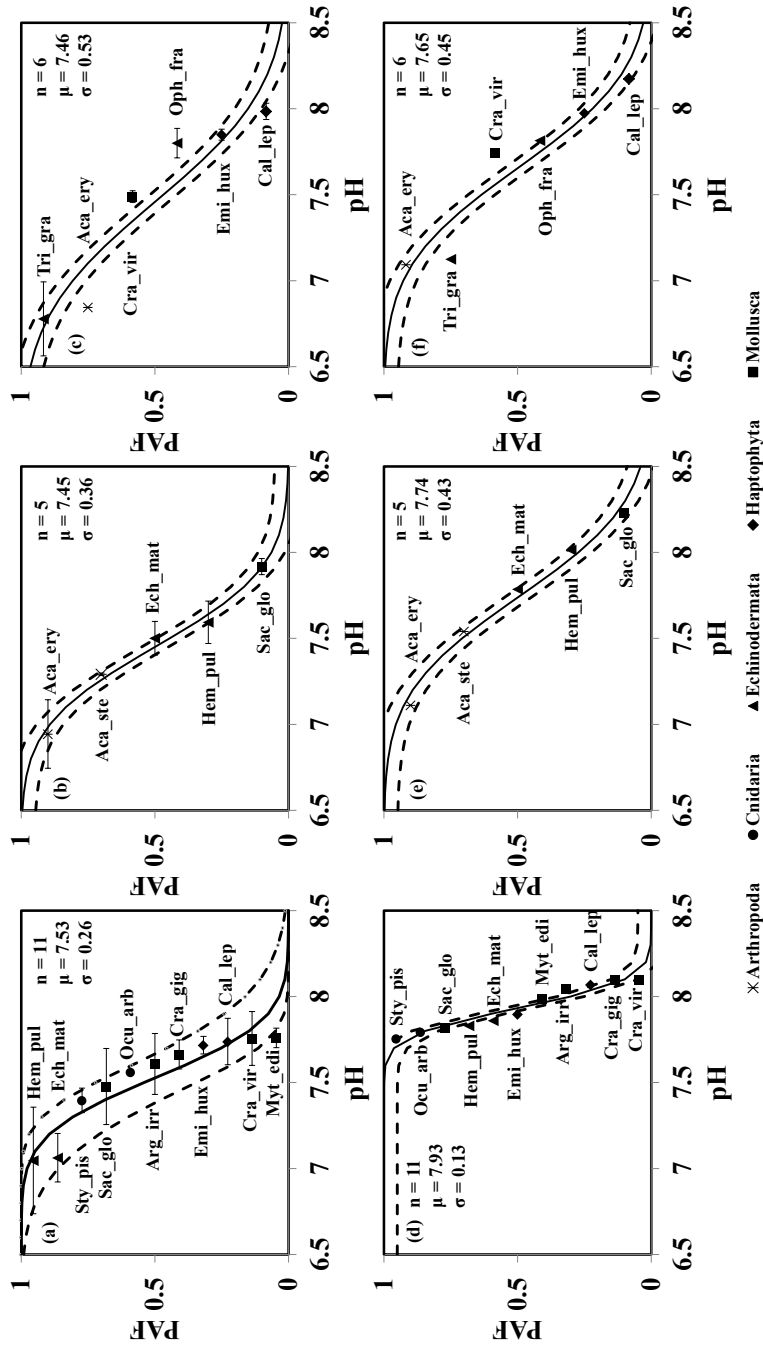


Figure 4.1 Species sensitivity distributions (SSDs) of the potentially affected fraction (PAF, continuous line) based on EC_{50} values for (a) growth, (b) reproduction, (c) and mortality and based on EC_{10} values for (d) growth, (e) reproduction, and (f) mortality. Legend of abbreviations species can be found in Table S4.2.1. The error bars illustrate the 95% confidence intervals around the EC_{50} or EC_{10} of each species determined with the logistic regression. Dashed lines are the 5th and 95th percentile around the PAF.

Table 4.2 Results of the multiple linear regression of the influence of temperature (T) and duration (D) of experiments on EC_{50} for the three life processes. In the three regressions, the Shapiro-Wilk test for normality of residuals yielded non-significant results (p value > 0.05).

	Coefficient (\pm S.E.)	p value	Model sum of squares / R^2
(a) Growth	.		0.089 / 0.13
Intercept	7.487		
T	-0.003 (0.025)	0.898	
D	0.004 (0.004)	0.342	
(a) Reproduction			0.351 / 0.670
Intercept	8.129		
T	-0.023 (0.038)	0.597	
D	-0.051 (0.061)	0.491	
(c) Mortality			1.141 / 0.823
Intercept	8.963		
T	-0.087 (0.026)	0.044	
D	0.037 (0.024)	0.216	

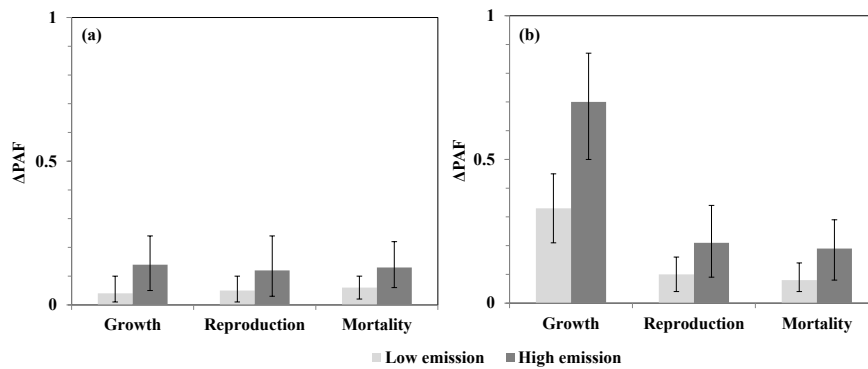


Figure 4.2 The change in the potentially affected fraction (ΔPAF) in low and high greenhouse gas emission scenarios on (a) severe (i.e., EC_{50}) and (b) subtle (i.e. EC_{10}) effects. Error bars are the 5th and the 95th percentile around ΔPAF .

4.4 Discussion

In this work, we gathered data on ocean acidification experiments reported by peer-reviewed studies. In each experiment, the effect of pH decreases on species was allocated to three possible responses: growth, reproduction, and mortality of individual organisms. Species-specific EC_{50} data were employed in the construction of SSDs and we estimated the change in the PAF of calcifying species in two global climate change

Marine water pH – potentially affected fraction

scenarios. Below, we discuss the main uncertainties of the analysis and interpret our results.

4.4.1 Uncertainties

We constructed SSDs based on EC_{50} and EC_{10} derived from experiments where detrimental effects of pH declines on calcifying species were confirmed. However, pH effects were not always detrimental to species since, for many experiments, we found no significant logistic function between pH declines and effects to life processes of species (Table S4.3.2). Occasionally, pH declines prompted a beneficial effect on the growth and reproduction of species (Table S4.3.1). Although, in general, calcification may decrease under increasing acidic conditions, Wood *et al.* (2008) argued that echinoderms may counterweight such effects by altering other physiological processes (such as enhancing muscle wastage and, consequently, reducing their motility) so as to maintain high calcification rates.

In some cases, multiple EC_{50} results were obtained for individual species (i.e. total of four, Table 4.1). For *E. huxleyi*, for example, both benefiting and detrimental effects of pH declines were found. These discrepancies may be due to inherent differences between populations of species across experiments, e.g. Beaufort *et al.* (2011) or the metabolic plasticity of species exposed to ocean acidification (Godbold & Calosi, 2013, Wood *et al.*, 2008). However, discrepant EC_{50} results for one species may have resulted from the lack of standardization between the experiments with respect to their duration, temperature, salinity, etc., (de Vries *et al.*, 2013).

Nevertheless, with the exception of mortality responses, neither temperature nor duration of experiments appears to interact with pH on determining EC_{50} results. Interacting effects of temperature and acidity of oceans remain inconclusive since there are evidences of both antagonistic and synergistic effects of these two climate change related stressors (Benner *et al.*, 2013, Byrne *et al.*, 2009).

In the derivation of logistic regressions in each experiment, we only included the effects at pH levels below 8.35. The choice of discarding more alkaline conditions is based on the fact that marine waters rarely reach 8.35 (Takahashi & Sutherland, 2013). For the calculations of expected changes in the PAF from current to estimated pH scenarios, we assumed current pH levels of 8.1, which is the level of monthly averages of ocean pH reported by Takahashi & Sutherland (2013) at different world's locations.

The SSDs we developed do not take into account spatial variability or seasonal differences across species assemblages. However, such differences are known to occur. For example, while some of the species considered have a global distribution (e.g., *C. leptoporus*), while others have narrower distribution (e.g., *Oculina arbuscula*). Testing if the SSDs would differ depending on spatial or temporal patterns are beyond the scope of this study but, primarily, because acquiring enough EC₅₀ data for different locations or seasons would be a limiting factor in the derivation of SSDs and would considerably decrease the confidence around PAF estimates.

4.4.2 Interpretation of results

Species growth is particularly affected by ocean acidification because changes in water chemistry directly influence the dissolution of calcium carbonate in extracellular tissue (Kroeker *et al.*, 2010). This pattern appears to be homogeneous across the species comprising the SSDs since the variability of species-specific EC₅₀ for growth is considerably lower than for reproduction or mortality (Figure 4.1a-c). This effect has previously been documented for different species of *Acropora* and attributed to an energy-saving strategy whereby metabolic rates of coral larvae are suppressed and, consequently, survivorship remains unaffected under short term acidified seawater (Nakamura *et al.*, 2011).

In this study, we did not find any detrimental but a beneficial effect to the growth of arthropods (Table S4.3.1). Likewise, the reproduction and mortality of arthropods and the growth of the echinoderms were among the least affected by pH declines. This lack of sensitivity to acidified water may have been prompted by attributed to the presence of spines in the calcareous exoskeleton of sea urchins (de Vries *et al.*, 2013) or the more extensive biogenic covering of some crustaceans, e.g. *Penaeus plebejus*, which can diminish the dissolution of CaCO₃ from their exoskeleton to seawater (Ries *et al.*, 2009). By contrast, molluscs such as *Mytilus edulis* comprise an exoskeleton that with a high content of highly soluble aragonite in their skeleton, which prompts their growth to be particularly affected by acidified ocean waters (Beesley *et al.*, 2008). The difference in chemical composition of the exoskeleton of mussels and crustaceans may have generated the apparent discrepancies between EC₅₀ results between the two species groups.

Mortality of hapophytes (i.e. *E. huxleyi* and *C. leptoporus*) was affected by pH declines and yet we also found beneficial effects to the growth of *E. huxleyi* (Table S4.3.1). This seeming contradiction has been reported before (Beaufort *et al.*, 2011) and it may be a consequence of, one

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hand, their increasing photosynthetic activity, which would promote the organism's development, and, on the other hand, their decreasing calcification (Engel *et al.*, 2005).

4.4.3 Concluding remarks

Our study shows how species-specific responses of calcifying species to pH declines can be implemented in environmental risk assessments. Our results show that responses not only vary across taxa but also across life processes of species. The employment of SSDs for ocean acidification may be useful to assessments of ocean acidification risks since they allow for the identification of particularly sensitive groups of calcifying species and the estimation of inter-species variability responses to pH declines. Additionally, we show how SSDs can be used for the estimation of the potential fraction of the species assemblage affected in different global climate change scenarios.

ACKNOWLEDGMENTS

We thank Thomas M. W. J. van Goethem for his support in calculating the uncertainty ranges of the results.

Chapter 5

Species richness – phosphorus relationships for lakes and streams worldwide

Ligia B. Azevedo
Rosalie van Zelm
Pieter M. F. Elshout
A. Jan Hendriks
Rob S. E. W. Leuven
Jaap Struijs
Dick de Zwart
Mark A. J. Huijbregts

Modified version of manuscript published in *Global Ecology & Biogeography* (2013) 22: 1304 – 1311

Freshwater total phosphorus – relative species richness

MODIFICATIONS FROM PUBLISHED VERSION

- 1- Figures 5.2, 5.3, and S5.2.1 are shown in grey scale, not in color;
- 2- The projection of the map of Figure 5.2 is Gall-Peters not Aitoff;
- 3- Table S5.2.2 shows total phosphorus concentration ranges of species per habitat not ranges in across all regions.

ABSTRACT

We investigated the patterns of autotrophic and heterotrophic relative species richness along a total phosphorus (TP) concentration gradient on a global scale. The relative species richness – TP relationships were calculated separately for four different regions [(sub)tropical, xeric, temperate, and cold] and two types of water bodies (lakes and streams). Using data from peer-reviewed articles reporting the occurrence of freshwater species at specific TP concentrations, we determined the species richness along a TP gradient. Using log-logistic regressions, we then estimated the TP concentration at which the potential decrease of relative species richness (RSR) equals 0.5 and the slope at which the decrease occurs (β). The RSR is given as the ratio of species richness to maximized species richness along a TP gradient. The RSR of streams generally decreased more rapidly than that of lakes with increasing P, as illustrated by the steeper slope of the log-logistic functions for streams ($\beta_{\text{lakes}} < \beta_{\text{streams}}$). Although there was no consistent trend between autotrophs and heterotrophs in the different regions, we found that the TP concentration at which the RSR equals 0.5 was lower in cold regions (0.04 – 0.22 mg P/L) than in warmer regions (0.28 – 1.29 mg P/L). The log-logistic relationships between RSR and TP concentration vary considerably among regions of the world, between freshwater types (lakes and streams) and between species groups (autotrophs and heterotrophs). This variability may be attributed to differences between the two freshwater types in respect to their species groups and evolutionary patterns, nutrient demand, biogeochemical and hydrologic processes. We were not able to derive log-logistic regressions for all combinations of freshwater type or species type and region [e.g., (sub)tropical lakes]. For other areas, our results can be used to assess the potential impact of phosphorus eutrophication on freshwater biota.

5.1 Introduction

The intensification of agriculture, industrialization, and urbanization has led to increasing fluxes of phosphorus (P) worldwide (Liu & Wang, 2007). In freshwater systems, this nutrient is regarded as the main factor

driving primary productivity (Schindler, 1974). In addition to increases in biomass, changes in autotrophic and heterotrophic species richness associated with P concentrations have been reported (McIntyre *et al.*, 2007, Penning *et al.*, 2008, Rumes *et al.*, 2011). For example, high crustacean species richness was found in eutrophic (sub)tropical lakes, while richness of macrophytes in temperate lakes (Rumes *et al.*, 2011) was maximized at intermediate total-phosphorus levels (Penning *et al.*, 2008). The rate of nutrient recycling in tropical streams has also been linked to fish species richness (McIntyre *et al.*, 2007), suggesting that total-phosphorus levels and faunal richness are strongly correlated.

Because aquatic eutrophication is currently considered one of the strongest threats to water quality and stream biodiversity worldwide (Björklund *et al.*, 2009, Vörösmarty *et al.*, 2010), it is important to identify the freshwater types and regions whose biotic communities are most affected by P imbalances. Many studies have focused on the effects of increasing P in one or more specific water bodies, species, or regions (Dodson *et al.*, 2000, Smith *et al.*, 2007, Struijs *et al.*, 2011b). However, to our knowledge, no study has outlined the effects of different P concentrations on relative species richness on a global scale. Understanding how decrease in relative species richness due to P increases may occur in different regions of the world and in different freshwater types is essential for the ecological assessment of eutrophication impacts.

The goal of this study was to compare the relationships between P concentration and the relative species richness of autotrophs and heterotrophs in lakes and streams in different regions of the world. We first performed an inventory of peer-reviewed observational field data, which yielded a large number of studies worldwide. We then derived concentration-response relationships based on this dataset. Given that the cause-effect relationships obtained from nutrient-addition experiments may reflect only small spatial and temporal coverage, observations from surveys make it possible to derive concentration-response relationships for other areas or periods.

Concentration-response relationships are commonly applied in toxicology and can be used to compare the sensitivity of different species groups to changes in the concentration of the stressor of interest. They can also be directly coupled with existing biogeochemical models of the fate of P in inland waters, such as those used in Global NEWS (Harrison *et al.*, 2005, van Drecht *et al.*, 2005), the Millennium Ecosystem Assessment (van Drecht *et al.*, 2009b), life cycle impact assessments (Helmes *et al.*, 2012), or

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estimation of past or expected ecological risk of stressors (Fedorenkova *et al.*, 2012, Leuven *et al.*, 2011), to ultimately determine the relationships between environmental stressors and relative species richness in freshwater systems.

5.2 Material and methods

5.2.1 Species richness – total P relationships

We chose total P (TP) as our stressor of interest because it is the recommended P fraction for water quality monitoring (Lewis *et al.*, 2011) and is commonly reported in water-quality studies. Based on observational studies of species occurrence, we calculated the relative species richness of autotrophs and heterotrophs along a TP gradient. Subsequently, we derived log-logistic regressions of the relative species richness in lakes and streams in (sub)tropical, temperate, cold, and xeric regions. Each step is described in detail below, and the complete framework is illustrated in Figure 5.1.

We computed the overall species richness (SR) as the number of species reported in $0.1 \log_{10}$ -transformed concentration intervals (C_i , mg P/L) for streams and lakes in different regions as

$$SR_{i,t,h,g} = \sum_{\log_{10} C_i} O_{t,h,g} \quad (5.1)$$

where $O_{t,h,g}$ is the occurrence of a given species in species group g (autotrophs or heterotrophs) at nutrient concentration C_i in freshwater type t (stream or lake) in region h . O is one if the species is reported to be present and zero if the species is not present.

We identified the concentration of TP at which $SR_{i,t,h,g}$ is at its maximum (SR_{\max}). This approach has been applied by Struijs *et al.* (2011b) for genus-level macroinvertebrate richness in Dutch streams as a function of TP-induced stress and by Azevedo *et al.* (2013b) for vascular-plant species richness in biomes as a function of low-pH stress. The TP concentration at which SR equals SR_{\max} is hereafter referred to as the optimum TP concentration, C_{opt} . To compare SR – TP concentration relationships between autotrophs and heterotrophs, between lakes and streams, and among regions, we transformed SR into a relative species richness measure as

$$eRSR_{i,t,h,g} = \frac{SR_{i,t,h,g}}{SR_{\max_{i,t,h,g}}}, \text{ for } C_i \geq C_{\text{opt}} \quad (5.2)$$

following Azevedo *et al.* (2013b) and Struijs *et al.* (2011b), where eRSR is the empirical relative species richness (eRSR) of species in group g at concentration C_i in freshwater type t in region h . At C_{opt} , eRSR is one. Conversely, an eRSR of zero represents the complete absence of species. At C_i values lower than C_{opt} , we consider that SR is no longer affected by the excess P (Struijs *et al.*, 2011b). Thus, eRSR is here described only for C_i values larger than C_{opt} . It is important to note that species richness – TP relationships are typical bell-shaped curves, with species richness also decreasing at limiting nutrient levels (Penning *et al.*, 2008, Struijs *et al.*, 2011b). In this study, we were interested in how individual species' tolerance to high TP levels might influence species richness – TP relationships. Therefore, we limited the analysis to the eutrophic side of the curve, i.e. at C_i greater than C_{opt} (Struijs *et al.*, 2011b).

Next, we used a log-logistic model of the calculated RSR (cRSR) by fitting it to eRSR as

$$cRSR_{i,t,h,g} = \frac{1}{1+e^{-\left(\frac{\log_{10}C_i - \alpha_{t,h,g}}{\beta_{t,h,g}}\right)}}, \text{ for } C_i \geq C_{opt} \quad (5.3)$$

The coefficient α indicates the \log_{10} TP concentration at which relative species richness is 0.5, and β indicates the slope of the log-logistic regression. We fitted both cRSR coefficients (α and β) using logistic regression in SAS 9.2. The sample size for the log-logistic regression is given by the number of $SR_{i,t,h,g}$ data points (at 0.1 \log_{10} TP-concentration intervals). We considered a log-logistic model to fail to fit the empirical data if it had a p value > 0.05 , a β coefficient non-different from zero at a 95% confidence level, or an α coefficient outside the concentration range at which eRSR data were available (between C_{opt} and the maximum observed TP level). To test for potential sampling bias resulting from different sampling effort across regions, we tested whether the number of species or the number of studies was correlated with our results for C_{opt} , α , or β .

5.2.2 Sensitivity analysis

We conducted a sensitivity analysis to investigate how our regressions might vary if smaller spatial units were used. For this analysis, we used the methodology described above, but at smaller spatial levels of detail: freshwater ecoregions [delineated by Abell *et al.* (2008)], regions within individual realms, and individual studies in our data inventory. Azevedo *et al.* (2013b) have suggested employing a sensitivity analysis based on repeating the procedure using smaller spatial-aggregation levels to

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identify differences in ecoregions within terrestrial biomes.

We repeated the sensitivity analysis to determine how our results would change if we distinguished among specific taxonomic groups within the autotrophic and heterotrophic groups. Autotrophs were divided into cyanobacteria, silicon-based algae, non-silicon-based algae, and macrophytes, while heterotrophs were divided into fish and invertebrates.

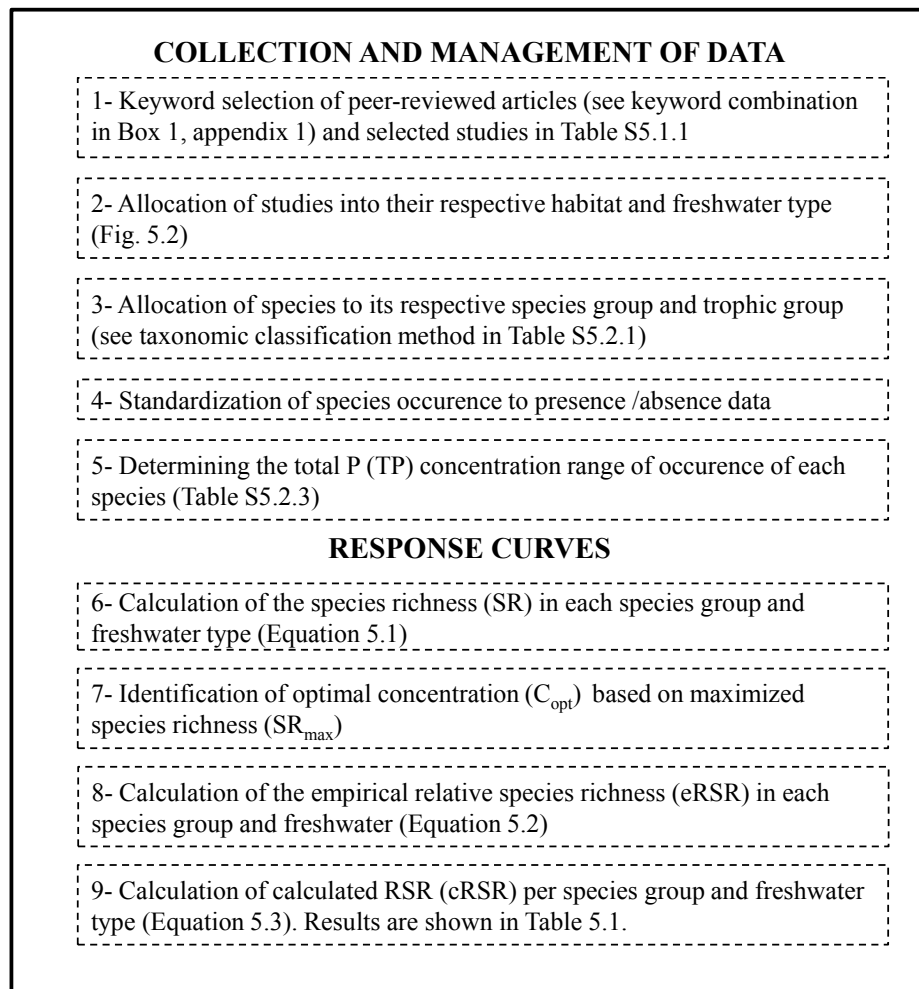


Figure 5.1 Description of the steps taken for acquisition of data and derivation of response curves.

5.2.3 Collection and management of data

To acquire data about the TP-concentration ranges at which specific aquatic species were reported to be present, we selected peer-reviewed articles using a combination of relevant keywords in *Web of Science* (lake, freshwater, phosphorus, etc.). The specific keyword combinations can be found in Appendix S5.1 in the Supporting Information. We included only articles that reported the locations of their field surveys and that recorded TP concentrations and species occurrences at the same sampling location and time. We also included species records from the *Limnodata Neerlandica* database (STOWA, 2010), which includes invertebrate-occurrence data and water-quality measurements for inland waters in the Netherlands. We did not consider brackish or inland saline waters or anthropogenic ecosystems, such as fish ponds or wastewater-treatment plants.

We grouped ponds and reservoirs with freshwater lakes and springs, rivers, and creeks with streams. Wetlands were excluded from this study. Furthermore, based on the geographical location of each study, we assigned each freshwater system to a biogeographical region: (sub)tropical, temperate, cold, or xeric. This division was based on the major freshwater habitat types (MHT) of the world, recently developed by Abell and colleagues of the FEOW project (Freshwater ecoregions of the world, <http://www.feow.org>). We combined the regions designated as temperate coastal rivers, temperate floodplain rivers and wetlands, and temperate upland rivers into one temperate region. Likewise, we combined (sub)tropical coastal rivers, (sub)tropical floodplain rivers and wetlands and (sub)tropical upland rivers into one (sub)tropical region. Although the MHT map delineated by the FEOW includes many freshwater types, such as temperate floodplain rivers and wetlands, we used the freshwater-type classification given by each inventoried study. Montane and polar freshwater systems were combined and referred to as the cold region. Studies located in the MHT classes Oceanic Islands, Large Lakes, and Large River Deltas (such as studies located in the Great Lakes and Lake Peipsi regions, the Paraná River basin, and the Azores Islands) were assigned to the closest adjacent habitat.

We selected species belonging to the following groups: autotrophs (comprising cyanobacteria, silicon-based algae, non-silicon-based algae, and macrophytes) and heterotrophs (comprising aquatic invertebrates and fish). We used the Integrated Taxonomic Information System database (www.itis.gov) for the nomenclature of invertebrates and fish, the PlantList (www.theplantlist.org) for macrophytes, and the AlgaeBase (www.algaebase.org) for cyanobacteria, silicon-based algae, and non-silicon-

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based algae (for details on the allocation of each organism, Table S5.2.1). We included records at taxonomic levels lower than species (i.e., variety and subspecies) when they were available, considering them as species-level records. Next, we standardized the different reporting methods in each study (e.g., biomass and abundance) into an occurrence/non-occurrence dataset for each species. For example, if biomass was greater than zero, then we considered the species as occurring.

We then derived the TP-concentration range at which each species occurred in streams or lakes within each water body in each region following the method described by Azevedo *et al.* (2013b). Each concentration range represents the tolerance of an individual species to TP levels in a given freshwater type and region. Outside of these concentration boundaries, the species was considered absent. The range of occurrence (minimum and maximum concentration values) was calculated using one of the following procedures, in order of preference: (1) the lognormal variation distribution of 90% of the sample (Slob, 1994), (2) the minimum – maximum reported concentration range, or (3) the mean value alone. Finally, we considered the overall range of occurrence of each species to be represented by the lowest minimum and highest maximum concentrations obtained for that species in a given freshwater type in a given region. Species whose final minimum- and maximum-concentration values were equal were excluded from the dataset because this condition does not represent a true concentration range found in the environment.

5.2.4 Data set

Approximately 6800 studies were found using the keyword combinations, and 186 of these studies were applicable (see list of studies in Table S5.1.1). Most studies did not fulfill all the requirements of this data inventory, such as identifying organisms at the species level, sampling either lake or stream freshwater systems, and providing spatially explicit, field-observation data on TP concentrations.

Many studies (142) represented North American and European freshwater systems (Figure 5.2). The number of studies conducted in lakes and streams was 155 and 35, respectively (Table S5.1.1). The inventory included 2294 unique species, with 1318 and 1596 species-occurrence – TP-concentration records for autotrophs and heterotrophs, respectively (see Table S5.2.2 for specific species ranges). We found no data for autotrophs in

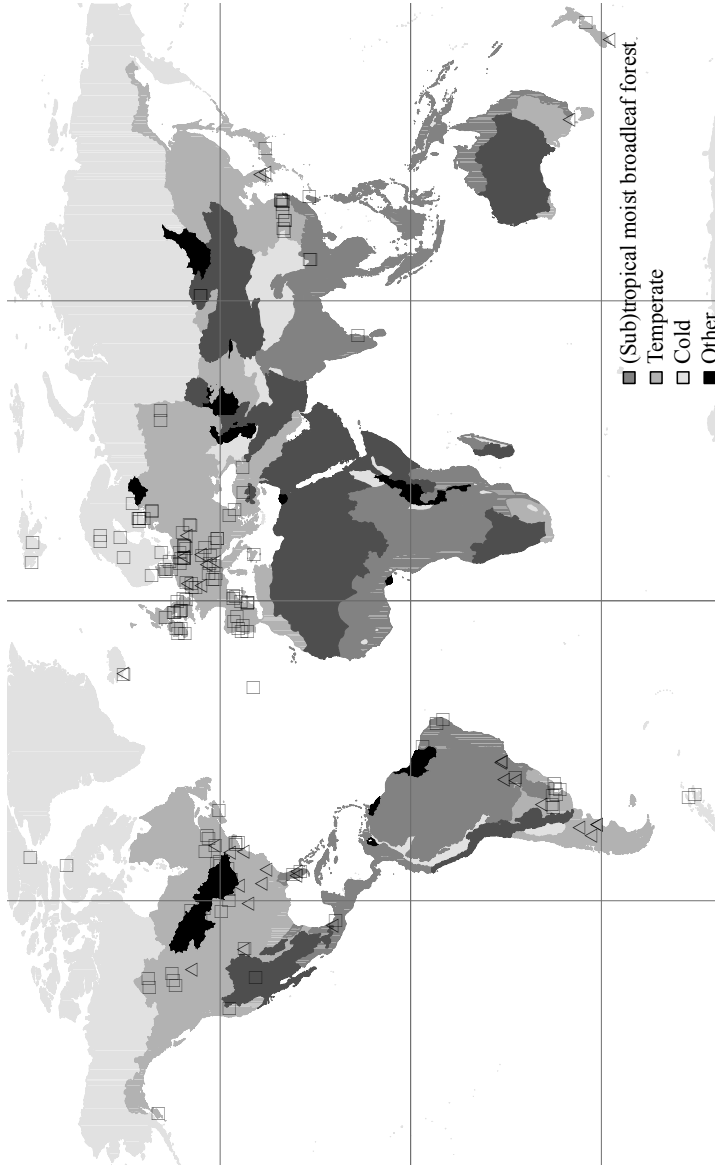


Figure 5.2 World map with the location of the freshwater bodies used in this study allocated to four regions. The studies within “Other” areas (11), which represent large freshwater bodies and oceanic islands, were allocated to their closest region. Squares (155) and triangles (35) represent lakes and streams, respectively.

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cold-region streams or for autotrophs and heterotrophs in xeric-region streams.

5.3 Results

We were able to derive log-logistic functions for eight of the thirteen combinations of species group (autotrophs and heterotrophs), freshwater type (lakes and streams), and region for which eRSR data were available (Figure 5.3). The number of available species in each combination varied considerably, from 45 autotrophic species in xeric lakes to 835 heterotrophic species in temperate streams (Table 5.1). Figure S5.2.1 shows the scatter-plots of species richness vs. TP concentration that were used to define C_{opt} and to calculate eRSR.

The TP concentration at which species richness is maximized, C_{opt} , was lowest in cold-region lakes (0.02 to 0.03 mg P/L, Table 5.1). C_{opt} was generally higher in streams (0.07 to 0.20 mg P/L) than in lakes (0.02 to 0.10 mg P/L). We found no clear distinction between the C_{opt} values of heterotrophs and autotrophs across freshwater types and regions.

The log-transformed TP concentration at which RSR equals 0.5, represented by α , was highest in temperate streams (for both autotrophs and heterotrophs) and in xeric lakes (for autotrophs) ($10^\alpha = 1.0$ to 1.3 mg P/L, Table 5.1). α was lowest for heterotrophs in cold-region lakes ($10^\alpha = 0.04$ mg P/L).

The sensitivity of species to increasing nutrient levels is represented by the slope of the log-logistic function, β (the higher the β , the steeper the function). Heterotrophic RSR was systematically more sensitive to increases in P compared to autotrophic relative species richness, except in temperate streams. Autotrophs in temperate and cold lakes were the least sensitive to TP increases ($\beta = -0.53$ to -0.63).

Figure 5.3 Empirical (eRSR, circles) and the calculated (cRSR, lines) relative species richness of autotrophs along a total phosphorus (TP) gradient in lakes (a) and in streams (b) and of heterotrophs in lakes (c) and in streams (d). Log-logistic coefficients used in the cRSR functions are shown in Table 5.1.

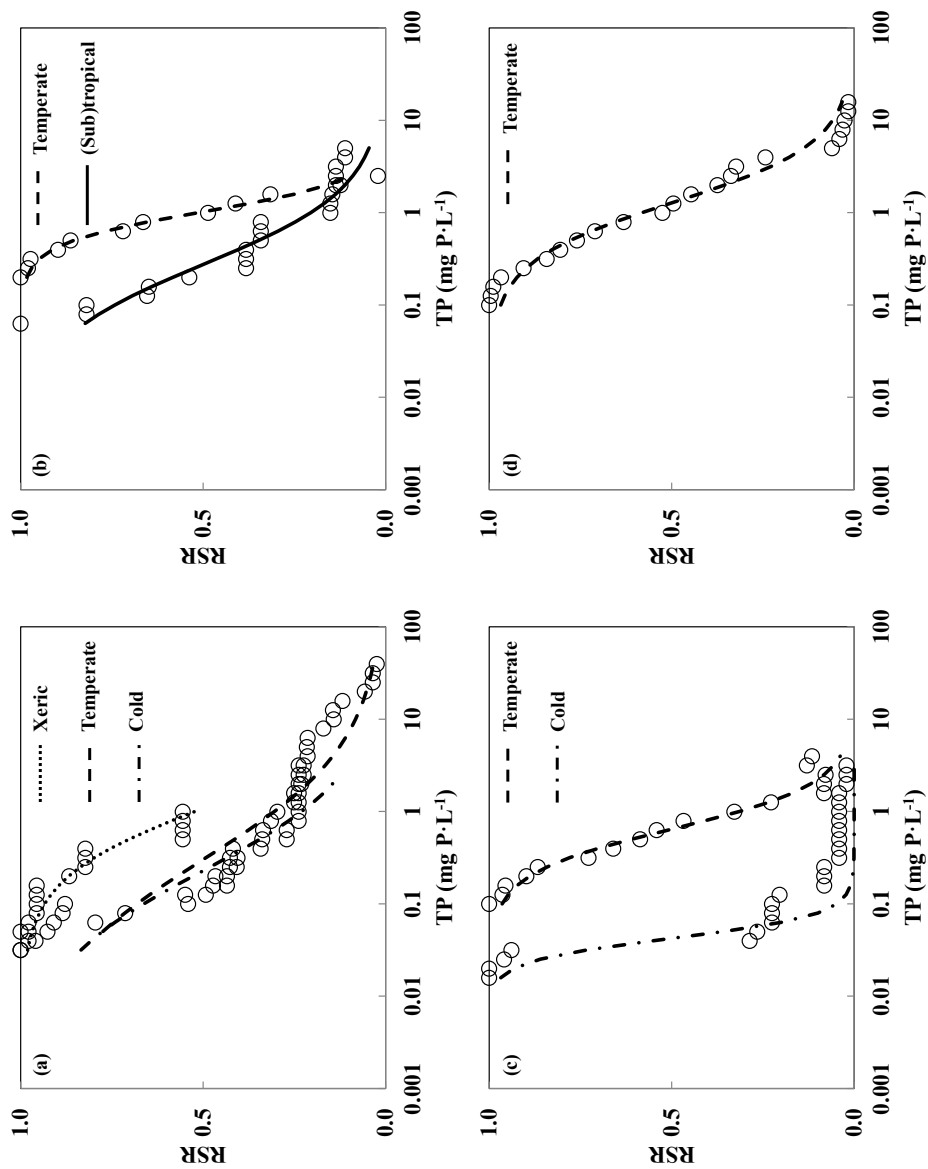


Table 5.1 Number of studies, surveyed range of TP (mg P/L), number of species (SR_{max}), optimum TP level in habitat, C_{opt} (C_{opt} across ecoregions in brackets), relative species richness (RSR) coefficients α and β and 95% confidence intervals (in brackets), $R^{2\#}$ (p value in brackets) of log-logistic regressions for two organism groups, in two freshwater types, and four world's regions.

	Studies	Surveyed range	Species	SR_{max}	C_{opt}	α (95% CI)	β (95% CI)	$R^{2\#}$ / p value
(a) Lake autotrophs								
Cold	10	0.002 to 3.155	163	122	0.03 (0.005 to 0.03)	-0.64 (-0.76 to -0.52)	-0.53 (-0.67 to -0.40)	0.88 / < 0.001
Temperate	74	0.001 to 41.970	614	459	0.05 (0.002 to 0.32)	-0.52 (-0.66 to -0.38)	-0.63 (-0.78 to -0.48)	0.88 / 0.001
Xeric	2	0.009 to 1.180	45	45	0.03 (0.03 to 0.03)	0.03 (-0.07 to 0.14)	-0.39 (-0.50 to -0.28)	0.91 / 0.001
(Sub)tropical [#]	7	0.003 to 35.000	95	42	15.85 (0.001 to 15.85)	1.58 (0.98 to 2.18)	-0.19 (-0.78 to 0.39)	0.72 / 0.013
(b) Lake heterotrophs								
Cold	14	0.002 to 3.155	54	49	0.02 (0.003 to 0.02)	-1.37 (-1.43 to -1.31)	-0.12 (-0.18 to -0.07)	0.92 / 0.001
Temperate	61	0.001 to 4.070	682	488	0.10 (0.003 to 3.2)	-0.19 (-0.23 to -0.15)	-0.24 (-0.281 to -0.21)	0.98 / 0.001
Xeric	1	0.385 to 4.124	4	4	0.63 [†]	No successful fit with the log-logistic regression		
(Sub)tropical [#]	4	0.001 to 0.220	9	7	0.04 (0.005 to 0.04)	-0.82 (-0.86 to -0.78)	-0.03 (-0.07 to 0.01)	0.92 / 0.001
(c) Stream autotrophs								
Temperate	11	0.001 to 2.625	182	146	0.20 (0.001 to 0.50)	0.01 (-0.02 to 0.04)	-0.17 (-0.20 to -0.15)	0.99 / 0.001
(Sub)tropical	6	0.001 to 5.088	203	199	0.07 (0.001 to 0.08)	-0.56 (-0.64 to -0.48)	-0.41 (-0.50 to -0.33)	0.94 / 0.001

	Studies	Surveyed range	Species	SR _{max}	C _{opt}	α (95% CI)	β (95% CI)	R ^{2N} / p value
(d) Stream heterotrophs								
Cold	1	0.010 to 0.044	2	2	0.02 [†]	No successful fit with the log-logistic regression		
Temperate	16	0.007 to 17.000	835	697	0.10 (0.01 to 0.40)	0.11 (0.06 to 0.15)	-0.32 (-0.36 to -0.29)	0.99 / 0.001
(Sub)tropical [#]	3	0.052 to 1.225	9	8	0.40 (0.1 to 0.40)	0.13 (-0.02 to 0.29)	-0.15 (-0.29 to -0.01)	0.85 / 0.001

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^u coefficient was outside the TP concentration range of relative species richness (defined by C_{opt} to upper boundary of surveyed TP concentration)

[†] Minimum and maximum range of C_{opt} based on one ecoregion only

[‡] $Pseudo - R^2 = 1 - \frac{SS_{Residual}}{SS_{Corrected Total}}$, as defined by Schabenberger & Pierce (2001)

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To analyze the robustness of our results, we compared how the choice of spatial scale would affect the log-logistic regression coefficients by aggregating the dataset into realms, ecoregions, and individual studies. We found that there may be high spatial variability across spatial units within a region (Appendix S5.3). However, the variability of the coefficients obtained for spatial aggregation at the level of regions was within the range of results obtained for these additional levels of aggregation.

The three phytoplankton groups showed similar sensitivity to TP changes within lakes in the same region (Table S5.3.5). The results for cyanobacteria species were not different for similar freshwater types across regions (Tables S5.3.5 and S5.3.6). On the other hand, phytoplankton species of temperate lakes (cyanobacteria, silicon-based and non-silicon-based algae) are less sensitive to TP changes than macrophytes (Table S5.3.5). However, invertebrates in cold-region lakes were more sensitive to TP changes than invertebrates in temperate lakes (Table S5.3.7). The overall heterotrophic group also showed greater sensitivity in cold-region lakes than in temperate lakes (Table 5.1). In the temperate region, the level of P at which heterotrophic lake species maintained 50% of their richness was similar to that obtained for invertebrates but higher than that obtained for fish (Table S5.3.7).

We were not able to derive log-logistic regressions for all smaller spatial units and specific taxonomic groups. For example, although there were nine ecoregions within the temperate region, we were able to derive regressions for stream autotrophs in only four of these ecoregions (i.e., Central & Western Europe, Northeast US & Southeast Canada Atlantic Drainages, Southeastern Korean Peninsula, and Upper Mississippi, Table S5.3.2). Likewise, no data were available for macrophytes in (sub)tropical streams; therefore, this species group was not evaluated.

5.4 Discussion

We derived the concentration-response relationships between TP and the RSR of autotrophic and heterotrophic species in two freshwater types (lakes and streams) in temperate, (sub)tropical, xeric, and cold regions. Below, we explore the main uncertainties of our study and interpret our results.

5.4.1 Uncertainties

First, the optimum concentration (C_{opt}) reported here corresponds to

the maximal species richness found within an observed TP-concentration gradient. Thus, we assume that the RSR – TP patterns we report are valid for TP levels above but not below C_{opt} . This concentration does not necessarily correspond to minimally disturbed, “baseline” conditions. Nonetheless, the calculated C_{opt} values are within the range of target values established by the European Union and the United States Environmental Protection Agency, which range from 0.01 to 0.15 mg P/L (European Commission, 2000, Smith *et al.*, 2003). The species used in the regression above C_{opt} may have been more represented by high-TP-tolerant algae and less by species that are typically present at low nutrient levels. In fact, many species in our inventory were present at TP conditions below C_{opt} (Table S5.2.3), suggesting that these species may also be adapted to survive at low TP levels.

Second, in our study, the response of organisms to stress was estimated based on phosphorus levels alone because this nutrient is considered the primary limiting nutrient in freshwater systems (Carpenter *et al.*, 1998, Schindler, 1974). We did not consider the influence of other stressors, although these can also influence freshwater species. For example, nitrogen has been reported to influence primary productivity as much as phosphorus, and co-limitation has also been reported to drive eutrophication (Elser *et al.*, 2007). Lower light availability due to increasing turbidity or growth of macrophytes may hinder the influence of P (Le Bagousse-Pinguet *et al.*, 2012). Likewise, grazing pressure, oxygen availability, chlorophyll concentration, substrate texture, stream width or area, and lake depth have been reported as factors to explain the variability in species-richness responses to P (Amarasinghe & Welcomme, 2002, Friberg *et al.*, 2010, Huszar *et al.*, 2006).

In addition to abiotic stressors, the nutrient demands of planktivores or higher-order consumers may vary widely (Hall, 2009). These differences are frequently addressed by biomanipulation experiments (Carpenter *et al.*, 2001). Although the present study did not account for each species’ position in the food chain, we distinguished organisms according to their primary nutrition pathways (i.e., their ability or inability to perform photosynthesis).

Third, the type or number of species representing each species group (autotrophs and heterotrophs) may depend on the research focus. For example, diatoms are commonly used for water-quality monitoring, but the Dutch water-quality database we employed (STOWA, 2010) focuses on macroinvertebrates. In cold- and temperate-region lakes, the number of invertebrate species was more than three times the number of fish species (Table S5.3.7). One outcome of the high number of invertebrates is that the

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TP level at which 50% of the species are maintained for the overall heterotrophic group was similar to that for invertebrates but not to that for fish. Although taxa differ in their tolerance to high P levels (Caputo *et al.*, 2008), we did not account for these differences in this study. Our results should therefore be interpreted at the level of the overall autotrophic and heterotrophic species groups but not at lower taxonomic levels.

Fourth, due to the strong research effort in Western Europe and in eastern North America, we found numerous studies in the temperate region (Figure 5.2). This prompted the number of species employed to derive the RSR – TP functions in temperate systems to be higher than elsewhere. However, neither the number of studies nor the number of species used to derive our regressions influenced the results we obtained for C_{opt} , α , or β (appendix 4). In any case, the sensitivity analysis showed that there may be strong variability among areas within a specific region. For example, while the 10^{α} and β coefficients for temperate lake autotrophs were 0.30 and -0.63 mg P/L, respectively, individual studies yielded 10^{α} values ranging from 0.02 to 4.07 and β values ranging from -0.53 to -0.01 (Table S5.3.1). The choice of spatial units into which localities are aggregated to derive log-logistic regressions (e.g., regions, ecoregions, or individual studies) remains under discussion. For example, Azevedo *et al.* (2013b) derived regressions at the biome level of spatial detail, while Struijs *et al.* (2011b) and Amarasinghe & Welcomme (2002) defined their species-richness patterns per country and per continent, respectively.

Fifth, we gathered data on TP concentration ranges at which freshwater species were present. In conditions outside this surveyed range, it is uncertain whether the species truly becomes absent because of life-threatening concentration levels. In contrast to controlled experimental studies, field-based observational studies like those surveyed here provide less certainty as to the exact boundaries between tolerable and intolerable stressor conditions (Struijs *et al.*, 2011b). Therefore, we cannot confirm factual species disappearance since the calculations of species richness are not based on verified species loss but on first-encounter species occurrence. Ultimately, there may be an underestimation of relative species richness estimations which are based on first-encounter analysis as opposed to confirmed species loss due to intolerable TP levels. This concern has been recently defined as ‘dark diversity’ (Pärtel *et al.*, 2011) and it is commonly under scrutiny when the stressor of interest is the potential loss of species caused by damage to the species living space as such (He & Hubbell, 2011). In observational studies such as ours, the issue caused by unconfirmed species loss may be alleviated by thorough monitoring of species occurrence

and by coverage of a wide TP-concentration gradient, up to highly eutrophic levels.

Finally, to compare the potential impact of phosphorus across regions with evident differences in species richness [e.g., cold vs. (sub)tropical freshwater systems], we employed a relative measure of relative species richness. Despite our effort to gather data from the literature, we were not able to successfully estimate the RSR in regions for which very few or no data were found, such as xeric-region streams and (sub)tropical lakes.

This species-occurrence/non-occurrence approach simplifies an effect type previously described in a continuous manner (e.g., biomass or abundance) into a simpler binary dataset (presence and absence). This standardization has the advantage of combining the different ways in which effects have been reported by different studies. While abundance is more commonly reported for species that are visible to the naked eye, other organisms are more frequently reported as present or absent in a given freshwater body.

5.4.2 Interpretation

Optimum TP

Our results show that the optimum TP concentrations are generally higher in streams than in lakes. This finding can be attributed to distinct biotic nutrient demands in the two freshwater types. First, because lakes require lower P levels than streams to reach the same net primary-productivity rate (Smith *et al.*, 1999), the optimum TP can be reached at lower concentrations in lakes than in streams. This pattern was observed across all autotrophic groups (cyanobacteria, silicon-based and non-silicon-based algae, and macrophytes) in the temperate region. Second, while nutrient surpluses in lakes are quickly reduced by widespread, fast-growing algae (Carpenter *et al.*, 1998, Doi, 2009), nutrient recycling in streams, especially those of lower size orders or with strong tree shading, depends primarily on the speed at which heterotrophs assimilate organic matter (Merritt *et al.*, 1984, Vannote *et al.*, 1980).

Another reason for the higher optimum TP levels in streams compared to lakes is the differences in hydrological patterns that influence nutrient removal from the water column. Once nutrients are deposited in the sediment layer via the sinking of soil, animal fecal pellets or algae, they can be either transported back into the water column or immobilized in the sediment for long periods (Holtan *et al.*, 1988). In streams, strong water

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currents enhance sediment uplift, favoring the maintenance of high TP levels in the water column (Bahnwart *et al.*, 1998). In addition, the short residence times of water in streams, especially lower-order streams, may decrease phytoplankton exposure to nutrients hence hinder autotrophic growth (Vannote *et al.*, 1980). Conversely, lakes, especially cold ones (Carpenter *et al.*, 1999), may be subjected to thermal stratification for many months, confining nutrients to the surface layer, where net primary productivity and nutrient recycling prevails, and hindering the vertical uplift of nutrient-rich sediments (Tylmann *et al.*, 2012).

Phosphorus loads are lower overall in the cold region than in the temperate and (sub)tropical regions due to lesser anthropogenic nutrient release in cold regions, e.g., agricultural runoff (Harrison *et al.*, 2010). Smaller decomposition rates in colder regions may also decrease nutrient release into water bodies. It is therefore likely that most species in cold regions are adapted to low nutrient concentrations. Because we were not able to derive regressions for both species groups in warmer regions [(sub)tropical and xeric], it is unclear how the climatic gradient represented by the four regions may influence C_{opt} across the two species groups.

Regression coefficients

Geological and evolutionary processes in freshwater systems will determine how tolerant the biotic community is to a given stressor. As a result, species in nutrient-rich environments will be more adapted to high nutrient levels than those unused to such conditions (Bontje *et al.*, 2011, Köhler, 1994). In this study, we found that the freshwater systems that could maintain half of the relative species richness at higher TP levels were also those with high optimum TP levels, C_{opt} . Nonetheless, this trend does not imply that organisms with high tolerance to elevated phosphorus levels are also less sensitive to changing levels of this nutrient.

Heterotrophs have higher P demands than autotrophs because autotrophs have higher N:P and C:P ratios (Elser *et al.*, 2000). Hence, heterotrophs are expected to be more affected by P surpluses than autotrophs (and more sensitive to changing P levels). In our study, however, this hypothesis was confirmed in temperate and cold-region lakes but not in temperate streams (Table 5.1). Here, we propose three explanations for the lower sensitivity of autotrophs in lakes compared to streams based on the difference in light availability and photosynthetic rates between the two freshwater types. This analysis is verified once phytoplankton species (cyanobacteria, silicon-based and non-silicon-based algae) are separated

from macrophytes in the autotrophic group in temperate lakes. First, the increased production of N-rich protein and RNA by small organisms with high growth rates suggests that the biological demand for N may surpass that for P (Elser *et al.*, 1996). The lesser effect of P on autotrophs in lakes compared to streams may be due to more intense autochthonous phytoplankton activity in lakes than in streams (Doi, 2009). Second, the lower sensitivity of autotrophic richness to P changes can be attributed to the insensitivity of cyanobacteria to low-oxygen and high-P conditions (Downing *et al.*, 2001). Many cyanobacteria, including toxic groups (e.g., *Aphanizomenon*), compensate for their light demand in light-abundant lacustrine systems and for their N demand via N fixation; ultimately, P supplementation allows them to overcome their primary growth limitations (Camargo & Alonso, 2006b). Third, macrophytes help to maintain algal diversity under increasingly eutrophic conditions by impeding the fast-growing, light-favored phytoplankton that prevail in eutrophic lakes (Le Bagousse-Pinguet *et al.*, 2012). Given that the proportion of macrophytes within the autotrophic group was considerably higher in temperate lakes than in streams, the buffering effects of increasing P may be more intense in lakes compared to streams in the temperate region.

The sensitivity of organisms could be compared across lakes and streams only in the temperate region. We found that heterotrophic species were less sensitive to TP changes in streams than in lakes. This difference may be due to the high dispersal ability of heterotrophs in lakes, generating stronger similarity between species assemblages and thus lower β -diversity in lakes compared to streams (Hof *et al.*, 2008). If lakes contain more similar species assemblages, which are expected to react in a more similar way following stress exposure, then relative species richness will change more rapidly in lakes than in streams because streams encompass more dissimilar species.

The comparison across regions was hindered by the scarcity of data for (sub)tropical lakes and xeric streams. In addition, the influence of P on primary productivity is less apparent in (sub)tropical lakes than in temperate lakes (Huszar *et al.*, 2006), which may explain why we were not able to derive a log-logistic regression for this ecosystem. Huszar *et al.* (2006) and Abell *et al.* (2012) have suggested that nitrogen may drive primary production more than P does in (sub)tropical lakes because higher temperatures enhance nitrogen losses, particularly through denitrification, and P transport to water bodies due to weathering (Abell *et al.*, 2012).

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Relevance of research and application of results

Global-scale assessments are available for the influence of P on net primary productivity in freshwater systems (Elser *et al.*, 2007). However, changes in species richness due to increasing P concentrations have previously been assessed in studies focusing on a specific freshwater type or covering a smaller area, e.g., Struijs *et al.* (2011b) and Friberg *et al.* (2010). The results of the present study show that the patterns of relative species richness along a TP-concentration gradient can be described using logistic regressions.

We identified patterns in the RSR along a TP-concentration gradient for two species groups (autotrophs and heterotrophs), in two freshwater types (lakes and streams), and in four regions [(sub)tropical, xeric, temperate, and cold]. We found that lakes generally, but not always, have lower optimal TP levels and that their species assemblages are less sensitive to TP changes than those in streams. Furthermore, autotrophs and heterotrophs in cold regions have lower optimal concentrations compared to those in other regions. The regressions can be used to describe the potential decrease in relative species richness in a quantitative manner, although it is important to note that factual causal relationships between species losses and P increases are not tackled in this study. In combination with biogeochemical models of the fate of nutrients, this procedure can assist in estimating the ultimate effects of stressors on species richness maintenance (Struijs *et al.*, 2011a, van Zelm *et al.*, 2007, Verbrugge *et al.*, 2012).

ACKNOWLEDGMENTS

This research was funded by the European Commission under the 7th framework program on environment; ENV.2009.3.3.2.1: LC-IMPACT – Improved Life Cycle Impact Assessment methods (LCIA) for better sustainability assessment of technologies, grant agreement number 243827. We thank Michael D. Guiry for providing taxonomic classification of algal species and Robin Abell for providing the map of major habitat types. This manuscript benefited from comments by Pedro R. Peres-Neto, David J. Currie and two anonymous reviewers.

Chapter 6

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

Ligia B. Azevedo
Andrew D. Henderson
Rosalie van Zelm
Olivier Jolliet
Mark A. J. Huijbregts

Modified version of manuscript published in *Environmental Science & Technology* (2013) 47: 13565 – 13570

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MODIFICATIONS FROM PUBLISHED VERSION

- 1- TOC/Abstract Art is not included;
- 2- Description of the calculation of normalization scores (sub header 6.2.5) is included.
- 3- The projection of the map of Figures S6.2.2, S6.2.3, S6.3.2, and S6.3.3 is Gall-Peters not Plate Carée;
- 4- Figures S6.2.2, S6.2.3, S6.3.2, and S6.3.3 are shown in grey scale, not in color;
- 5- Results of the assumption tests of the analysis of variance shown in legend of Table S6.3.4 not as individual figures.

ABSTRACT

In Life Cycle Impact Assessment (LCIA) both spatial variability and model choices may be influential. In the case of the effect model, the effect factors differ with respect to their assumption of linear/non-linear responses to increases in environmental stressor levels, and whether or not they account for the current stressor levels in the environment. Here, we derived spatially-explicit characterization factors of phosphorus emissions causing eutrophication based on three different effect models (depicted by marginal, linear, and average effect factors) and two freshwater types (lakes and streams) and we performed an analysis of variance (ANOVA) to investigate how the selection of the effect models and the freshwater types influence the impacts of phosphorus emissions to freshwater on heterotrophic species. We found that 56% of the variability of ecological impacts per unit of phosphorus emission was explained, primarily, by the difference between freshwater types and, to a lesser extent, by the difference between effect models. The remaining variability was attributed to the spatial variation between river basins, mainly due to the variability in fate factors. Our study demonstrates the particular importance of accounting for spatial variability and model choices in LCIA.

6.1 Introduction

Life cycle impact assessment (LCIA) links an anthropogenic activity related to the life cycle of a product, service, or technology with its impact on the environment. As the impact may depend on site-specific characteristics, e.g. climate or sensitivity of resident species, spatially-differentiated methodologies for LCIA are now being developed for different categories of pollutants, nutrients, and resources (Hanafiah *et al.*, 2011, Núñez *et al.*, 2013, Saad *et al.*, 2011, Sala *et al.*, 2011, Struijs *et al.*, 2011a).

Spatial specificity is an important step in LCIA because it accounts for different regional responses to an anthropogenic activity. For example, Saad *et al.* (2011) found that groundwater recharge capacity varied eight-fold across different Canadian ecozones. Furthermore, not only are there differences across landscapes, but similar landscapes may also comprise compartments with differentiated sensitivity to stressors. For example, streams and lakes located in temperate regions comprise different food web structures and, consequently, their trophic level thresholds differ considerably (Doi, 2009, Smith *et al.*, 1999).

A spatially-explicit LCIA framework describes the environmental impact of an emission of a given pollutant on the ecosystem with characterization factors (CFs) as

$$CF_{w,i} = \sum_j FF_{i \rightarrow w,j} \cdot EF_{w,j} \quad (6.1)$$

where $CF_{w,i}$ is the characterization factor for the pollutant emitted from region i to compartment w , $FF_{i \rightarrow w,j}$ is the fate factor (in days) describing the residence time of the pollutant in the environment transported from region i to compartment w in region j , and EF_j is the effect factor (in $\text{m}^{-3} \cdot \text{kg}$) describing the environmental impact (the fraction of potentially non-occurring or the disappeared fraction of species) following an increase of the pollutant concentration in compartment w in region j . The compartments included in the model can be numerous; here, we focus on freshwater lakes and streams.

Three different effect factor (EF) models are suggested for LCA (Huijbregts *et al.*, 2011, Rosenbaum *et al.*, 2008, Van de Meent & Huijbregts, 2005). The EF models differ with respect to the assumption of linearity/non-linearity of responses and data input requirements. The marginal effect factor model (MEF) estimates a small change of the impact of an emission due to a small change in the environmental concentration of a stressor. The rationale for the MEF is that the impact caused by an emission from an individual product system has only a small share in the overall impact on the environment (Van de Meent & Huijbregts, 2005). The linear effect factor model (LEF), primarily used if the ambient concentration of the pollutant is unknown, describes the change from a preferred state (a target state, with “zero” effect), where the concentration of the pollutant is zero, to the concentration where the effect is 50% of the maximum (Rosenbaum *et al.*, 2008). The average effect factor model (AEF) was recently proposed as an alternative to the MEF (Huijbregts *et al.*, 2011), reflecting the average distance between the current state and the preferred state of the environment.

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Up to now, the influence of spatial variability versus effect model choices on characterization factors has not been investigated.

The goal of our study was twofold. First, we derived spatially-explicit endpoint CFs for phosphorus (P) emissions to freshwater by employing three effect models coupled with an existing model of the transport of phosphorus in freshwaters (Helmes *et al.*, 2012) on the Europe scale. A spatially-explicit impact assessment of the impact of phosphorus emissions is crucial given that anthropogenic P flows in the lithosphere over the last decades (Bouwman *et al.*, 2009, Cordell, 2010) and effects on species diversity are spatially-dependent (Penning *et al.*, 2008, Rumes *et al.*, 2011). Second, we assess how spatial variability and model choices affect CFs by comparing (1) spatial variability between river basins, (2) differences in impacts to two freshwater types (i.e. lakes and streams), and (3) differences between effect factor models. The term stream is hereafter used to denote flowing freshwaters, including rivers and streams.

6.2 Material and methods

6.2.1 Fate factors

We employed a grid-based model of the fate of P from its emitting location i to its receiving downstream grids j developed by Helmes *et al.* (2012) as partial fate factors $FF_{i \rightarrow w, j}$ (resolution: $0.5^\circ \times 0.5^\circ$). The fate factors describe the removal rates of P due to water advection, P retention, and water use in downstream grids j . In order to estimate the residence time of P in each freshwater type w (i.e. lake or stream), we included the volume fraction of freshwater type w in j . In each grid, the sum of the volume fractions of lakes and streams was equal to one. In cases where a single grid cell's freshwater volume was entirely lake or stream, the CF for the type with a zero volume fraction was also zero ($n = 121$, a total of 1789). These zero valued CFs were excluded from further analysis.

6.2.2 Effect factors

The three effect models are described by effect factors $EF_{w, j}$ for freshwater type w in receiving grid j ($\text{kg P}^{-1} \cdot \text{m}^3$) and they are based on log-logistic relationships between the potentially not occurring fraction (PNOF, dimensionless) of heterotrophic species and total P (TP) concentration ($C_{w, j}$, $\text{kg P} \cdot \text{m}^{-3}$). The PNOF – TP relationships were determined using data on the highest concentration of TP where a species was observed in field surveys in temperate regions (Azevedo *et al.*, 2013a), see details in appendix S6.1 of the

Chapter 6

Supporting Information. The three model types chosen cover the range of effect approaches available to and meaningful in LCA.

The first effect factor, MEF (Van de Meent & Huijbregts, 2005), represents the marginal increase in PNOF due to a marginal increase in TP concentration $C_{w,j}$ and it is described as

$$MEF_{w,j} = \frac{\partial PNOF_{w,j}}{\partial C_{w,j}} = PNOF_{w,j} \cdot (1 - PNOF_{w,j}) \frac{1}{C_{w,j} \cdot \beta_w \cdot \ln(10)} \quad (6.2)$$

where β_w is the slope of the PNOF – TP function in freshwater w .

The second effect factor, LEF, represents the linear change in PNOF due to an increase from $C_{w,j} = 0$ to a $C_{w,j}$ where PNOF in w in grid j is 0.5 (10^{α_w} , equation 6.3). It is commonly used in the derivation of effect factors for toxicants (Gandhi *et al.*, 2010, Rosenbaum *et al.*, 2008), for effect models employing with multiple endpoints (Amores *et al.*, 2013), or when stressor levels in the environment are unknown. It is described as

$$LEF_{w,j} = LEF_w = \frac{\Delta PNOF_{0.5}}{\Delta C_{w,j}} = \frac{0.5}{10^{\alpha_w}} \quad (6.3)$$

The third effect factor, AEF, represents the average change in PNOF due to an increase from a “zero effect” ($C_{w,j} = 0$) to a monitored TP concentration $C_{w,j}$ (Huijbregts *et al.*, 2011). It is described as

$$AEF_{w,j} = \frac{\Delta PNOF_{w,j}}{\Delta C_{w,j}} = \frac{PNOF_{w,j}}{C_{w,j}} \quad (6.4)$$

For the calculation of MEF and AEF, the environmental concentrations ($C_{w,j}$) were obtained from the water quality monitoring database of the European Environment Agency, EEA (2013b). We then calculated the annual mean TP concentration of lake and stream monitoring stations within each grid j (appendix S6.2).

6.2.3 Characterization factors

Grid-specific CFs are described as

$$CF_{w,i} = \sum_j FF_{i \rightarrow w,j} \cdot EF_{w,j} \quad (6.5)$$

where $C_{w,i}$ ($\text{day} \cdot \text{kg P}^{-1} \cdot \text{m}^3$) is the characterization factor of emitting grid i for freshwater type w .

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Using the centroid of each emitting grid i , we recorded in which river basin each grid was and then calculated characterization factors for each European river basin r and freshwater type w ($C_{w,r}$) as the mean of grid-specific CFs ($C_{w,i}$) within each basin. The river basins (total of 91) were mapped by the EEA (2012).

6.2.4 Influence of model choices

River basin characterization factors ($C_{w,r}$) were used as the experimental unit for an analysis of variance (ANOVA) as the fate of P transport emitted to grid i determines the CF of i but also influences the CF of grids downstream of i . By employing river basin instead of grid CFs, we avoid the interdependence of CFs between grids because P is not transported across but only within basins.

First, we tested to what extent the effect model and the freshwater type influenced river basin CFs with a completely randomized design ANOVA as

$$\log_{10}CF_{w,r} = \mu + M_m + W_w + MW_{m,w} + \varepsilon \quad (6.6)$$

where μ is the intercept, M represents the main effect of method type ($m = \text{LEF, MEF, or AEF}$); W represents the main effect of freshwater type w ; MW represents the interaction between method and freshwater type; and ε is the residual, which represents the spatial variability across river basins CFs. $CF_{w,r}$ was \log_{10} transformed prior to the analysis to fulfill the assumptions of normality of residuals and homogeneity of variance of factors M and W (Table S6.3.4, appendix S6.3).

Second, in order to isolate the spatial variability across river basin CFs ($CF_{w,r}$) due to the fate and effect factors, we calculated river basin CFs whereby the variability was solely due to the residence time of P in each freshwater (thus, no effect factor influence) and due to the sensitivity of species to P increases (thus, no fate factor influence). This exercise was done six times, i.e. for the three effect factor models and two freshwater type combinations (see appendix S6.4 for calculation procedure).

6.2.5 Normalization scores

Normalization scores (NS, m^3) were calculated for each river basin r as

$$NS_{m,w,r} = CF_{m,w,r} \cdot [E_{S,r} + A_r \cdot f_{\text{soil} \rightarrow \text{water}} \cdot (E_{M,i} + E_{F,i})] \quad (6.7)$$

where $CF_{m,w,r}$ is the characterization factor ($\text{day}\cdot\text{kg}^{-1}\cdot\text{m}^3$) for river basin r and freshwater w based on method m , A_r is the area (ha) of river basin r , $f_{\text{soil}\rightarrow\text{water}}$ is the fraction of phosphorus emitted to soil by manure and mineral fertilizer applications and that reaches the freshwater compartment, and E_S , E_M , and E_F ($\text{kg}\cdot\text{ha}^{-1}\cdot\text{day}^{-1}$) are the emissions for individual grid cell i of phosphorus from wastewater treatment plants, manure, and mineral fertilizers to water within river basin r , respectively.

$CF_{m,w,r}$ are reported in Table S6.3.1, A_r were calculated using the river basin map delineated by the EEA (2013b), and $f_{\text{soil}\rightarrow\text{water}}$ was estimated to be 0.1 (Bouwman *et al.*, 2009). Emission data for individual wastewater treatment plant (WTP) were reported by the EEA (2013a). For point sources (i.e., E_S), emissions were reported for individual WTP within a river basin r ($\text{kg}\cdot\text{day}^{-1}$); WTPs within each basin were then summed to obtain E_S and it is assumed that there are no unreported WTP by the EEA (2013a). For nonpoint sources (i.e., E_M and E_F), emissions reported for individual grid cells i (resolution $0.5^\circ \times 0.5^\circ$) by Potter *et al.* (2011) were averaged per river basin.

6.3 Results

6.3.1 Characterization factors

The concentration of TP at which the PNOF is 0.5 (10^a , Figure 6.1) was lower for lakes than for streams by a factor of 1.8 ($10^{a,\text{lake}} = 3.99\cdot 10^{-4} \text{ kg P}\cdot\text{m}^{-3}$ and $10^{a,\text{stream}} = 7.41\cdot 10^{-4} \text{ kg P}\cdot\text{m}^{-3}$). Additionally, the sensitivity of species to changes in TP levels (β coefficient) was higher in lakes than in streams ($\beta_{\text{lakes}} < \beta_{\text{stream}}$). Likewise, reported TP levels were generally higher in streams (Figure 6.2), with uppermost levels found in streams in Greece and throughout Germany and Poland (Figure S6.2.3b). High TP levels in lakes were found in Great Britain, Belgium, the Netherlands, and western Germany (Figure S6.2.3a) and the lowest TP levels were reported in the highlands of Scotland and in the Alps in both freshwater types.

The range of concentration-dependent effect factors (MEF and AEF) across grids was relatively similar for lakes (varying from zero to $1775 \text{ kg P}^{-1}\cdot\text{m}^3$, Figure 6.2a) and for streams (varying from zero to $1235 \text{ kg P}^{-1}\cdot\text{m}^3$, Figure 6.2b). EFs were observed at TP levels of $4.0\cdot 10^{-5} \text{ kg P}\cdot\text{m}^{-3}$ to $7.3\cdot 10^{-5} \text{ kg P}\cdot\text{m}^{-3}$ in lakes and $7.0\cdot 10^{-6} \text{ kg P}\cdot\text{m}^{-3}$ to $1.4\cdot 10^{-5} \text{ kg P}\cdot\text{m}^{-3}$ in streams. Grid-specific CFs were generally higher in lakes (Figures S6.3.1) compared to streams (Figure S6.3.2), especially in Ireland, the Baltic countries, Denmark, and northern Italy.

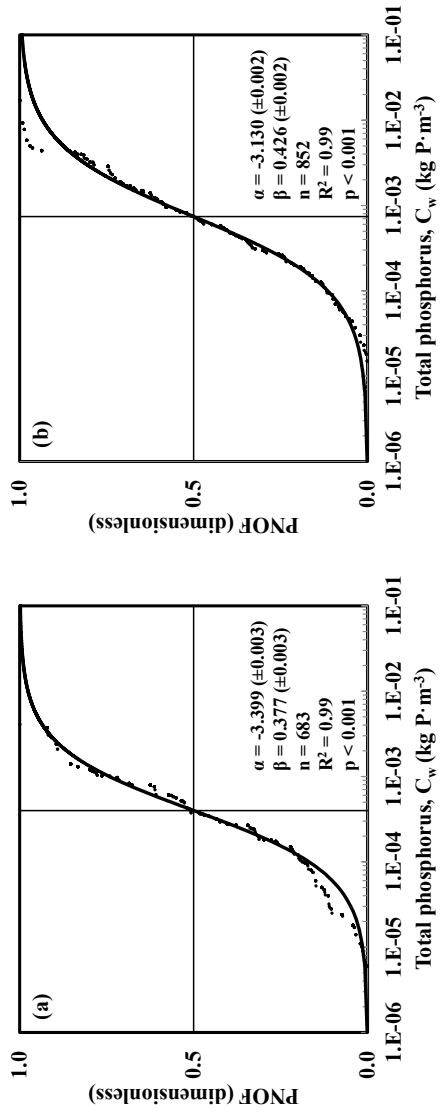


Figure 6.1 Species sensitivity distributions (SSDs) of the potentially not occurring fraction of heterotrophic species (PNOF) and total P, illustrated by the log-logistic regression
$$\text{PNOF}_w = \frac{1}{1 + e^{\frac{\beta C_w - \alpha}{\beta_w}}}$$
 (see details in appendix 6.1). Coefficients α and β (\pm standard error), number of species n , R^2 and p value of the regression in shown for (a) lakes and (b) streams SSDs.

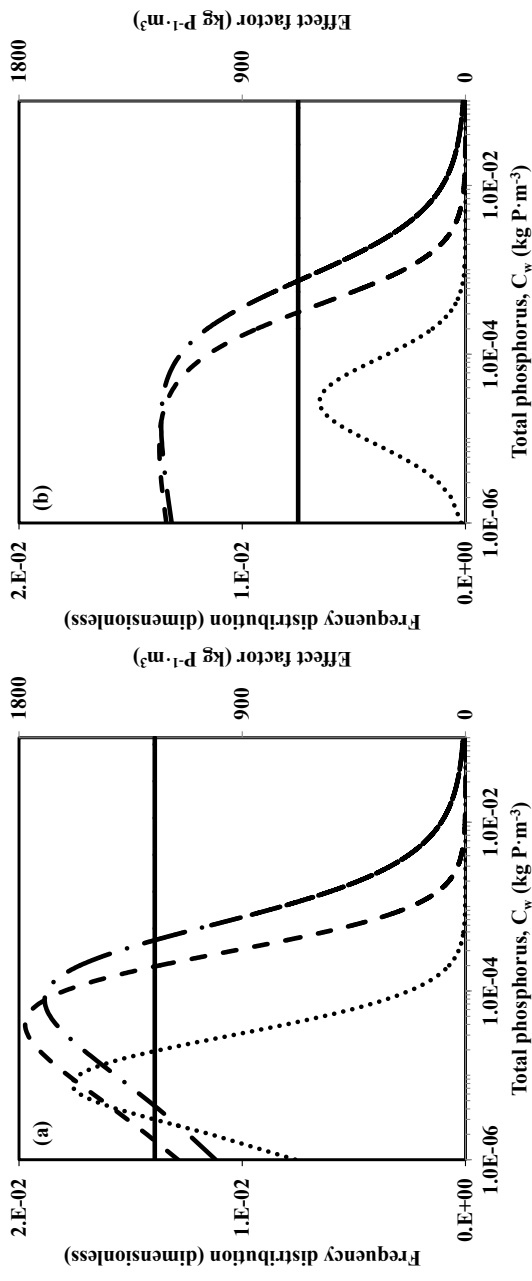


Figure 6.2 The probability density function (round-dotted, left axis) of TP concentration ($C_{w,j}$) and the marginal (dashed), linear (continuous), and average (dashed-dotted) effect factors (right axis) as a function of $C_{w,j}$ levels for (a) lake and (b) stream heterotrophs.

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6.3.2 Model choice and spatial variability

River basin CFs for lakes were, on average, approximately 1.2 orders of magnitude higher than those for streams, irrespective of effect model type (Figure 6.3, see results of the ANOVA in Table S6.3.4). Additionally, average river basin CFs based on the linear model were significantly lower than those based on the average model (Figure 6.3a); yet no differences were found between the two concentration-dependent effect models. The differences between CFs derived with the average and linear effect factors for lakes are evident in grids occupying the Po and the Scheldt river basins, for example (Figure S6.3.1b,c). CF and NS results based on the three effect models are reported per river basin in Tables S6.3.1 and S6.3.2, respectively. Over half of the total variance of the ANOVA ($R^2 = 56\%$, S6.3.4) was explained by freshwater type (sum of squares = 134.71) and to effect model type (sum of squares = 1.62). The relative contribution of freshwater type (0.55, S6.3.4) to the total variance of the ANOVA was higher than that of model type (0.01). The remaining variance originates from the variability within-samples, namely spatial variability.

This spatial variability across CFs was primarily driven by the variability across fate factors and, to a lesser extent, to the variability across effect factors (Table 6.1). Ultimately, the least variability was found in CFs derived using the linear effect model (as the variability is solely due to fate factors) and the highest variability was found in CFs derived with the marginal effect model for streams.

6.4 Discussion

6.4.1 Influence of freshwater type

Higher CFs for lakes are attributed to higher fate factors and effect factors for that freshwater type. Regarding fate, P is retained in the water column of lakes for longer periods since they have a longer hydraulic residence time of water in grid cells compared to streams (Helmes *et al.*, 2012). Regarding effect, the higher taxonomic similarity of lake species compared to those in streams prompt individual responses of species to TP shifts to be more homogeneous in the former than in the latter (Hof *et al.*, 2008). Accordingly, since the characterization model is based on the response of the overall heterotrophic species community (represented by PNOF), we find that CFs are greater if they are based on lakes than on streams.

6.4.2 Influence of effect model

Concentration-dependent effect factors are higher than the linear factors at lake concentrations from $0.5 \cdot 10^{-5} \text{ kg P} \cdot \text{m}^{-3}$ to $4.0 \cdot 10^{-4} \text{ kg P} \cdot \text{m}^{-3}$ or stream concentrations from $1.0 \cdot 10^{-6} \text{ kg P} \cdot \text{m}^{-3}$ to $7.0 \cdot 10^{-4} \text{ kg P} \cdot \text{m}^{-3}$. Given that current TP levels in European freshwater bodies are generally within those ranges, the linear model underestimates the emission impacts compared to those based on average changes in the PNOF.

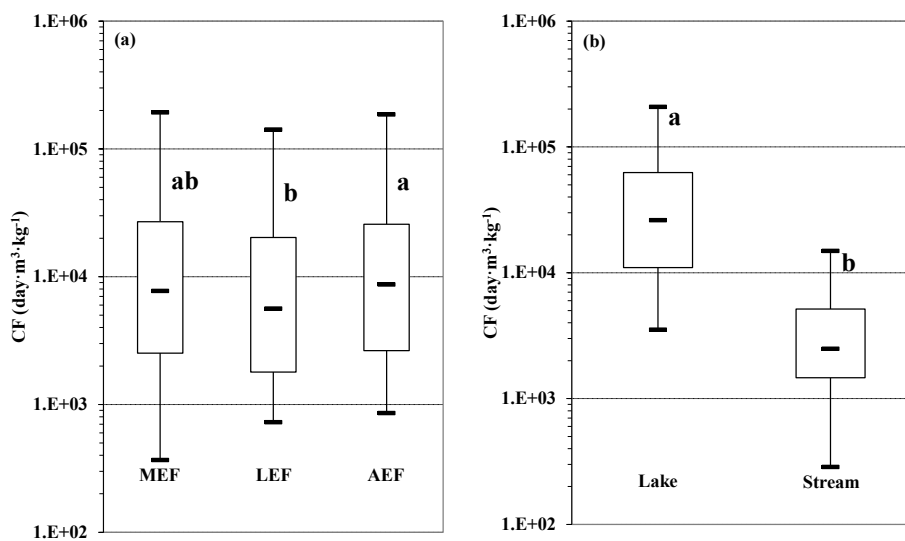


Figure 6.3 Whisker plot (2.5^{th} , 25^{th} , 50^{th} , 75^{th} , and 97.5^{th} percentiles) of river basin characterization factors (CF) based on marginal (MEF), linear (LEF), and average (AEF) effect factors for (a) lakes and (a) streams. Different lower case letters represent means that are significantly different from one another (at a 95% confidence level) using Tukey pairwise comparison test following the analysis of variance (ANOVA, S6.3.4).

Under current trophic conditions, the differences between the marginal and the average effect models are minimal. As a result, our study did not detect significant differences between CF results determined with the two models. Had TP levels been higher than today (above $1.0 \cdot 10^{-4} \text{ kg P} \cdot \text{m}^{-3}$, for example), those differences may have been revealed since the marginal effect model estimates little damage from P discharges into previously-eutrophied freshwater bodies compared with the average model (Huijbregts *et al.*, 2011).

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Table 6.1 Fate, effect, and characterization factor variability across river basins expressed as the ratio between the 97.5th / 2.5th values of river-basin characterization factors.

	Lake			Stream		
	Marginal	Linear	Average	Marginal	Linear	Average
Fate factor [#] , $\sum_j FF_{i \rightarrow w, j}$, unit: day		48			19	
Effect factor [#] , $\overline{EF_{w, j}}$, unit: kg P ⁻¹ ·m ³	1.5	1	1.3	11	1	4
Characterization factors [#] , $\sum_j FF_{i \rightarrow w, j} \cdot EF_{j, w}$, unit: day·kg P ⁻¹ ·m ³	51	48	56	69	19	41

[#]River-basin values were obtained as the mean of grid-specific fate, effect, and characterization factors within each basin.

6.4.3 Spatial variability

Our results show that intrinsic differences between European basins account for nearly half of the variation between CFs. This adds to the existing body of evidence of the influence of spatial differentiation on characterization factor outcomes (Saad *et al.*, 2013, Wegener Sleeswijk & Heijungs, 2010). In this study, two main components contribute to the variability of fate factors: the grid-based residence time of P and then size of the river basin.

Grid cells with large fractions of water in lakes generally have a higher fate factor than river cells (as discussed above). Therefore, they likewise have high CF results (Helmes *et al.*, 2012), e.g. the East Estonian river basin. Furthermore, the fate factor of P is related to the number of downstream grid cells (Helmes *et al.*, 2012). Absent large lakes, small river basins (e.g. the Jucar and the Cyprus) will have smaller fate factors than large river basins (e.g. the Danube and the Elbe).

6.4.4 Model uncertainties

We employed the maximum TP concentration at which the species was confirmed to be present to derive PNOF – TP relationships. Using the maximum TP level is motivated by the fact that certain species may be subjected to P stress even in relatively unpolluted systems, where P concentrations are low. Nevertheless, P is also an essential nutrient to living cells and the maximum diversity of genera was found in Dutch streams at TP level equal to $1.0 \cdot 10^{-4}$ kg P·m⁻³, for example (Struijs *et al.*, 2011b). In this study, we quantify the impact of eutrophication not as the decrease in species richness in a freshwater community but by the cumulative decrease in each

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species occurrences. The latter can commence at TP levels much lower than the former.

We used TP concentrations from neighboring monitoring stations to account for the lack of monitoring data in certain grids. For 34% and 83% of European grid cells, we located at least one lake and stream monitoring station, respectively. The lower number of grid cells that have monitored lake concentrations compared to streams is due to the lower level of spatial detail outlined by the technical EEA guidelines for lakes (i.e. one sample every 1,750km²) compared to streams (i.e. one sample every 1,000km²). In any case, these different monitoring guidelines did not result in different variability in TP levels between the two freshwater types as the coefficient of variation across grid log₁₀-transformed TP levels is nearly the same: 0.12 in lakes and 0.13 in streams. The extrapolation of monitoring TP data to non-monitored grid cells was a necessary step in the effect model, since the CF is the summation of the impacts on cells in and downstream of the cell of emission. Stronger monitoring efforts would be necessary (especially in lakes) in order to avoid extrapolation of TP levels to non-monitored European areas.

The TP levels used to derive our EFs (median of TP concentration in grids equals 1·10⁻⁴ kg P·m⁻³) were generally lower than those applied by Struijs *et al.* (2011a), where the median TP in river catchments was 3.75·10⁻³ kg P·m⁻³. As a result, average CFs across river basins was 2.2 times lower in our study than those reported for emissions to water from sewage treatment plants. (Note that this comparison is made for stream-based, MEF only.) We attribute this difference to the fact that Struijs *et al.* (2011a) use monitoring data from the 1980s to 2005, when streams were likely more P-enriched than they were in recent years. Lower, recent TP concentrations are attributed to successful reduction of P discharges by controlling emissions from wastewater treatment plants and the use of detergents based on phosphates (EEA, 2010, Millennium Ecosystem Assessment, 2005). In addition to the effect model, the fate factors we used in this study are lower than those reported by Struijs *et al.* (2011a) the fate factors we employed include estimates of P losses through water use and retention (Helmes *et al.*, 2012).

Another uncertainty in the effect model refers to the taxonomic level of species described by the PNOF – TP relationships. In this study, we used records at the species level while Struijs *et al.* (2011b) derive relationships by employing a higher (genus) taxonomic level. As evidence of stream impairment was hindered when family but not species taxonomic levels were used as the indicator of impact (Lenat & Resh, 2001), this may also have

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been the case for PNOF – TP relationships we employ since the slope of the logistic function we employ is steeper than the genera-based function employed by Struijs *et al.* (2011b). Ultimately, the impact of a stressor will be more easily perceived at the species rather than genus or family levels. In the latter, the loss of the genus or the family group would only occur when the last remaining species of that higher taxonomic group no longer occurred.

Our study derives CFs for emissions of P to water but not to soil. Characterization models where the fate from soil to water is included were developed by previous eutrophication models in LCIA (Huijbregts & Seppala, 2001, Seppälä *et al.*, 2004, Struijs *et al.*, 2011a) and, recently, it has been suggested that typically 10% of the P emitted to soil reaches water bodies (Bouwman *et al.*, 2009).

6.4.5 Implications

We tested the influence of effect models and freshwater types on characterization factors describing the impacts of P emissions to freshwater on the PNOF of heterotrophs. This test was performed for inland water bodies in temperate Europe. Our results show that CF results are influenced by both freshwater type (primarily) and effect model choices. However, CFs are also strongly influenced by the spatial variability in fate factors, thereby suggesting that spatially explicit methodologies in LCIA are crucial for an accurate assessment of phosphorus emission impacts in freshwater systems. This methodological effort has also commenced in the inventory phase of LCA (Geyer *et al.*, 2013, Tessum *et al.*, 2012). As LCIA continues to develop spatially-explicit effect models, it is important to test the influence of the different types of effect models and the main drivers of CF variability across their spatial units for other impact categories as well.

ACKNOWLEDGMENTS

This research was funded by the European Commission under the 7th framework program on environment; ENV.2009.3.3.2.1: LC-IMPACT – Improved Life Cycle Impact Assessment methods (LCIA) for better sustainability assessment of technologies, grant agreement number 243827. We thank Rik Oldenkamp, Patience Muchada, and Harrie W. H. Hendriks for technical support in handling the data and two anonymous reviewers for their helpful comments on the previous version of this document.

Chapter 7

Combined ecological risks of nitrogen and phosphorus in European freshwaters

Ligia B. Azevedo
Rosalie van Zelm
Rob S. E. W. Leuven
A. Jan Hendriks
Mark A. J. Huijbregts

Submitted

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ABSTRACT

Eutrophication is a key water quality issue triggered by increasing nutrient levels in many lakes and streams, thereby posing risks to aquatic biota. In order to improve water quality and to realize a good ecological status, the European Water Framework Directive requires that the quality of freshwater bodies in member states are monitored. In this study, we predict the ecological risks of invertebrate species losses due to nitrogen and phosphorus pollution in European lakes and streams from 1985 to 2011. This risk indicates the probability that an invertebrate species within a community assemblage may become absent due to nutrient stress. Our results show that the ecological risk in streams and in lakes decreased in respectively 38% and 22% of river basins during the twenty-six monitored years. In addition, we find that the risk from nitrogen stress surpassed that of phosphorus in both freshwater systems during the studied period. The ecological risk framework can be applied to identify which river basins are most subjected to risks of invertebrate absences and what are the main stressors driving eutrophication impacts.

7.1 Introduction

The “limiting nutrient” concept, following Liebig’s Law of the Minimum, was based on experiments testing the effects of added nutrients on crop performance (van der Ploeg *et al.*, 1999). Later, the concept was extended to productivity-based experiments for eutrophication research, such as those testing the effects of nutrient surplus on chlorophyll concentration or biomass productivity (Allgeier *et al.*, 2011, Elser *et al.*, 2007). Despite the benefit prompted by the increase in the availability of a resource, such as productivity stimulated by nutrient increases, a further increase in the same resource availability could cause ecosystem damage, such as a shift in species composition (Odum *et al.*, 1979).

Eutrophication in freshwater is mainly triggered by agricultural and urban discharges of nitrogen, N, and phosphorus, P (Bouwman *et al.*, 2009). On one hand, the increase in nutrient availability generally increases primary production and, thus, the availability of food to planktivores and herbivores (Carpenter *et al.*, 1985). On the other hand, it may lead to it may also lead decreases in food quality and increased predation by secondary consumers (Carpenter *et al.*, 1985, Grimm & Fisher, 1989).

Besides changes in trophic cascades, increases in primary production may trigger decreasing water transparency and light availability, thereby

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eliciting competing phytoplankton to release allelochemicals, particularly cyanobacteria (Leflaive & Ten-Hage, 2007). Furthermore, enhanced decomposition of nuisance algae may generate hypoxic or (in extreme cases) anoxic conditions in aquatic systems (Carpenter *et al.*, 1998). Ultimately, the presence of oxygen depleted conditions, exposure to toxins released by phytoplankton, and shifts in food availability may be harmful to invertebrates (Camargo & Alonso, 2006a, Correll, 1998).

As a result of increasing N and P flows, eutrophication is given as one of the primary issues of freshwater systems (Millennium Ecosystem Assessment, 2005). However, eutrophication is a complex issue as it encompasses potential feedback mechanisms (van Donk & van de Bund, 2002), non-linear responses of primary production to trophic conditions (Genkai-Kato & Carpenter, 2005), and synergistic effects of nitrogen and phosphorus surplus on primary production (Elser *et al.*, 2000). The mechanisms driving primary productivity can be examined by analyzing past nutrient level patterns (Anderson, 1998) or nutrient stoichiometry changes (Glibert, 2012), ecological modeling (Genkai-Kato & Carpenter, 2005), or via nutrient addition experiments (Schindler, 1977). Complementary to mechanistic models, ecological indicators may be used to underpin the effects of eutrophication on species and provide environmental protection agencies with guidelines for the improvement and the maintenance of water quality (Smith *et al.*, 2007).

Indicators of eutrophication based on the performance of invertebrates may be less certain than those based on autotrophic species since consumer organisms are not directly affected by N and P concentrations as are photosynthesizing organisms (Johnson *et al.*, 2014). However, they are particularly useful to environmental agencies because they are extensively monitored (Growthns *et al.*, 1997). One example of a water quality indicator are ecological quality ratios (EQRs) where different biological parameters (e.g. composition of invertebrate species) are compared with a reference representing minimum impairment (Clarke, 2013). The EQR is advised under the European Union Water Framework Directive (2000) because it is a clear way to identify and communicate about the overall health of the monitored freshwater body. Nevertheless, this indicator does not detect the specific cause of impairment.

In the case of eutrophication, the estimation of the overall health quality of freshwater needs also to uncover what the main cause of impairment is (namely, N and P). Therefore, an ecological indicator that allows for estimation of the ecosystem health as well as for identification of

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the source of impairment may provide environmental agencies with the tools to recognize impaired areas and to target the source of the issue. In this study, we propose an indicator for ecological impairment of freshwaters subjected to eutrophication. This indicator, defined as ecological risk (ER) is currently employed in the field of ecotoxicology (Fedorenkova *et al.*, 2012, van Straalen, 2002) and, in our case, is interpreted as the probability that a randomly chosen species belonging to an invertebrate species assemblage may not be present as a result of nutrient stress, namely N and P.

To that end, we employ monitoring data on nutrient concentrations and stressor – response relationships to quantify the risks of freshwater ecosystem stress triggered by high N and P concentrations. The ER is estimated separately for temperate European lakes and streams and on a yearly basis. Our study considers the risk to lakes and streams separately because they differ considerably with respect to water and nutrient cycling and their sources of energy supply (Doi, 2009).

7.2 Material and methods

7.2.1 Ecological risk (ER)

The risk posed to a group of species depends upon the sensitivity of each species to the stressor of concern and the probability that the species are subjected to the stressor (Figure 7.1). Thus, ER (dimensionless) is the definite integral

$$ER_i = \int_{-\infty}^{\infty} PDF(x) \cdot CDF(x) dx \quad (7.1)$$

where PDF is the probability density function of the stressor i of $^{10}\log$ concentration x (e.g. NO_3 or total P) and CDF is the cumulative distribution function of the sensitivity of species to increasing x (Fedorenkova *et al.*, 2012, van Straalen, 2002). The effects of different stressors can be added in order to estimate the total ER to species as

$$ER_T = 1 - \sum_i (1 - ER_i) \quad (7.2)$$

where ER_i is the individual ER of stressors i (Fedorenkova *et al.*, 2012). In our case, the ecological risks are calculated for two stressors (NO_3 and TP) and in two freshwater types (i.e. lakes and streams) in different European river basins (total of 88) per year (from 1985 to 2011). Finally, we used linear regression to test if the ER_T changed with time in each river basin.

The ecological risks posed by NO_3 and TP are hereafter referred to ER_N and ER_P , respectively. This relationship assumes an additive effect of ER_N and ER_P on species and it assumes no interaction between stressors (van Straalen, 2002) as there appears to be an additive effect of high resource supply (i.e. nutrients) in observational field studies (Harpole & Tilman, 2007). We focus on TP and NO_3 as indicators for P and N stress since they are commonly monitored by water quality programs (Lewis *et al.*, 2011).

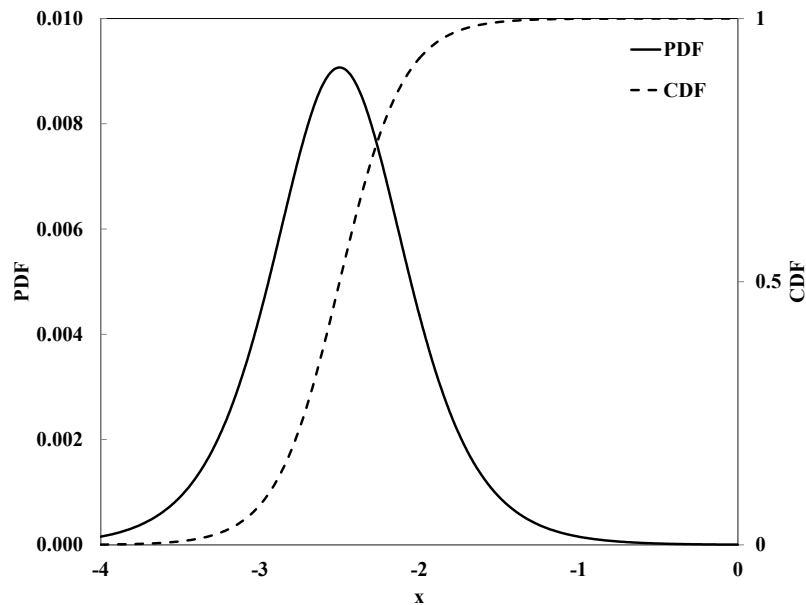


Figure 7.1. Illustration of ecological risk (ER) defined as the area under the probability density function (PDF) of stressor $^{10}\log$ concentration x and the cumulative distribution function of the cumulative fraction of absent species with x , adapted from Fedorenkova *et al.* (2012). In this example, the α_c and β_c coefficients of the PDF are -0.25 and 0.28 and the α and β coefficients of the CDF are -2.5 and 0.20 , respectively.

7.2.2 Cumulative distribution function (CDF)

With increasing x , an increasing number of species no longer tolerant to high stressor levels is expected (illustrated by the dashed line in Figure 7.1). The sensitivity to x can be illustrated in different ways, such as decreasing frequency of occurrence or reproduction, increasing mortality, among others. Ultimately, a species subjected to high enough stressor level x will no longer be able to subsist in the environment. Here, the tolerance to x is defined as the threshold level at which an individual species is no longer present in field surveys.

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To attain the CDF, species-specific maximum tolerance x levels were ordered from low to high values (highest being the species most tolerant to x) and ranked from zero to one. CDF (dimensionless) was then fitted to a logistic describing the fraction of species becoming absent with increasing x levels as

$$CDF(x) = \frac{1}{1 + \exp\left(-\frac{x-\alpha}{\beta}\right)} \quad (7.3)$$

where the coefficients α represents the $^{10}\log$ concentration at which 50% of the all species become absent because of nutrient excess, also called location parameter, and β represents the slope of the CDF. (Both coefficients are dimensionless.) This function was determined for the two stressors (i.e. NO_3 and TP) in two freshwater types (i.e. lake or stream).

The underlying data on invertebrate species-specific maximum TP tolerance was obtained from Azevedo *et al.* (2013a). The data consisted of a collection of peer-reviewed surveys whereby the presence of heterotrophs was recorded in the field alongside the TP concentration in temperate lakes or streams. The confirmation that a species was present at a given TP concentration was either given by confirmation of its presence but also by non-zero accounts of abundance, density or mass, for example. The maximum level at which invertebrate species was confirmed to be present was employed in the derivation of the CDF. The same procedure described by Azevedo *et al.* (2013a) was employed in our study in order to determine the maximum tolerance to NO_3 of species inhabiting temperate lakes and streams and, thus, to derive the CDF for NO_3 . Species-specific data on maximum concentrations of NO_3 and TP at which each species was present are available in appendix S7.1 of the Supporting Information.

7.2.3 Probability density function (PDF)

The probability of a stressor being found at a concentration x (illustrated by the continuous line in Figure 7.1) can be described by a PDF of a logistic curve as

$$PDF(x) = \frac{\exp\left(-\frac{x-\alpha_c}{\beta_c}\right)}{\beta_c \left[1 + \exp\left(-\frac{x-\alpha_c}{\beta_c}\right)\right]^2} \quad (7.4)$$

where α_c and β_c are, respectively, mean and the slope of $^{10}\log$ -transformed

stressor concentrations x . The slope β_c is equal to $\frac{\sigma\sqrt{3}}{\pi}$, where σ is the standard deviation of $^{10}\log$ -transformed stressor concentrations.

To derive the PDFs of NO_3 and TP per river basin, we used mean annual concentration data reported by the European Environment Agency, EEA (2013b), per monitoring station from 1985 to 2011 within each river basin of the European temperate zone. We employed the river basin delineation reported by the EEA (2012) and temperate freshwaters as defined by the major freshwater habitat types (MHT) of the Freshwater Ecoregions of the World (FEOW) project (<http://www.feow.org/>). Each monitoring station was allocated to its respective river basin based on its geographic coordinate (see summary statistics of river basins in appendix S7.2 and river basin delineation in appendix S7.3).

7.3 Results

The number of species available for the derivation of the CDFs varied from 390 (for NO_3 in lakes) to 804 (for TP in streams). The lowest maximum tolerance levels varied from 0.03 mg N/L to 27 mg N/L for NO_3 and 0.01 to 17 mg P/L (appendix S1), respectively. Our results show that the tolerance to N and P levels is lower in lakes than in streams ($\alpha_{Lake,TP} < \alpha_{Stream,TP}$ and $\alpha_{Lake,NO_3} < \alpha_{Stream,NO_3}$, Figure 7.2). Additionally, the sensitivity to increasing nutrient levels is higher in lakes than in streams, as shown by steeper slopes of the CDF ($\beta_{Lake,TP} < \beta_{Stream,TP}$ and $\beta_{Lake,NO_3} < \beta_{Stream,NO_3}$).

The number of stations monitored for nutrient levels increased in both lake and stream systems over the 26 monitored years. From 1985 to 2011, the number of monitored lakes increased from 2 to 25 while the number of monitored streams increased from 8 to 68 (appendix S7.2). Of 51 river basins, 10 basins comprised lake ER_N decreasing with time (slope $S < 0$ at a 95% confidence level, Figure 7.3a) and 39 basins were not subjected to significant changes in ER_N . Likewise, the number of basins whereby lake ER_P decreased with time was rather low (total of 11) compared with the number of unchanging ER_P (total of 42). Accordingly, most basins show no change in lake ER_T (total of 33, Figure 7.3c) over time. Similarly to lakes, most basins show no change in stream ER_T (total of 42, Figure 7.4c) with time. Nevertheless, the number of basins with decreasing stream ER_N , ER_P , and ER_T relative to the total number of estimated basins was considerably higher than that in lakes. For example, 11 of 42 basins were subjected to a decrease in lake ER_T (Figure 7.3b) while the same was only observed in 30

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of 44 basins for streams (Figure 7.4c).

The ER_N (Figure 7.5a) was predominantly higher than ER_P in streams (Figure 7.5b). For example, from 2001 to 2011, 46 to 77% of river basins comprised ER_N higher than ER_P in a given year. However, the opposite pattern is observed in lakes. Over the same period, 11 to 52% of river basins in a given year comprised ER_N above ER_P . We also found a strong variability in the ER across European river basins, especially for ER_N . This can be seen as the range of 95th and 5th percentiles of ER_N in European basins in a given year were, on average, 58.1% in lakes and 45.1% in streams (Figure 7.5a) while the range in of 95th and 5th percentiles of ER_P were, on average, 25.3% in lakes and 31.3% in streams (Figure 7.5b). The increase in monitoring efforts over the years prompted the increasing variability across river basins, Figure 7.5c.

7.4 Discussion

7.4.1 Lakes versus streams

Streams comprise a shorter hydraulic residence time than lakes and, thus, the former may serve as an instantaneous indicator of recent nutrient discharges. The decrease in ER_P in streams (which occurred in 38% of river basins) can be attributed to successful efforts to reduce P discharges to freshwater by controlling wastewater emissions and by the use of banning phosphates in detergents (EEA, 2010, Glibert, 2012). By contrast, since lakes are subjected to continuous recycling and uplift of P in sediments that have already been enriched in the past (Marsden, 1989), the decrease in lake ER_P was observed in only 20% of European river basins.

Despite the success in reducing P discharges from wastewater, this management strategy alone may not solve issues of freshwater eutrophication in Europe because ER_P and ER_N remained constant in a large number of basins. Discharges from agriculture account for an important share of freshwater eutrophication impacts and, thus, additional stream reductions will be more easily achieved if emissions from non-point sources (e.g. agricultural fertilizers) use are controlled as well (EEA, 2010).

Stream fauna appeared to be less vulnerable to high nutrient levels ($\alpha_{Lake} < \alpha_{Stream}$, Figure 7.1). This also corresponds with the lower N and P levels defining trophic state thresholds for lakes than for streams (Smith *et al.*, 1999). Additionally, lake invertebrates are more sensitive to increasing nutrient levels compared to streams ($\beta_{Lake} < \beta_{Stream}$, Figure 7.1). Azevedo *et*

al. (2013a) suggest that this higher sensitivity is due to the fact that insects in lakes (corresponding to 42% of the invertebrates) respond to increasing nutrient stress more similarly to one another than those in streams (corresponding to 64% of invertebrates) due to the higher β -diversity in the latter (see also Hof *et al.*, 2008). A second reason may be due to the fact that streams are subjected to larger input from adjacent areas (namely, terrestrial systems) than lakes (Johnson *et al.*, 2014). Since streams may be more subjected to nutrient input from terrestrial systems, there is a possibility that species may have adapted to corresponding nutrient levels. (The adaptation of species to the environmental conditions they are exposed to through time is depicted by the evolutionary species pool hypothesis (Pither & Aarssen, 2005). Despite the higher sensitivity of lake invertebrates to increasing nutrient concentrations, efforts to monitor nutrient levels in lakes were considerably less than in streams. We attribute that to the higher level of spatial detail required in the guidelines of monitoring data, whereby the sampling per covered area in streams is more frequent than in lakes (Nixon *et al.*, 1998).

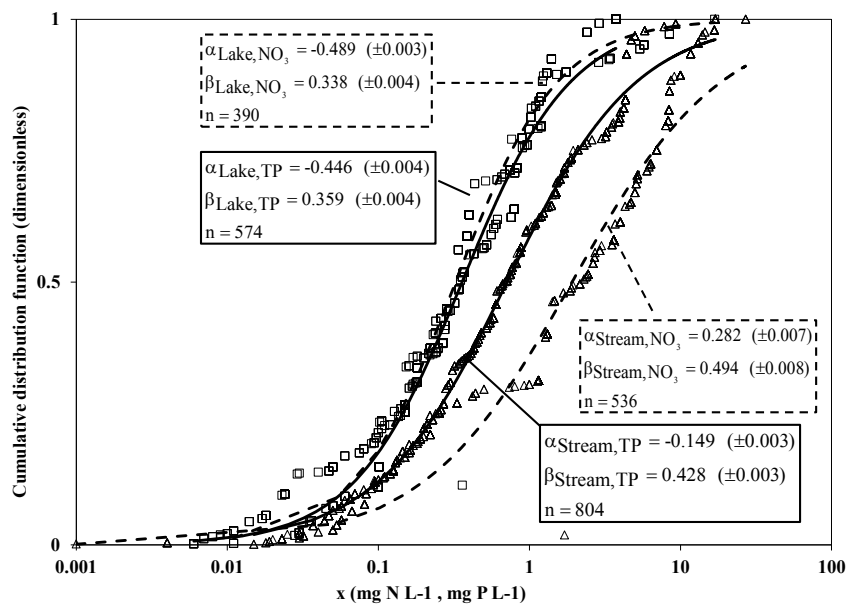


Figure 7.2 Cumulative distribution functions of invertebrate species losses and nitrogen and phosphorus concentration x . The sample size and standard error (in brackets) are shown following the coefficient values. Triangles and squares represent lakes and streams and dashed and continuous lines represent NO_3 and total phosphorus (TP), respectively.

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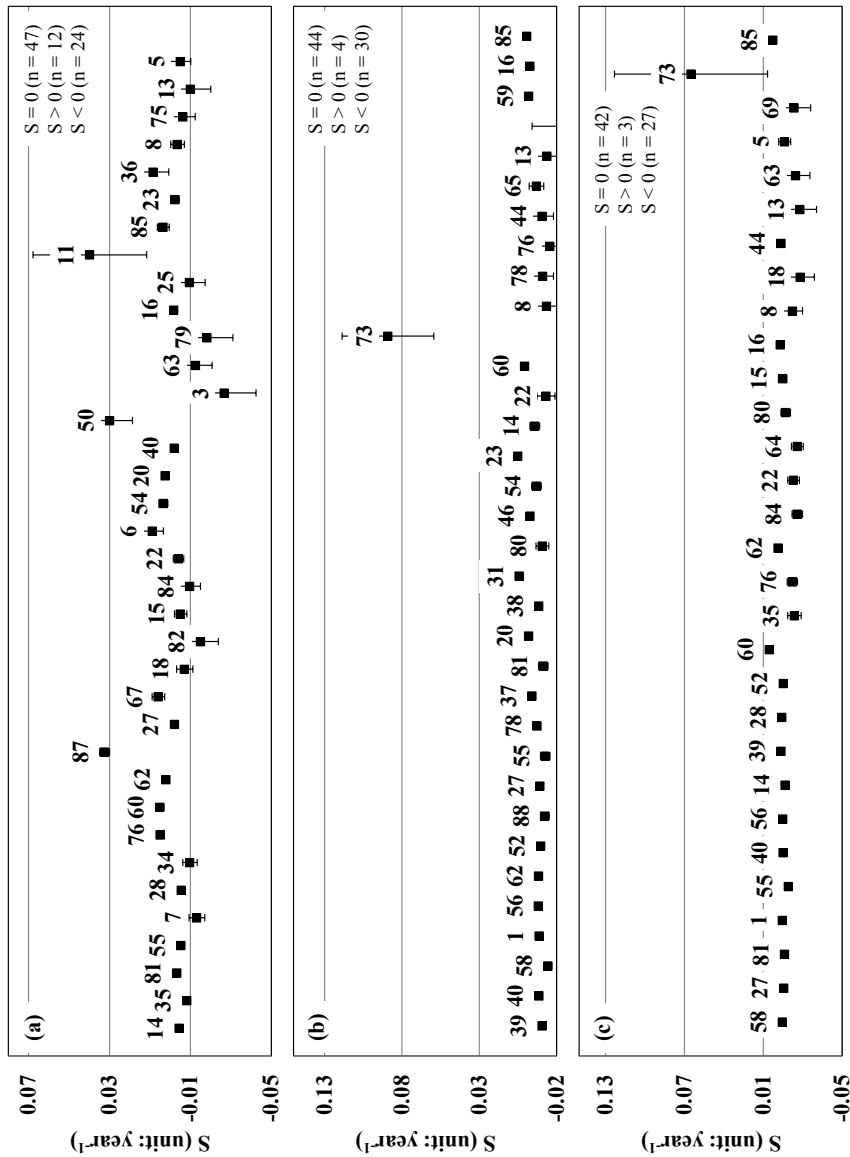
7.4.2 Nitrogen versus phosphorus

The ecological risk of N stress is considerably higher than the ecological risk of P stress in both freshwater systems (Figure 7.4a,b). Here, we propose a number of reasons for higher risks posed by nitrogen in lakes. Sterner (2011) observed high NO_3 values in Lake Superior and attributed these high values to two common biogeochemical patterns resulting from their low primary production rates: the slow uptake of NO_3 due to low nutrient demand and the low denitrification rates due to low concentrations of organic carbon and infrequent low redox conditions. The excess of N supply compared to P was also indicated by the lower stoichiometric N:P ratios in herbivore tissue compared to the organic matter on which they feed (Elser *et al.*, 2000). The fact that herbivores dispose of nitrogen available in their food supply to a greater extent than they dispose of phosphorus in lakes (Elser *et al.*, 2000, Glibert, 2012) might suggest that nitrogen is not limited but saturated in that freshwater type. Ultimately, the excess of N available in food supply may prompt N stress to herbivores.

Finally, the relatively high ER_N in lakes can be possibly attributed to the high atmospheric N deposition rates, particularly in midwestern Europe (Dentener *et al.*, 2006b). This region also shows the highest $\text{ER}_{\text{N+P}}$. The differentiated atmospheric deposition patterns across European landscapes may have also prompted the higher variability in river basin ER_N compared to that of ER_P .

It is important, however, to discern the indicators of ecological impact due to nutrient stress. In this study, we expect nitrogen to be the nutrient in excess due to the fact that the ecological risk to invertebrate species posed by nitrogen was found to be greater than the risk posed by phosphorus. This contrasts with previous studies, where primary productivity increase in temperate lakes in Canada by phosphorus surplus (Schindler, 1977, Schindler, 2012). A decrease in macroinvertebrate families were driven by phosphorus more than by nitrogen (Weijters *et al.*, 2009), although our results may contrast to these since western Europe is subjected to higher atmospheric N depositions than the global average. As far as diversity of invertebrates is concerned, the question of whether nitrogen versus phosphorus control remains unanswered.

Figure 7.4 Results of the linear regression for ecological risk as a function of year (from 1985 to 2011) due to (a) nitrogen, (b) phosphorus, and (c) N+P stress in streams. The slope of the regression (S , with error bars showing the 95% confidence level) is shown for each basin number (the legend of basin names can be found in appendix S3). Slopes S which are higher, lower, and non-different than zero (p value < 0.05) are shown in the bottom right corner.



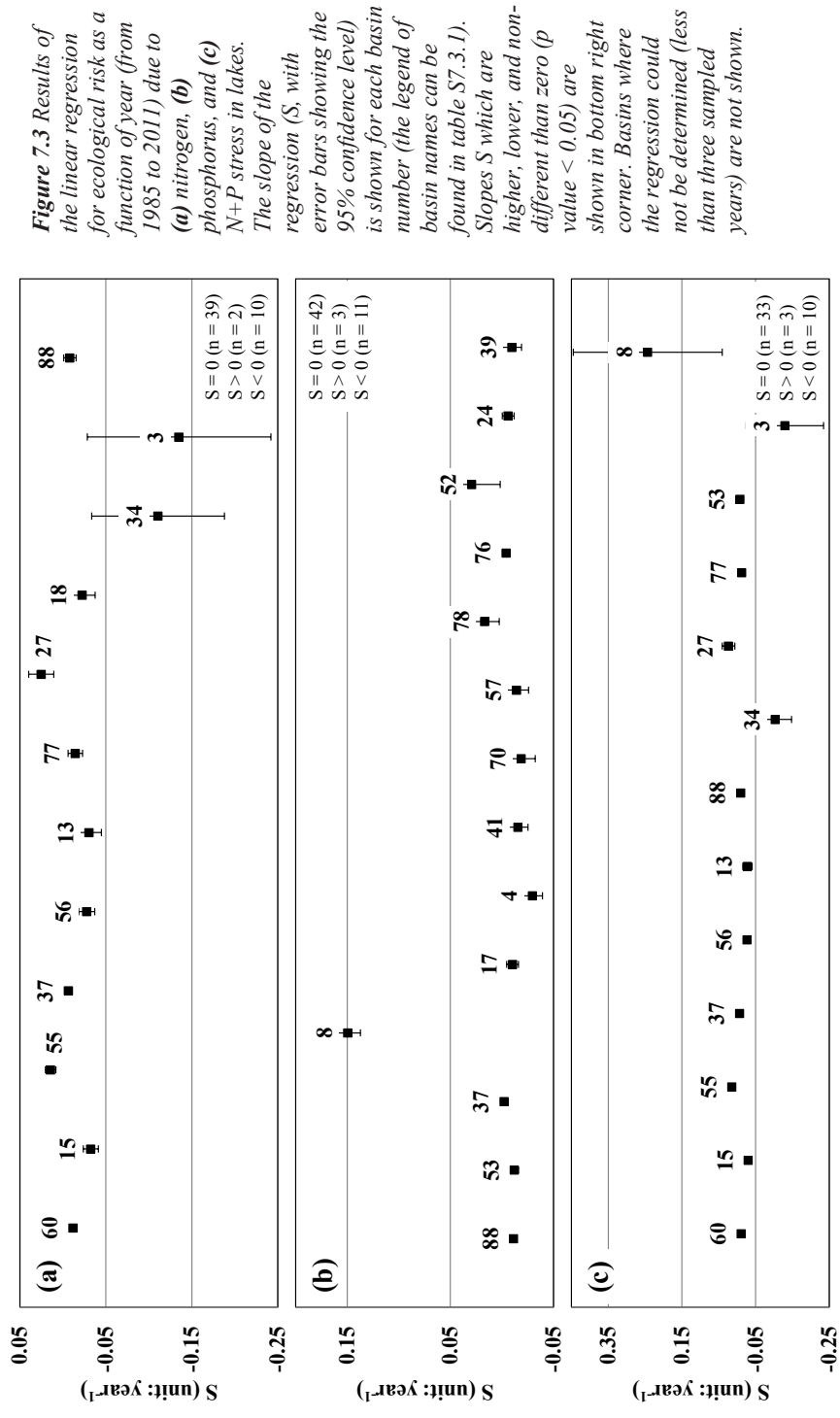
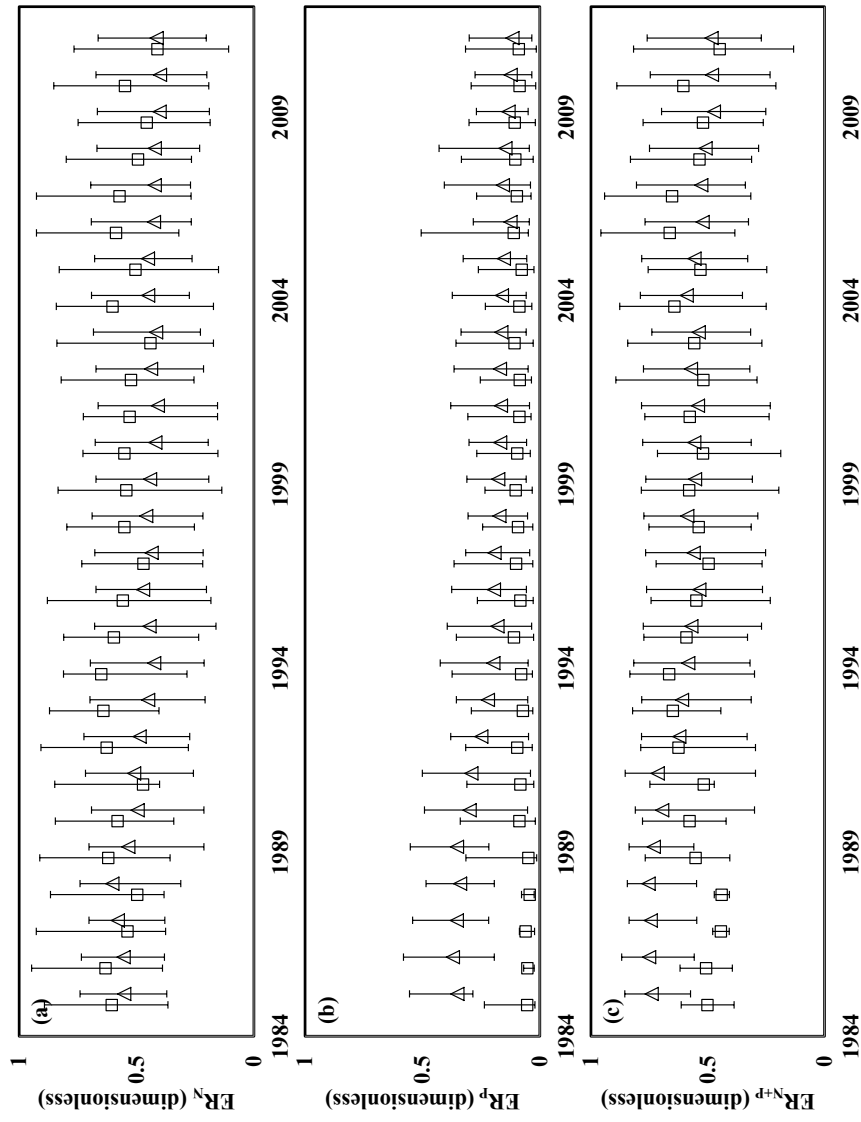


Figure 7.3 Results of the linear regression for ecological risk as a function of year (from 1985 to 2011) due to (a) nitrogen, (b) phosphorus, and (c) N+P stress in lakes. The slope of the regression (S , with error bars showing the 95% confidence level) is shown for each basin number (the legend of basin names can be found in table S7.3.1). Slopes S which are higher, lower, and non-different than zero (p value < 0.05) are shown in bottom right corner. Basins where the regression could not be determined (less than three sampled years) are not shown.

Figure 7.5 Ecological risk (ER) due to (a) N , (b) P , and (c) $N+P$ from 1985 to 2011. Square and triangle symbols represent the median of ER in lakes and streams, respectively, and bars represent the 5th and 95th percentiles.



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7.4.3 Limitations

Non-additive effects of N and P have been confirmed for indicators of eutrophication related to productivity, such as primary productivity and autotrophic biomass, or levels of nutrient in water bodies compared with reference sites (Allgeier *et al.*, 2011, Dodds, 2006, Elser *et al.*, 2007). However, we are not aware of observational studies confirming interacting effects of N and P on diversity of invertebrate species in freshwaters. Similarly, Harpole & Tilman (2007) observed interactive effects of stressors on plant species losses in experimental studies but only an additive effect in observational studies. We do not rule out the possibility that there are interactive effects of N and P on invertebrate losses. However, as environmental concentrations in observational studies are not deliberately designed as are those in controlled experiments (Tilman, 1987), it is not possible to test this interaction based on our field survey study.

We use the same cumulative distribution function expressing the vulnerability of species towards high nutrient levels (expressed by the β coefficient) and their sensitivity to changes (expressed by the α coefficient) across the years and across river basins. We expect that this function is unlikely to change in such a short period of time as these are characteristics inherited during years of evolution, determined by differentiated exposures to hydrological and biogeochemical patterns in the two freshwater types (Azevedo *et al.*, 2013a).

Our study uses the maximum NO_3 and TP concentrations at which each invertebrate species was confirmed present and they represent the threshold whereby species are no longer tolerant to higher nutrient levels. However, field surveys may simply have been unable to detect the species at levels higher than this threshold (Azevedo *et al.*, 2013a), a characteristic that is common to presence-only studies of species occurrence (Walker & Cocks, 1991).

Furthermore, this study does not include potential invertebrate species absences as a result of decreasing food supply, resulting from nutrient depletion. Although nutrient depletion may alter species composition similarly to nutrient excess (Merritt *et al.*, 1984), such stress is not considered in our study because the issue of oligotrophication is not as prevalent as is eutrophication. We also assume that the species composition represented by the logistic functions is not influenced by other stressors, such as temperature, pH, etc.

7.4.4 Concluding remarks

Because the monitoring of biodiversity shifts can be costly, ecological indicators of water quality impairment should be an available tool for environmental agencies (Johnson *et al.*, 2014). In this study, we account for eutrophication risks triggering the absence of invertebrates. Here we focus on the potential absence of invertebrate species as this species group is frequently monitored (Growth *et al.*, 1997). But, most importantly, we focus on the species composition, not primary productivity.

We estimated the ecological risks due to N, P, and N+P stress to invertebrates in lakes and streams. Efforts to improve water quality in Europe should take into account that risks of absence of invertebrates due to excess of nutrients were generally triggered by high N levels, not P. Thus, a stricter control of nitrogen discharges to Europe inland waters is necessary in order to comply with the requirements of the WFD (James *et al.*, 2005). As water bodies in the European Union are required to achieve ‘good ecological status’ by 2015 (Water Framework Directive, 2000), this study helps providing a framework to identify which nutrients cause the highest risks of invertebrates species decreases and which European river basins are most subjected to such risks.

ACKNOWLEDGEMENTS

We thank Pieter M. F. Elshout for helping with data collection. This research was funded by the European Commission under the 7th Framework Programme on environment; ENV.2009.3.3.2.1: LC-IMPACT – Improved Life Cycle Impact Assessment methods (LCIA) for better sustainability assessment of technologies, grant agreement number 243827.



Chapter 8

General discussion

General discussion

This thesis aimed at developing stressor – response relationships to understand biogeographical patterns of species communities and conduct impact assessments involving the following stressors: soil pH (chapters 2 and 3), ocean pH (chapter 4), and freshwater total phosphorus (TP) and NO₃ (chapters 5 to 7). This was attained by employing observational field data on species occurrence or experimental data concerning effects on their life processes.

This chapter is composed of three sections. The first conveys the limitations and uncertainties of the stressor – response relationships developed in chapters 2 to 7 (section 8.1). The second section comprises the interpretation and comparison of the main results of this thesis, namely some of the evolutionary patterns and inherent and human-driven processes that influence environmental nutrient levels and the impact on species. The third concludes with the main findings and implications of this thesis and recommendations for future research (section 8.3).

8.1 Uncertainties and limitations

Understanding the attributes of the stressor – response relationships is vital to the comprehension of relevant uncertainties and limitations. In the following, the uncertain aspects of the stressor – response relationships are described, followed by an evaluation of their possible implications.

8.1.1 Nutrient pollution, not nutrient depletion

This thesis addressed the impacts of nutrient pollution, namely its excess in the environment. If the same stressors would not have been subjected to increasing but decreasing stressor levels, the richness of species will be hampered all the same (Grime, 1973). For that reason, species richness is maximized at intermediate levels of stress and minimized at the two extremes. This phenomenon is defined as the intermediate disturbance hypothesis, IDH (Grime, 1973), and it seems to explain species responses to different biotic and abiotic stressors. According to the IDH, species were exposed to an environmental stress in the past (low, intermediate, or high levels). As a consequence of millions of years of evolution, few species adapted to low and high levels and many species adapted to intermediate levels. In this thesis, only the losses in biodiversity (indicated as richness or absence of species) as a result of increasing stressor levels were evaluated.

8.1.2 Community of species, not individual species

The ecological impacts of nutrient pollution were indicated for the species community rather than for specific (groups of) organisms. Accordingly, keystone, endemic, or commercially valued species are given the same importance in the stressor – response function as other species. Stressor – response curves based on specific species groups may prompt different results. For example, the stressor – response relationships developed for ecological effects of temperature revealed that the sensitivity of native species to warming of riverine waters appear to be higher than that of non-native (Leuven *et al.*, 2011), but see also cases of undifferentiated sensitivity between native and non-native species subjected to extended droughts (Collas *et al.*, 2014), chemical stressors (Fedorenkova *et al.*, 2013), or hypoxia (Elshout *et al.*, 2013).

Besides differences between individual species, there are also differences between species groups. In this thesis, macrophytes in temperate lakes appear to be more sensitive to TP increases (depicted by slope of the stressor – response curve) than phytoplankton (i.e. cyanobacteria, silicon and non-silicon based algae, Table S5.3.5), both of which are autotrophic species.

8.1.3 Variability across biogeographic units

Besides taxonomic variability, illustrated by differences between among stressor – response coefficients derived for different species groups, there can also be considerable spatial variability within biogeographic units. However, within spatial unit variability was not account for. When logistic relationships were developed at the ecoregion scale (Appendices S2.5 and S5.3), the number of species available for the derivation of the relationship decreased, thereby often resulting in unsuccessful fitting of the logistic regressions. For example, while the log-logistic relationship was successfully derived for autotrophs in (sub)tropical streams (chapter 5), relationships for autotrophs in streams were only successfully derived for two of four freshwater ecoregions of this habitat (Table S5.3.6). Ultimately, the use of more detailed biogeographical units (in this case, ecoregions) may prompt stressor – response functions that more accurately represent its species assemblage but it may also decrease the statistical power to derive regressions.

General discussion

8.1.4 Confirmed presence, not confirmed absence

As an inherent attribute of presence-only observational field studies, the actual stressor level boundaries represent the range of concentration where each species was confirmed to be present, not confirmed to perish. Hence, it is not possible to determine if the minimum and maximum stressor level boundaries of a species represent indeed life-threatening conditions or if they are false confirmations of absences (Engel *et al.*, 2005, Pearce & Boyce, 2006, Tsoar *et al.*, 2007). False positives of species absences are an upshot of insufficient sampling or other environmental constraints or the nonexistence of stressor levels at the field beyond the surveyed range (Felzer *et al.*, 2009).

Insufficient sampling may be solved with standardization of protocols for surveys so as to guarantee that these are thorough enough to identify with more certainty that the species is not present beyond the surveyed range as a result of actual stress (Felzer *et al.*, 2009). Other constraining environmental variables, such as limited species dispersal, interaction with other stressors, historic events, or local extinctions may prompt a species to not be present in a surveyed area even though the levels of the stressor of concern are favorable (Felzer *et al.*, 2009). Absences as defined as potential habitats and, thus, species presences are a result of the realized habitats (Roelofs *et al.*, 2003). The difference between realized and potential habitats may also be triggered by the absence of stressor levels in the surveyed area. For example, while a plant occupying an acidic soil may have potential to survive in alkaline soils, such conditions are rarely realized in a survey.

8.1.5 Unaccountability of short term species adaptation

Since human interferences on nutrient biogeochemistry began many years ago, particularly during the Industrial and Green Revolutions (Smil, 2001, Smith, 1994), species have most likely been subjected to increasing stress levels years before the surveys used in this thesis were initiated. For example, large scale nutrient emissions have commenced earlier in the temperate zone of developed countries than elsewhere. If these short-term (i.e. years or centuries) past pollution events were severe enough to cause shifts in species assemblages, a short but intense natural selection (known as microevolution) may have taken place. For example, Trubina & Vorobeichik (2012) report that pollution may favor the maintenance of species adapted to high stressor levels even though the overall species density has decreased. In this thesis, it is not possible to determine the extent by which microevolution influenced the underlying data of species occurrences. As one example of

long-term evolution being more dominant than that on the short-term, the species assemblage of (sub)tropical moist broadleaf forests encompass many more aluminum-tolerant species than other biomes, such as species of the Melastomataceae and Theaceae families (Hayde Gonzalez-Santana *et al.*, 2012). The selection of species tolerant to aluminum is unlikely to have occurred in the few centuries of large scale human interference since soil weathering and the formation of acidic soils in (sub)tropical areas is in the order of millions of years (Volkoff, 1998).

8.1.6 Unaccountability of multiple or possible interacting effects

The stressor – response relationships represent the effect of one stressor only. Thus, other effects triggered by the same stressor are not accounted for. For example, besides terrestrial acidification, atmospheric nitrogen emissions may cause increases in tropospheric ozone, both of which have been shown to have detrimental effects on the performance of species (Bobbink *et al.*, 2010, van Goethem *et al.*, 2013). Other impacts of nutrient stress may arise. For example, atmospheric CO₂ or freshwater N and P emissions may also affect certain ecosystem services, e.g. nutrient cycling (Jeffries & Ouimet, 2004, Miltner, 2010) or recreational activities, e.g. fishing (Carpenter *et al.*, 1998), or may cause secondary impacts or feedbacks to other species populations (Le Bagousse-Pinguet *et al.*, 2012).

Possible interacting effects between stressors were also not included. For example, the synergy between nitrogen and phosphorus have been thoroughly documented for impact assessments where the ecological response is based on primary productivity (Elser *et al.*, 2007, Lewis *et al.*, 2011). However, in a comparison between types of effects encountered in experimental and observational studies, Harpole & Tilman (2007) found that additive effects of different stressor types on species richness predominate in observational studies while interactive effects predominate on experimental ones.

8.2 Interpretation

8.2.1 Biogeography explaining stressor – response functions

Each species assemblage of the present is a result of a gradual change in environmental conditions of the past, whereby each of its constituents, the species, continually died out and disappeared while others were favored or adapted and, thus, persisted (Wallace, 1855). Since species assemblages today are a direct upshot of the exposure to stressors following historic

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events or geographical trends, e.g. a glacial age or latitudinal gradient (Pärtel, 2002), stressor – response relationships are able to describe how species assemblages respond to an environmental stressor at a present state. Therefore, the stressor – response relationships developed in this thesis allow for the comparison of the sensitivity to nutrient pollution across different stressors, ecosystems, or species groups.

The biogeochemical processes driven by climate and by geological events in the past have profound influences on the responses of ecosystems to stressors. These responses may be explained by the evolutionary species pool hypothesis (ESPH), whereby the persistence of certain environmental conditions will prompt the selection of species which are able to prevail under those conditions (Pither & Aarssen, 2005). Below, the optimal soil pH and freshwater TP conditions are explained by the ESPH. Further, the stressor – response relationships coefficients (α and β) are explained by the species composition embedded in each stressor – response relationship.

8.2.2 Coefficients of stressor – response functions

The high temperature and high precipitation patterns of low atmospheric pressure world zones prompts high soil weathering rates, thereby prompting the depletion of base cations (Matson *et al.*, 1999). Ultimately, (sub)tropical ecosystems, with the exception of (sub)tropical dry broadleaf forests, encompass low optimum pH values. This pattern also predominates in another low atmospheric pressure zone (around $\pm 60^\circ$ latitude), where temperate broadleaf mixed forests and boreal forests are found. By contrast, high atmospheric pressure zones (located between $\pm 20^\circ$ and $\pm 35^\circ$ and around $\pm 90^\circ$ of latitude), are covered by deserts and xeric shrublands, Mediterranean forests, woodland, and scrubs, and tundra and hence their soils comprise relatively high optimum pH (Table 2.1).

As opposed to streams, lakes are generally subjected to long water residence times and slow water currents. Additionally, deep lakes are subjected to lake stratification that conserves surface waters at high temperatures and rich in nutrients. These features prompt fast nutrient immobilization by photosynthesizing organisms in lakes (Carpenter *et al.*, 1998, Doi, 2009, Holtan *et al.*, 1988, Vannote *et al.*, 1980). The shape of streams, on the other hand, renders a stronger later connection to adjacent ecosystems (i.e. land) than does that of lakes (Johnson *et al.*, 2014). The fast depletion of available P and the lower input of terrestrial-derived P in lakes may have induced the low concentrations of P in lakes in the past, thereby favouring species which adapted or thrived under such conditions (as stated

in the ESPH). Finally, this might explain why temperate lake P concentration at which autotrophic species richness is maximized today to be lower than that of streams (e.g., $C_{\text{opt,lake}} = 0.05$ and $C_{\text{opt,stream}} = 0.20$, chapter 5).

Ecosystems exposure to past stressor levels may reflect the optimal conditions they adapt afterwards, as discussed above, but may also affect the tolerance of the species assemblage to stressors today. This is reflected in the strong correlation between optimum pH and the pH at which the relative species richness (RSR) is 0.5, i.e. α , Figure 8.1(a). The same correlation also exists between the optimum concentration of TP and α , yet to a lower extent (p value = 0.07). Thus, not only does the ESPH explain the favoring of species assemblage at a specific optimum level, it also explains the favoring of a specific fraction of the same assemblage to a specific pH or TP condition, e.g. α .

Likewise, if the concentration of the stressor is changed, the fraction of the species in the assemblage will change accordingly. The tolerance of species assemblage to these changing stressor levels is depicted by the slope of the stressor – response curve (i.e. β). In terrestrial systems, the tolerance to acidic soils is negatively correlated with the tolerance to changing pH (correlation between optimum and β , p value = 0.04, Figure 8.1b). The same correlation occurs between optimum and β , yet to a lower extent (p value = 0.08, Figure 8.1b). On the contrary, there is no significant correlation between optimum TP and β (p value = 0.56, Figure 8.1b) or α and β (p value = 0.87, Figure 8.1c) for RSR – TP relationships in freshwater systems. For possible explanations of this discrepancy, it is important to review which ecosystems the different stressor – response relationships represent.

(Sub)tropical moist broadleaf forests encompass vascular plants which are tolerant to acidic conditions following historic exposure to low pH. However, these plants are also highly sensitive to soil acidity as the high temperature and moisture conditions wherein they subsist trigger (1) a higher mobility of pollutants and, added to the high metabolism of plants, culminate in a higher exposure of plants to pollutants (Zvereva *et al.*, 2008) and (2) a constant exposure of aluminum-sensitive new roots produced year-round (Wilcox *et al.*, 2004). As a consequence, it is possible that, below a certain pH, physiological processes are hampered, causing plants subsiding in acidic conditions to also be the most sensitive to increasing acidity. The higher sensitivity of low latitude was also reported elsewhere (Zvereva *et al.*, 2010, Zvereva *et al.*, 2008). In the case of freshwater systems, the correlation depicted in Figure 8.1 includes multiple ecosystems (lakes and streams distributed over four climatic zones) and two species groups (autotrophs and

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heterotrophs), which may have prompted no apparent trend between the β and the optimum TP and α .

In this thesis, three indicators of species community responses to nutrient pollution are applied: relative species richness (chapters 2 and 5), relative species absences (chapters 3, 6, and 7), and performance at different life processes (chapter 4). To estimate relative species richness, the number of present species was summed at individual stressor levels by using the species-specific minimum and maximum stressor levels at which each species was confirmed to be present (Figure 8.2a). Species absences were determined using the maximum stressor level value available for that species (i.e., lowest soil or marine pH or highest TP or NO_3 values), Figure 8.2b. The performance at different life processes was determined with species-specific half maximum effective concentrations, i.e. EC_{50} , and 10% maximum effective concentrations, i.e. EC_{10} , from manipulated experiments (Figure 8.2c). Hence, the stressor – response functions should be interpreted as the nutrient pollution driving (i) the decrease in relative species richness, (ii) the possible absence of a random species of the community, and (iii) the decrease in growth, mortality, or reproduction of a random species of the community, respectively. Despite the difference in the underlying data used to derive stressor – response relationships, there were no significant differences within α and within β of the stressor – response curves derived with species richness and species absence (Test 8.3.1 in Figure 8.3). This suggests that the stressor – response relationships developed in this thesis may be used interchangeably for applications to comparison of ecosystems, for effect analysis in LCIA, and for ERA. While comparing the sensitivity to changing levels of the four stressors studied in this thesis (i.e., soil and marine water pH and freshwater TP and NO_3), we found no significant differences between them (Test 8.3.2 in Figure 8.3).

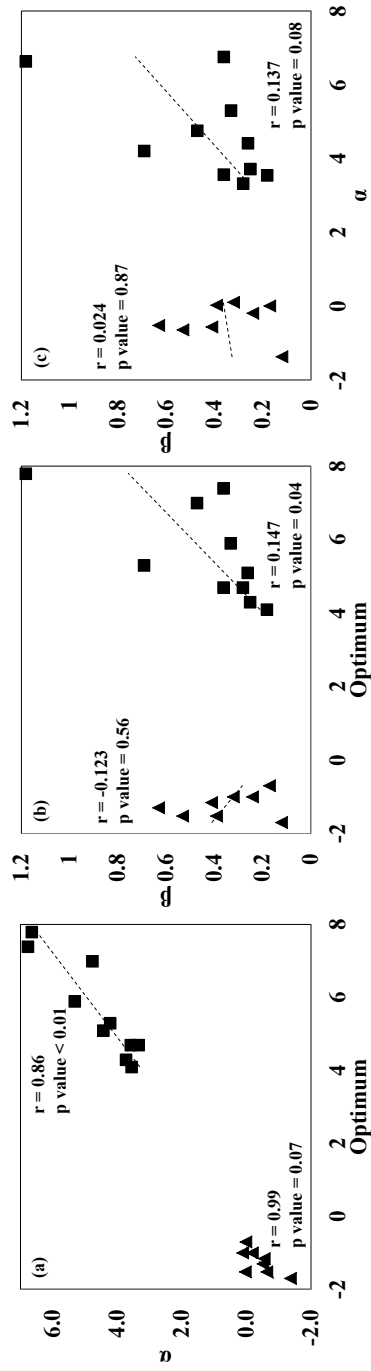


Figure 8.1 Linear regression results between (a) optimum and α , (b) optimum and β , and (c) α and β coefficients. The slope (r) and p value (p) are shown next to correlation line. Squares and triangles illustrate coefficients for species richness – soil pH (chapter 2) and species richness – total phosphorus (chapter 5) relationships.

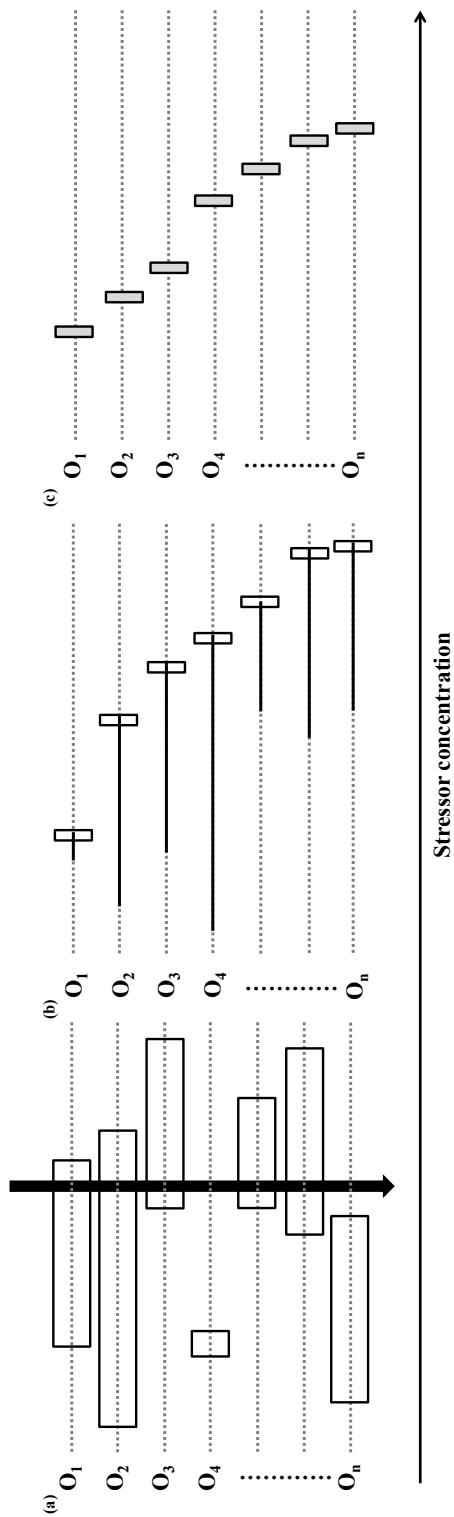
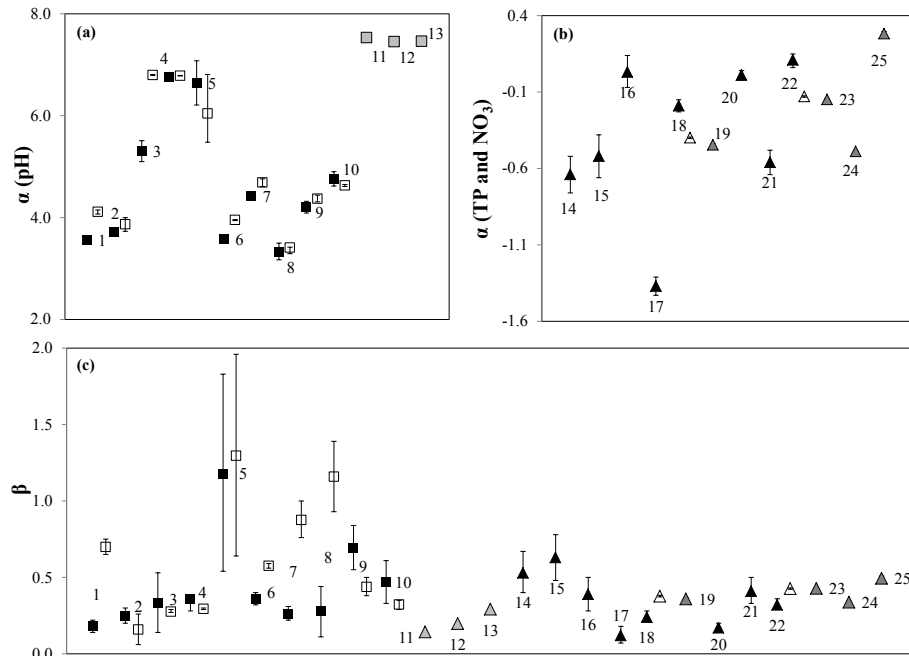


Figure 8.2 Underlying data used in the derivation of stressor – response functions for (a) species richness, (b) potential species absence, and (c) potential affected fraction as a function of stressor concentration (horizontal arrow). The rectangles of (a) represent the stressor range at which the species was confirmed present and the vertical black arrow represents the sum of species presences at a specific stressor level. The rectangles in (b) represent maximum level concentration at which each species was confirmed present and they are ordered from most to least sensitive (O_1 to O_n , respectively). The grey-filled rectangles in (c) represent the half maximum effective concentration (EC_{50}) of species ordered from most to least sensitive.



(1) (sub)tropical moist broadleaf forest, (2) mangroves, (3) flooded grassland and savannas, (4) desert and xeric shrubland, (5) Mediterranean forest, woodland, and scrub, (6) temperate broadleaf mixed forest, (7) temperate grassland, savanna, and shrublands, (8) temperate coniferous forest, (9) boreal forest and taiga, and (10) tundra and alpine land; EC_{50} based on (11) growth, (12) reproduction, and (13) mortality, total phosphorus for (14) cold, (15) temperate, and (16) xeric lake autotrophs, (17) cold and (18) temperate lake heterotrophs, (19) temperate lake invertebrates, (20) (sub)tropical and (21) temperate stream autotrophs, (22) temperate stream heterotrophs, and (23) temperate stream invertebrates; and nitrate (right graph): (24) temperate lake invertebrates and (25) temperate stream invertebrates. The slope β for 11-13 was converted from the standard deviation σ originally reported in chapter 4 as $\beta=0.55 \cdot \sigma$.

Test 8.3.1 (two-tailed paired t-test):

$$H_0: \alpha_{RSR} = \alpha_{RSA} \text{ (p value = 0.12)}$$

$$H_0: \beta_{RSR} = \beta_{RSA} \text{ (p value = 0.30)}$$

Test 8.3.2 (Kruskal-Wallis):

$$H_0: \beta_{\text{soil pH}} = \beta_{\text{ocean pH}} = \beta_{\text{freshwater TP}} = \beta_{\text{freshwater NO}_3} \text{ (p value = 0.99)}$$

Figure 8.3 Stressor – response relationships derived for (a) soil and marine water pH and (b) total phosphorus (TP) and NO_3 and (c) β . Coefficients for relative species richness (RSR) – pH soil (chapter 2, filled squares), relative species absence (RSA) – pH (chapter 3, unfilled squares), and pH_{50} – marine water pH (chapter 4, grey squares), RSR – TP (chapter 5, filled triangles), RSA – TP (chapter 6, unfilled triangles), and RSA – TP and NO_3 (chapter 7, grey triangles), respectively.

General discussion

8.2.3 Applications LCIA and ERA

The stressor – response relationships were applied into the context of LCIA and ERA because these are two techniques to quantify the impacts of anthropogenic activities on ecosystems. Still, while LCIA quantifies ecosystem damage due to a specific human intervention, e.g. emissions of pollutants due to the manufacture of a certain product (Udo de Haes *et al.*, 2002b), ERA quantifies ecosystem damage due to the concentration of stressors in the environment, irrespective of which human activity may have caused the impact.

In this thesis, the impacts of anthropogenic emissions of TP (estimated via LCIA, chapter 6) and of increased NO₃ and TP levels (estimated with an ERA, chapter 7) were executed on the same scale (i.e., temperate Europe) and for the same freshwater compartments (i.e., lakes and streams). When comparing the two impact assessment approaches, the total impact caused by P emissions in a given year, expressed with a normalization scores (NS), and the ecological risk due to P stress (ER_P) appear to be uncorrelated (Figure 8.4). For example, the Elbe, Danube, Loire, Rhine, and Seine river basins comprise the highest stream-based NS values (above 1E+14 m³) yet their ER_P values (of 10 to 15%) are similar to the median of ER_P of river basins in 2010 (see TP levels in appendix S7.2.1).

The discrepancy between LCIA and ERA is triggered by how impact scores are derived in each approach. For example, in highly polluted systems where the PNOF is high, the marginal effect model in LCIA gives relatively low impact scores to emissions taking place in considerably polluted systems (since it considers the change in PNOF) yet the ecological risk given to those basins is relatively high (since it includes the cumulative PNOF). Additionally, the characterization factors (CFs) employed in the derivation of NS also include the residence time of P in water (the longest the residence time in the river basin, the highest its CF). Therefore, even though the period that P remains in the water may be long thereby increasing the probability of triggering damage to species, the ecological risk is fairly low if TP concentrations are as well.

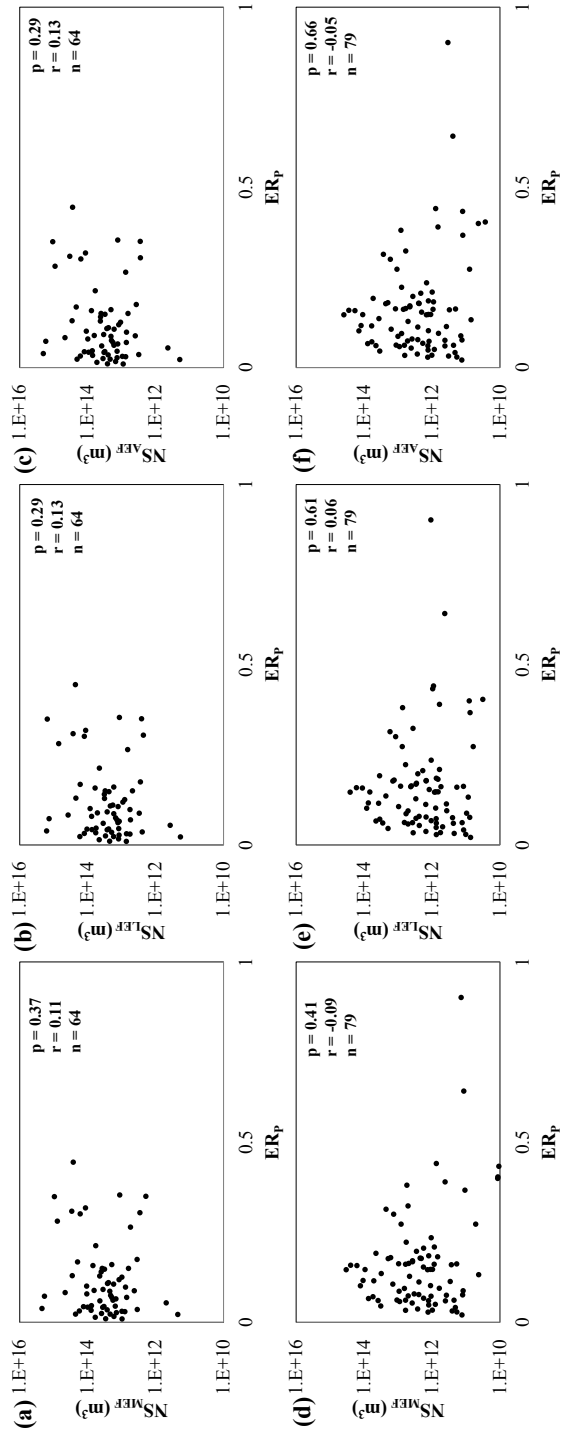


Figure 8.4 Results of Spearman correlations between ecological risk of phosphorus (chapter 7) and normalized scores (NS) of phosphorus emissions based on (a) marginal (MEF), (b) linear (LEF), and (c) average (AEF) effect factors for lakes and (d) marginal (MEF), (e) linear (LEF), and (f) average (AEF) effect factors for streams (chapter 6). P value (p), correlation coefficient (r), and number of samples (n) are shown in top right.

General discussion

8.3 Implications and future research recommendations

This thesis developed stressor – response relationships of the impacts of stressor concentrations following important worldwide human interventions today (nutrient causing terrestrial and marine acidification and freshwater eutrophication) on species assemblages. These relationships encompass a large number of species-specific data supplied by a large number of studies performed in different parts of the world. Given that this thesis focuses on stressors that are nutrients and therefore are also essential to the maintenance of organisms, important model choices have been taken, such as the specification of an optimum stressor level beyond which impacts are not accounted for. This thesis provides evidence that inherent spatial variability, the transport of pollutants, and the freshwater type subjected to stress are crucial components to the outcome of impact assessments.

8.3.1 Research novelty

(i) Stressor – response relationships of relative species richness and soil pH and freshwater TP for different biomes and habitats, freshwater types, and species groups (vascular plants, autotrophs, and heterotrophs) were developed. This was attained by gathering a large number of studies and species so as to derive regressions in a similar way, thereby allowing for comparisons with one another.

(ii) In this thesis, novel stressor – response relationships are described for life processes of calcifying species and marine water pH following the development of a large dataset on manipulated pH experiments. Likewise, the employment of these relationships into existing marine acidification scenarios for climate change showed that impacts are highly dependent upon the life process of focus and the pH condition expected in the future.

(iii) The grouping of the stressor – response relationships with models of the transport of pollutants within a LCIA context was performed on larger spatial scales (i.e., global) than those available up to now for terrestrial acidification. Additionally, another important freshwater compartment (i.e., lakes) was included in the derivation of CFs for freshwater eutrophication.

(iv) Still, the comparison of nitrogen and phosphorus impacts has been performed at a broad range of spatial scales and levels of details.

However, up to now, most comparisons were performed for a specific (group of) species or pre-determined stressor levels.

8.3.2 Implications of findings

(v) This thesis provides evidence of long-term species adaptation to the environment they subsist. Furthermore, it estimates the sensitivity of species to changing stressor levels. Past adaptation and current sensitivity are two key components towards assessing the ecological impact of human interventions in the form of pollutant emissions (LCIA) or current stressor levels in the environment (ERA). These components indicate that N-driven eutrophication impacts in freshwater bodies is higher than that of phosphorus and that emission impacts to lakes is higher than that of streams.

(vi) The high variability of emission impacts across river basins confirms the importance of performing impact assessments in a spatially-explicit manner. In this thesis, variability in emission impacts from acidifying and P-driven eutrophying emissions were generally determined by the transport of pollutants and less by their impact they cause to species.

8.3.3 Recommendations for future research

(vii) This thesis does not use mechanistic but probabilistic models to estimate impacts of stressor concentrations on species. For example, high levels of nitrogen and phosphorus affect net primary productivity which, in turn, affects heterotrophic species nutrition and availability of dissolved oxygen. This sequence of events can be better explored so as to allow for the identification, concentration of efforts, and for more options in the control of eutrophication impacts (for example, control of organic matter or secondary consumer populations).

(viii) The impact assessments conducted in this thesis are limited to the estimations of potential losses in relative species richness. Secondary impacts (e.g., hampering of ecosystem services and cascade effects to other species), interactions between organisms (e.g., predator – prey relationships, species competition), interacting effects between stressors (e.g. synergism between eutrophication and acidification), and feedbacks between species and stressors (e.g. escalating effects of marine species losses on climate change) are not taken into account. Although it is nearly impossible to provide a quantitative analysis which includes all possible secondary impacts, interactions, and processes that feed back into the stressor of concern, they can be individually addressed by future research works.

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(ix) This thesis estimates additive impacts of phosphorus and nitrogen on freshwater species. The assumption of additive effects, although contested for impacts on net primary productivity, remains to be tested as far as species diversity is concerned.

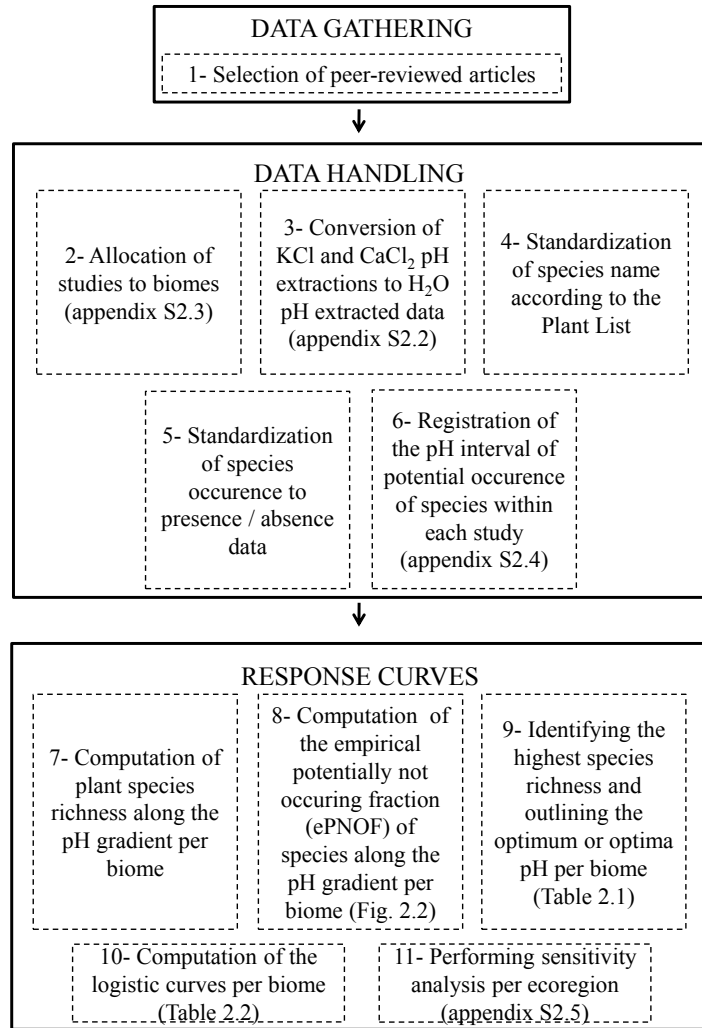
(x) Although the results of this thesis were often attributed to macroevolutionary patterns, such as the long-term favoring of acidophilus plants in inherently low pH soils, microevolutionary events may also influence stressor – response relationships and yet they were not included in this thesis. The influence of short-term evolution should be tested given that it may become more intensive as a result of rapid increasing flow of nutrients.

(xi) In the case of freshwater eutrophication, emission impacts and ecological risks were derived for Europe, for which ample monitoring of stressor levels were available. (Similar efforts elsewhere exist, e.g. GEMStat or the United States Geological Survey databases, but not nearly as intensively). In order for LCA and ERA to be conducted spatially-explicitly with a global coverage, systematic monitoring of stressor concentrations is indispensable. Alternatively, global scale models to predict environmental concentrations can be developed.

(xii) The LCIA effect factors derived for terrestrial acidification were based on marginal changes of the potentially not occurring fraction of vascular plants. Although differences between the marginal, linear, and average effect factors for freshwater eutrophication appear to be less pronounced than the differences triggered by freshwater type, these differences remain to be tested for other impact categories.

SUPPORTING INFORMATION

Appendix S2.1 Description of the methodological steps taken in our study



Appendix S2.2

Appendix S2.2 Conversion coefficients from (a) pH – KCl to pH – H₂O and from (b) pH – CaCl₂ to pH – H₂O and typical pH values per biome.

We used the pH data from the ISRIC-World Soil Information database (Batjes, 2009) to be able to create a regression from pH – KCl and pH – CaCl₂ to pH-H₂ (Figure S2.2.1). This conversion was necessary for 15% of the species occurrence ranges, which were distributed in eleven studies of the temperate broadleaf mixed forest biome, four of the temperate grassland, savanna, and shrubland biome, two for (sub)tropical grassland, savanna, and shrubland, and one of the (sub)tropical moist broadleaf mixed forest, boreal forest and taiga, and mediterranean forest, woodland, and scrub biomes. All studies in desert and xeric shrublands reported H₂O-extracted pH so no conversion was necessary in those cases.

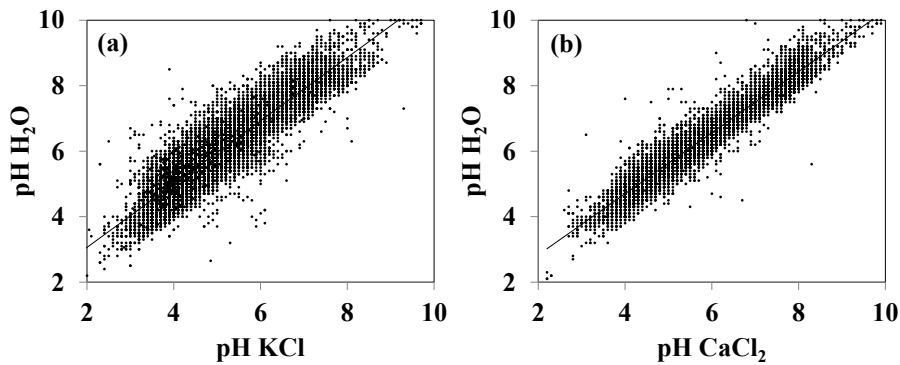


Figure S2.2.1 Conversion equation to H₂O extracted pH from KCl (a) and (b) CaCl₂ extractions. The red line represents the 95% confidence interval around the dependent variable (mean) for each observation. The equations for pH-KCl and pH-CaCl₂ transformation to pH-H₂O are $0.967 \cdot \text{pH-KCl} + 1.127$ ($R^2=0.843$, $n = 19,383$) and $0.933 \cdot \text{pH-CaCl}_2 + 0.965$ ($R^2=0.934$, $n = 10,883$), respectively.

We used the data from the same database to investigate (1) how soil pH would change along the soil profile (from the topsoil to 1m of depth, Figure S2.2.2) and (2) what are typical soil pH conditions existing today. The data reported by the ISRIC-World Soil Information database (reporting typical soil depths found in the environment) can have a broad range of pH (Figure S2.2.2). For example, pH values commonly found at 50cm of depth in temperate broadleaf mixed forests range from 3.0 to 10.0. However, the mean soil pH shows no clear trend of how pH increases or decreases with depth, suggesting that a 50cm soil depth can be representative of the top 1m of soil profile. The figure also shows what are typical pH conditions per biome. For example, desert and xeric shrublands have a pH value of approximately 8 while (sub)tropical moist broadleaf forests have a pH value of approximately 5.6 at 50cm of depth.

Supporting information

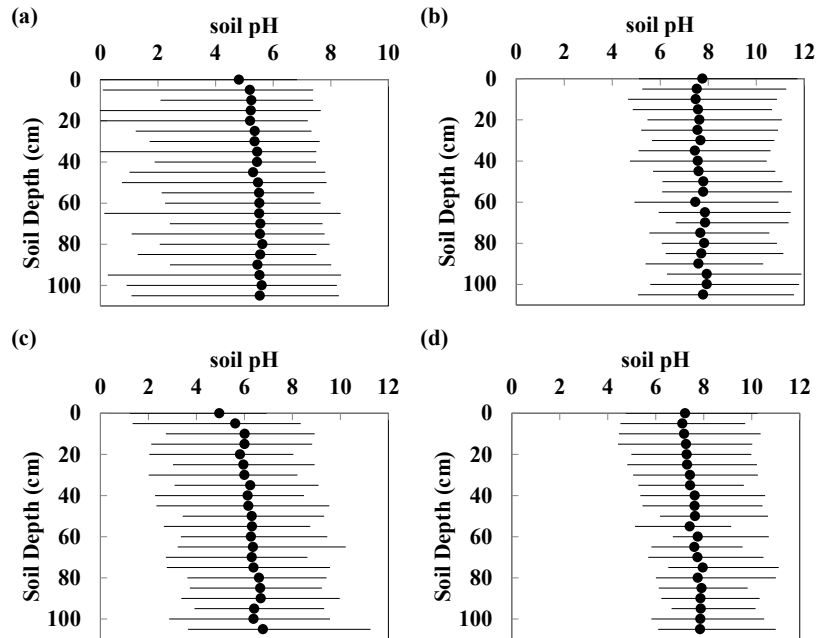


Figure S2.2.2 Soil pH throughout the soil profile (0 to 100cm of depth) for (a) (sub)tropical moist broadleaf forests, (b) desert and xeric shrubland, (c) temperate broadleaf mixed forest, and (d) temperate grassland, savanna, and shrubland. Dots and error bars are the mean and the minimum and maximum soil pH values that were found in the ISRIC-World Soil Information database (Batjes, 2009).

Appendix S2.3

Appendix S2.3 List of studies in each biome, the number of species and the pH range of each study.

Table S2.3.1 Total species per study, the total number of species in the optimum pH ($SR_{opt,j}$), the pH range of species occurrence and the (range of) optimum pH in **(a)** (sub)tropical moist broadleaf forests, **(b)** (sub)tropical grassland, savanna, and shrubland, **(c)** mangrove, **(d)** (sub)tropical dry broadleaf forests, **(e)** flooded grassland and savanna, **(f)** desert and xeric shrubland, **(g)** mediterranean forest, woodland, and shrubland, **(h)** temperate broadleaf mixed forest, **(i)** temperate grassland, savanna, and shrubland, **(j)** temperate coniferous forest, **(k)** montane grassland and shrubland, **(l)** boreal Forest / taiga, and **(m)** tundra and alpine.

Study	Species	$SR_{opt,j}$	pH range	(Range of) pH optimum
(a) (Sub)tropical moist broadleaf mixed forest				
Banack <i>et al.</i> (2002)	22	22	4.8 to 6.9	4.8 to 6.9
Banaticla & Buot (2005)	11	10	4.4 to 7.2	4.9 to 5.0
Chen <i>et al.</i> (1997)	50	50	4.1 to 4.7	4.2 to 4.7
Haro-Carrión <i>et al.</i> (2009)	14	14	5.9 to 6.4	5.9 to 6.4
Homeier <i>et al.</i> (2010)	155	155	3.5 to 5.8	3.8 to 4.3
Hsieh <i>et al.</i> (1998)	65	65	3.0 to 5.6	3.7
Ivanauskas <i>et al.</i> (2003)	67	67	3.4 to 4.3	3.5 to 3.8
Lesueur <i>et al.</i> (1993)	2	2	4.5 to 6.8	4.5 to 6.8
Paoli <i>et al.</i> (2006)	8	8	4.2 to 4.5	4.2 to 4.5
Penfold & Lamb (2002)	3	3	4.5 to 7.0	4.5 to 7.0
Poulsen (1996)	30	30	3.7 to 4.6	4.0 to 4.1
Proctor <i>et al.</i> (2007)	53	50	4.9 to 5.8	5.3
Siebert (2005)	9	9	4.9 to 7.3	4.9 to 7.3
Teo <i>et al.</i> (2003)	6	6	3.9 to 4.4	3.9 to 4.4
Turner <i>et al.</i> (1995)	24	24	3.8 to 4.2	3.8 to 4.2
Vetaas (1997)	29	29	6.6 to 8.2	6.6 to 8.2
Zhang <i>et al.</i> (2001)	39	39	5.4 to 6.7	6.4 to 6.7
(b) (Sub)tropical grassland, savanna, and shrubland				
Amorim & Batalha (2007)	80	80	4.7 to 5.3	5.0 to 5.1
da Silva & Batalha (2008)	50	50	4.5 to 4.9	4.7
Neto <i>et al.</i> (1999)	13	13	4.5 to 6.1	4.5 to 6.1
(c) Mangrove				
Ashton & Macintosh (2002)	12	12	4.1 to 7.2	6.0 to 6.5
Ukpong (1995)	21	21	3.4 to 7.2	4.1 to 5.8
(d) (Sub)tropical dry broadleaf forest				

Supporting information

Study	Species	SR _{opt,j}	pH range	(Range of) pH optimum
de Souza <i>et al.</i> (2007)	58	58	5.5 to 6.5	5.5 to 6.5
Dubbin <i>et al.</i> (2006)	17	12	5.7 to 8.5	7.3 to 8.5
White & Hood (2004)	71	65	6.9 to 7.6	7.0
 (e) Flooded grassland and savanna				
Haase (1999)	7	7	5.9 to 6.6	5.9 to 6.6
Ssegawa <i>et al.</i> (2004)	11	11	5.3 to 6.9	5.3 to 6.9
 (f) Desert and xeric shrubland				
El-Ghani (1998)	25	25	6.6 to 9.4	6.8 to 9.2
Camargo-Ricalde <i>et al.</i> (2002)	62	35	5.1 to 7.5	7.4
El-Demerdash <i>et al.</i> (1994)	32	32	6.2 to 9.7	7.9 to 8.0
El-Demerdash <i>et al.</i> (1995)	31	31	6.2 to 9.7	7.9 to 8.5
Franco-Vizcaino <i>et al.</i> (1993)	27	26	6.0 to 7.7	6.9 to 7.0
Kabir <i>et al.</i> (2010)	15	11	5.3 to 9.4	7.0 to 7.1
Li <i>et al.</i> (2008)	11	11	7.4 to 7.6	7.4 to 7.6
Mahmood <i>et al.</i> (1994)	15	9	7.7 to 9.8	7.7 to 7.9
Parker (1991)	13	13	6.6 to 8.7	7.2 to 8.0
Pettit & Naiman (2007)	107	107	7.0 to 8.0	7.0 to 8.0
Shaltout <i>et al.</i> (1997)	53	52	7.1 to 8.3	7.5 to 7.6
Titus <i>et al.</i> (2002)	3	3	7.8 to 8.8	8.1 to 8.5
Toft & Elliot-Fisk (2002)	2	2	9.6 to 9.7	9.6 to 9.7
Walker <i>et al.</i> (2001)	2	2	7.6 to 7.9	7.6 to 7.9
Zhang <i>et al.</i> (2005)	18	17	6.1 to 10.4	7.4 to 7.8
 (g) Mediterranean Forest, Woodland, and Shrubland				
Navas <i>et al.</i> (2008)	8	8	6.4 to 8.6	7.4 to 8.5
Richards <i>et al.</i> (1997)	14	9	4.9 to 6.2	5.4 to 5.5
Römermann <i>et al.</i> (2005)	6	6	6.4 to 6.7	6.5 to 6.7
Ruecker <i>et al.</i> (1998)	3	3	8.0 to 8.3	8.0 to 8.3
 (h) Temperate broadleaf mixed forest				
Abrams & Hayes (2008)	12	12	4.3 to 4.9	4.3 to 4.9
Ahokas (1997)	5	5	3.6 to 6.0	4.1 to 5.4
Akbar <i>et al.</i> (2009)	3	3	7.1 to 8.1	7.5
Andersson (1992)	19	19	3.2 to 5.0	3.2 to 5.0
Arii & Lechowicz (2002)	10	10	4.1 to 5.9	4.1 to 5.9

Appendix S2.3

Study	Species	SR _{opt,j}	pH range	(Range of) pH optimum
Baeten <i>et al.</i> (2009)	87	87	3.1 to 6.3	3.7 to 5.5
Bellemare <i>et al.</i> (2005)	89	89	4.7 to 5.1	4.7 to 5.1
Bernard & Seischab (1995)	16	14	3.4 to 4.1	3.5 to 4.0
Bigelow & Canham (2002)	6	6	3.4 to 7.1	4.3 to 6.1
Bjørnstad (1991)	31	31	4.0 to 5.3	4.0 to 5.3
Brososfske <i>et al.</i> (2001)	11	11	3.6 to 4.8	4.4
Brunet <i>et al.</i> (1996)	79	74	3.9 to 5.0	4.6
Brunet <i>et al.</i> (1997a)	104	104	4.5 to 5.1	4.7
Brunet <i>et al.</i> (1997b)	43	43	4.6 to 5.5	5.1 to 5.3
Chapman & Bannister (1995)	16	16	4.0 to 5.5	4.0 to 5.5
Cole & Weltzin (2004)	21	13	5.3 to 6.1	5.3 to 5.5
Coudun & Gégout (2007)	56	56	3.0 to 8.5	3.0 to 8.5
Coudun <i>et al.</i> (2006)	11	11	6.5 to 7.5	6.5 to 7.5
Dambrine <i>et al.</i> (2007)	35	35	4.8 to 5.1	4.8 to 5.1
De Graaf <i>et al.</i> (2009)	109	109	3.8 to 6.4	4.7 to 4.9
Dick & Gilliam (2007)	31	31	3.9 to 4.4	3.7 to 4.4
Diekmann & Lawesson (1999)	4	4	4.0 to 8.9	4.5 to 8.4
Dzwonko (2001)	40	19	4.0 to 5.8	4.5
Emerson <i>et al.</i> (2009)	11	11	4.5 to 8.2	4.5 to 8.2
Falkengren-Grerup <i>et al.</i> (1998)	4	4	4.8 to 5.1	4.8 to 5.1
Fennema (1992)	72	72	2.8 to 5.6	3.1 to 5.4
Gillian & Turrill (1993)	9	9	4.2 to 4.3	4.2 to 4.3
Graae (2000)	15	15	4.1 to 5.0	4.2 to 4.4
Graae <i>et al.</i> (2003)	27	27	3.3 to 6.3	3.4 to 5.5
Härdtle <i>et al.</i> (2005)	22	22	2.4 to 8.0	3.3 to 4.1
Hofmeister <i>et al.</i> (2009)	134	111	3.3 to 7.7	4.1 to 4.2
Hutchinson <i>et al.</i> (1999)	82	82	3.8 to 4.5	4.2
Jacob <i>et al.</i> (2009)	6	6	4.5 to 6.4	6.2 to 6.4
Kooijman (2010)	44	44	4.3 to 8.7	5.5 to 6.8
Lang <i>et al.</i> (2009)	21	13	4.0 to 7.9	4.6 to 4.7
Lukešová & Hoffmann (1996)	19	17	3.5 to 6.2	5.8 to 6.0
Petersen (1994)	57	37	4.7 to 8.0	6.0 to 6.5
Piernik (2005)	69	69	3.4 to 9.4	6.7 to 8.3
Plue <i>et al.</i> (2008)	38	38	3.3 to 8.4	5.2 to 7.0
Plue <i>et al.</i> (2009)	48	48	4.7 to 5.2	4.7 to 5.2
Roberts & Gilliam (1995)	27	18	4.4 to 5.6	4.4 to 4.6
Sage <i>et al.</i> (2005)	52	52	5.1 to 6.6	5.8 to 5.9

Supporting information

Study	Species	SR _{opt,j}	pH range	(Range of) pH optimum
Skousen <i>et al.</i> (1994)	10	10	3.3 to 6.9	4.3 to 5.2
Tyler (1996)	60	43	4.2 to 7.2	4.6 to 5.0
Van Couwenberghe <i>et al.</i> (2010)	8	8	3.8 to 7.9	3.8 to 7.9
Van Rossum <i>et al.</i> (1999)	43	43	3.8 to 8.0	3.8 to 8.0
Verheyen & Hermy (2001)	14	14	5.5 to 6.4	5.5 to 6.4
Vetaas (2000)	36	36	4.0 to 7.5	4.0 to 7.5
Ware <i>et al.</i> (1992)	21	21	4.5 to 8.0	6.6 to 7.8
West <i>et al.</i> (2009)	6	6	6.1 to 6.6	6.3 to 6.4
Xu & Inubushi (2009)	9	9	4.9 to 5.7	4.9 to 5.7
Zas & Alonso (2002)	19	19	4.2 to 5.6	4.8 to 4.9
(i) Temperate grassland, savanna, and shrubland				
Baasch <i>et al.</i> (2009)	3	3	2.6 to 7.9	3.2 to 7.6
Beumer <i>et al.</i> (2008)	26	26	4.6 to 6.2	4.6 to 6.2
Dollar <i>et al.</i> (1992)	15	14	4.9 to 6.4	5.4 to 5.5
Heikens & Robertson (1995)	94	68	4.1 to 8.1	7.6
Mårtensson & Olsson (2010)	3	3	4.6 to 9.1	5.9 to 9.1
Olsson <i>et al.</i> (2009)	25	25	4.5 to 9.1	4.5 to 9.1
Reinhammar <i>et al.</i> (2002)	75	75	4.4 to 5.8	4.4 to 5.8
Rodríguez <i>et al.</i> (1995)	45	42	5.0 to 6.7	6.2
Roem & Berendse (2000)	28	12	4.0 to 8.1	5.2 to 5.3
Sebastiá (2004)	13	5	5.4 to 7.4	5.4 to 6.0
Spiegelberger <i>et al.</i> (2006)	12	12	5.0 to 5.1	5.0 to 5.1
Stevens <i>et al.</i> (2010)	40	40	3.3 to 5.7	3.3 to 5.7
Tyler (2000)	63	63	4.5 to 8.7	6.1 to 7.2
Wagner (2009)	63	63	5.0 to 7.0	5.0 to 7.0
Walker <i>et al.</i> (2004)	33	33	4.3 to 6.1	5.4
Zuo <i>et al.</i> (2009)	25	25	7.0 to 7.6	7.3 to 7.5
(j) Temperate Coniferous Forest				
Dimopoulos <i>et al.</i> (1996)	29	24	4.5 to 8.3	7.4
Goldin (2001)	6	6	6.4 to 8.2	7.0
Hülber <i>et al.</i> (2008)	105	105	3.3 to 7.8	3.6 to 7.5
Johnston & Johnston (2004)	31	28	4.6 to 6.5	4.6 to 4.8
Kutnar & Martinčič (2003)	58	55	3.1 to 6.7	4.7 to 6.1
Nygaard & Abrahamsen (1991)	7	7	3.7 to 3.8	3.7 to 3.8
Nygaard & Ødegaard (1999)	22	22	3.3 to 5.3	3.3 to 4.5

Appendix S2.3

Study	Species	SR _{opt,j}	pH range	(Range of) pH optimum
Totland & Nylehn (1998)	16	16	4.1 to 5.6	4.1 to 5.6
(k) Montane grassland and shrubland				
Baniya <i>et al.</i> (2009)	135	135	6.0 to 7.0	6.0 to 7.0
Yimer <i>et al.</i> (2006)	4	4	5.5 to 6.2	5.5 to 6.0
(l) Boreal Forest / Taiga				
Elgersma & Dhillion (2002)	50	50	3.2 to 6.1	4.4
Giesler <i>et al.</i> (1998)	14	13	4.1 to 6.4	4.1 to 5.4
Karim & Mallik (2008)	33	33	5.3 to 6.9	6.9
Koptsik <i>et al.</i> (2001)	16	16	4.9 to 7.7	5.1 to 5.2
(m) Tundra and alpine				
Arnesen <i>et al.</i> (2007)	41	36	4.6 to 7.7	7.0 to 7.7
Auerbach <i>et al.</i> (1997)	5	5	4.0 to 7.3	4.0 to 7.3
Austrheim <i>et al.</i> (2005)	53	53	4.4 to 4.5	4.4 to 4.5
Razzhivin (1994)	73	72	4.5 to 7.9	6.0 to 6.4
Walker (2000)	6	6	5.3 to 7.0	5.3 to 7.0
Walker & Everett (1991)	34	30	6.9 to 7.7	7.3

Supporting information

Appendix S2.4 Species-specific data

Table S2.4.1 lists the number of species within each plant family within each biome. Table S2.4.2 lists the species occurring in each biome and their pH range of occurrence. Occasional records consist of genus or lower taxonomic ranks. The species, genus, or status in the Plant List database is either “accepted”, “unresolved”, or “genus” (in the case of genus records).

Table S2.4.1 Number of species in each family of vascular plants within each biome

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest / Taiga	Tundra and alpine	Total
Acanthaceae	4		3			6		1						14
Achariaceae	1													1
Actinidiaceae	1													1
Adiantaceae	1							1						2
Adoxaceae	1							6						7
Altingiaceae								1						1
Alzateaceae	1													1
Amaranthaceae	1	1	2			31		8	6		5			54
Amaryllidaceae								2	2		1			5
Anacardiaceae	5	2		3		2		1	3					16
Annonaceae	11	3		2										16
Apiaceae	3					3		12	13	6	4	1		42
Apocynaceae	4	2		2		7		2	1	1				19
Aquifoliaceae	14							1						15
Araceae	15							3			1			19
Araliaceae	5							4	1	1	1			12
Arecaceae	11	3	3	2		2								21
Aristolochiaceae								3		1				4
Asparagaceae						12		15	3	5	1	4	1	41
Aspleniaceae	1							2		1				4
Atherospermataceae	1													1
Balsaminaceae								2						2

Appendix S2.4

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest / Taiga	Tundra and alpine	Total
Begoniaceae	1													1
Berberidaceae	1							1			1			3
Betulaceae								13	3	2		6	1	25
Bignoniaceae	2	3		5		1								11
Bonnetiaceae	1													1
Boraginaceae	1			4		9		6	4	3	2		1	30
Brassicaceae	1					4		11	2	3	6		5	32
Bromeliaceae	2					1								3
Burseraceae	3			3		1								7
Cactaceae						20								20
Campanulaceae								7	5	1	2		2	17
Cannabaceae		1		1		1		1	1		1			6
Capparaceae						1								1
Caprifoliaceae	1							9	2	7	5	1	1	26
Caryophyllaceae						1		16	15	4	2		12	50
Celastraceae	4	1		2	1	1		2	1	1			2	15
Chloranthaceae	2													2
Chrysobalanaceae	5													5
Cistaceae								1	3					4
Cleomaceae						3								3
Clethraceae	2													2
Clusiaceae	6													6
Combretaceae			1	1		7								9
Commelinaceae						1		1						2
Compositae	15	8	1	1		37	5	57	55	23	18	9	20	249
Connaraceae	1	1												2
Convolvulaceae	1					3		2	2		2			10
Cornaceae								5	2	1				8
Crassulaceae								2	2				1	5
Cucurbitaceae						3								3

Supporting information

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest / Taiga	Tundra and alpine	Total
Cunoniaceae	7													7
Cupressaceae							1	2	2	1	1	1		8
Cyatheaceae	5													5
Cyperaceae	5	2			11	5		48	29	20	1	1	20	142
Daphniphyllaceae	1													1
Davalliaceae	1													1
Dennstaedtiaceae	1							2	1	1				5
Diapensiaceae									1				2	3
Dioscoreaceae								1						1
Dipterocarpaceae	8													8
Droseraceae		1						2	1					4
Dryopteridaceae	1							7		4		2		14
Ebenaceae	4	1		2		3		1						11
Elaeocarpaceae	4													4
Ephedraceae						1					1			2
Equisetaceae								2	2	2	1	1	2	10
Ericaceae	6	1					2	13	10	9	2	13	14	70
Escalloniaceae	1													1
Euphorbiaceae	13	3		6		7		4	3	3				39
Fagaceae	13			1			1	18	7	2				42
Fouquieriaceae						2								2
Gentianaceae	1	1						2	6	1	5		2	18
Geraniaceae						2		4	3	1	2	1	1	14
Gesneriaceae	1													1
Gleicheniaceae	1													1
Grossulariaceae								4		1				5
Hamamelidaceae								1						1
Humiriaceae	1													1
Hydrangeaceae	1							1						2
Hymenophyllaceae	3													3

Appendix S2.4

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest/ Taiga	Tundra and alpine	Total
Hypericaceae	2							6	3	2	1			14
Hypoxidaceae	1	1												2
Iridaceae		1							1			1		3
Iteaceae	1													1
Ixioliriaceae									1					1
Ixonanthaceae	1													1
Juglandaceae	1							6	4					11
Juncaceae						1		16	10	8	1	1	5	42
Juncaginaceae								1						1
Krameriaceae						2								2
Lacistemataceae	1													1
Lamiaceae	4	5		2	1	2		16	16	6	7			59
Lauraceae	30			1		1		2						34
Lecythidaceae	2													2
Leguminosae	21	22	2	30		45	2	31	30	5	10	2	6	206
Lentibulariaceae									1	1			1	3
Liliaceae								3		2	1		1	7
Limeaceae						1								1
Linaceae							1	1						2
Linderniaceae	1													1
Loranthaceae	1													1
Lycopodiaceae	1	1						2		2		2	1	9
Lythraceae	1	2	1					1						5
Magnoliaceae	2							1						3
Malpighiaceae	2	2		2										6
Malvaceae	5	6	1	4	1	16		3	1		1			38
Marantaceae	1													1
Melanthiaceae								3		2				5
Melastomataceae	23	2			1									26
Meliaceae	3			7	1	1								12

Supporting information

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest/ Taiga	Tundra and alpine	Total
Melanthaceae	1													1
Menispermaceae	1					1								2
Molluginaceae						1								1
Montiaceae								2						2
Moraceae	13			3			1							17
Myricaceae	1													1
Myristicaceae	2													2
Myrtaceae	14	13		9						1				37
Nartheciaceae								1						1
Nepenthaceae	2													2
Nitrariaceae						2								2
Nyctaginaceae	2			1										3
Ochnaceae	2	3				1								6
Olaceaceae	7													7
Oleaceae	5					2	4	2	2					15
Onagraceae						1	5	1	1		1	2		11
Ophioglossaceae							1	1						2
Orchidaceae	1						6	1	6	3	1			18
Orobanchaceae						2	8	12	3	2	2	10		39
Oxalidaceae	2						3		1		1			7
Pandaceae	1													1
Papaveraceae	1					1	4		1	1		1		9
Pedaliaceae						1								1
Pentaphragaceae	10													10
Peraceae	2													2
Phrymaceae	1													1
Phyllanthaceae	6	1		2		3				1				13
Pinaceae				2			1	9	7	1	5			25
Piperaceae	4													4
Pittosporaceae	1													1

Appendix S2.4

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest/ Taiga	Tundra and alpine	Total
Plantaginaceae	2					2		8	10	3	1	2	2	30
Platanaceae								1	1	1				3
Plumbaginaceae						1								1
Poaceae	10	18				40	4	72	67	23	17	6	13	270
Podocarpaceae	3													3
Polygalaceae								2	3	2				7
Polygonaceae				4	1	4		14	4	1	6		5	39
Polypodiaceae	3							1						4
Primulaceae	7			2				7	2	1	1	2	1	23
Proteaceae	2	1					7			1				11
Putranjivaceae	3			1										4
Ranunculaceae	2							17	11	8	5	4	9	56
Resedaceae						2								2
Rhamnaceae	1	1		5		1		2	1					11
Rosaceae	7							39	16	13	9	9	12	105
Rubiaceae	32	2		9		7		14	8	7	2	1		82
Rutaceae	2			1				1						4
Sabiaceae	2													2
Salicaceae	1	1		5		1	2	7	7	1		4	6	35
Salvadoraceae						1								1
Santalaceae	1													1
Sapindaceae	5	1		4		2		11	3	1		1		28
Sapotaceae	8	3		4										15
Sarcobataceae						1								1
Saxifragaceae								4	1				5	10
Schisandraceae	2													2
Schlegeliaceae	1													1
Scrophulariaceae						2		3		1	1			7
Selaginellaceae	1								1					2
Simaroubaceae	1													1

Supporting information

Family	(Sub)tropical moist broadleaf mixed forest	(Sub)tropical grassland, savanna, and shrubland	Mangrove	(Sub)tropical dry broadleaf forest	Flooded grassland and savanna	Desert and xeric shrubland	Mediterranean Forest, Woodland, and Shrubland	Temperate broadleaf mixed forest	Temperate grassland, savanna, and shrubland	Temperate Coniferous Forest	Montane grassland and shrubland	Boreal Forest/ Taiga	Tundra and alpine	Total
Simmondsiaceae						1								1
Siparunaceae	3													3
Smilacaceae	1							2	1					4
Solanaceae	3	1				5		3						12
Staphyleaceae	2													2
Styracaceae	3													3
Symplocaceae	6													6
Tamaricaceae						5								5
Theaceae	4													4
Thelypteridaceae	2							1		2		2		7
Thymelaeaceae								1		2	1			4
Tofieldiaceae									1				2	3
Trochodendraceae	1													1
Typhaceae									1					1
Ulmaceae								4	2	1				7
Urticaceae	6			2				3						11
Verbenaceae		1		1		4								6
Violaceae	3			1				12	5	2	1	1	3	28
Vitaceae						2		2	1					5
Vochysiaceae	1	2			1									4
Winteraceae	1													1
Woodsiaceae	2							5		3		2		12
Xanthorrhoeaceae	1													1
Zingiberaceae	6													6
Zygophyllaceae						9								9
Total	531	124	14	137	18	351	26	682	421	229	137	90	172	2932

Appendix S2.4

Table 2.4.2 List of species and their respective pH range of occurrence found in (a) Tropical and subtropical moist broadleaf forest, (b) Tropical and subtropical grassland, savanna, and shrubland, (c) Mangrove, (d) Tropical and subtropical dry broadleaf forest, (e) Flooded grassland and savanna, (f) Desert and xeric shrublands, (g) Mediterranean Forest, Woodland, and Shrubland, (h) Temperate broadleaf mixef forest, (i) Temperate Grassland, Savanna, and Shrubland, (j) Temperate Coniferous Forest, (k) Montane grassland and shrubland, (l) Boreal Forest / Taiga, and (m) Tundra and alpine.

Species	pH range	Species	pH range
(a) Tropical and Subtropical Moist Broadleaf Forest		<i>Antiaris</i> sp.	5.3 to 5.4
<i>Abarema killipii</i> (Britton & Killip) Barneby & J.	3.7 to 4.3	<i>Antidesma japonicum</i> var. <i>japonicum</i>	4.1 to 4.7
<i>Acacia mangium</i> Willd.	4.5 to 6.8	<i>Antidesma laciniatum</i> Müll.Arg.	4.9 to 5.3
<i>Acalypha australis</i> L.	6.4 to 6.7	<i>Antrocaryon klaineum</i> Pierre	4.9 to 5.3
<i>Acer caudatifolium</i> Hayata	3 to 3.7	<i>Aparisthium cordatum</i> (A.Juss.) Baill.	3.4 to 4.3
<i>Acer negundo</i> subsp. <i>mexicanum</i> (DC.) Wesm.	3.1 to 5.6	<i>Apostasia wallichii</i> R.Br.	3.7 to 4.1
<i>Actinodaphne mushaensis</i> (Hayata) Hayata	3 to 3.7	<i>Archidendron lucidum</i> (Benth.) I.C.Nielsen	4.1 to 4.7
<i>Adinandra dumosa</i> Jack	3.9 to 4.4	<i>Ardisia quinquegona</i> Blume	4.1 to 4.7
<i>Adinandra formosana</i> Hayata	3 to 4.7	<i>Ardisia sieboldii</i> Miq.	3 to 5.6
<i>Aechmea angustifolia</i> Poepp. & Endl.	5.9 to 6.4	<i>Aspidosperma discolor</i> A.DC.	3.4 to 4.3
<i>Ageratum conyzoides</i> (L.) L.	6.4 to 6.7	<i>Asplenium cymbifolium</i> Christ [#]	4.7 to 5.2
<i>Aidia cochinchinensis</i> Lour.	3.6 to 5.6	<i>Astronia ferruginea</i> Elmer	4.1 to 4.7
<i>Alchornea grandiflora</i> Müll.Arg.	3.7 to 5.8	<i>Begonia</i> sp.	3.7 to 4.6
<i>Alchornea triplinervia</i> (Spreng.) Müll.Arg.	3.7 to 4.4	<i>Beilschmiedia erythrophloia</i> Hayata	3.7 to 5.6
<i>Alchorneopsis floribunda</i> (Benth.) Müll.Arg.	3.8 to 5.8	<i>Beilschmiedia tovarensis</i> (Klotzsch & H.Karst. ex Meisn.) Sachiko Nishida	3.7 to 4.4
<i>Alibertia edulis</i> (Rich.) A.Rich. ex DC.	3.4 to 4.3	<i>Beilschmiedia tsangii</i> Merr.	4.1 to 4.7
<i>Alniphyllum pterospermum</i> Matsum.	4.1 to 4.7	<i>Bejaria aestuans</i> Mutis ex L.	3.7 to 4.4
<i>Alocasia peltata</i> M.Hotta	3.7 to 4.1	<i>Bellucia grossularioides</i> (L.) Triana	3.4 to 4.3
<i>Alzatea verticillata</i> Ruiz & Pav.	3.7 to 4.3	<i>Berberis asiatica</i> Roxb. ex DC.	6.6 to 8.2
<i>Amaranthus spinosus</i> L.	6.4 to 6.7	<i>Berlinia bracteosa</i> Benth.	4.9 to 5.4
<i>Amomum coriaceum</i> R.M.Sm.	3.7 to 4.1	<i>Bersama abyssinica</i> Fresen.	5.4 to 5.7
<i>Amydrium medium</i> (Zoll. & Moritzi) Nicolson	3.7 to 4.6	<i>Bidens biternata</i> (Lour.) Merr. & Sherff	6.4 to 6.7
<i>Aniba muca</i> (Ruiz & Pav.) Mez	3.8 to 5.8	<i>Boesenbergia flavoalba</i> R.M.Sm.	3.7 to 4.6
<i>Anisomeles indica</i> (L.) Kuntze	6.4 to 6.7	<i>Bothriospermum zeylanicum</i> (J.Jacq.) Druce	6.4 to 6.7
<i>Annickia chlorantha</i> (Oliv.) Setten & Maas	5.1 to 5.4	<i>Brachiaria eruciformis</i> (Sm.) Griseb.	6.4 to 6.7
<i>Annona andicola</i> (Maas & Westra) H.Rainer	3.8 to 5.8	<i>Bridelia micrantha</i> (Hochst.) Baill.	5.1 to 5.3
<i>Anthurium asplundii</i> Croat	5.9 to 6.4	<i>Byrsonima crispa</i> A.Juss.	3.4 to 4.3
<i>Anthurium dolichostachyum</i> Sodiro	5.9 to 6.4	<i>Byrsonima homeieri</i> W.R.Anderson	3.8 to 5.8
<i>Anthurium obtusum</i> (Engl.) Grayum	5.9 to 6.4	<i>Calamus didymocarpus</i> Warb. ex Becc.	4.9 to 7.3
		<i>Calamus leiocaulis</i> Becc. ex K.Heyne	4.9 to 7.3
		<i>Calamus leptostachys</i> Becc. ex K.Heyne	4.9 to 7.3

Supporting information

Species	pH range	Species	pH range
<i>Calamus minahassae</i> Warb. ex Becc.	4.9 to 7.3	<i>Clusia ducuoides</i> Benth.	3.7 to 4.3
<i>Calamus ornatus</i> Blume	4.9 to 7.3	<i>Coffea liberica</i> Hiern	5.1 to 5.5
<i>Calamus symphysipus</i> Mart.	4.9 to 7.3	<i>Cola praeacuta</i> Brenan & Keay	5.1 to 5.3
<i>Calamus zollingeri</i> Becc.	4.9 to 7.3	<i>Cola verticillata</i> (Thom.) Stapf ex A.Chev.	5.1 to 5.3
<i>Calyptranthes concinna</i> DC.	3.8 to 5.8	<i>Colquhounia coccinea</i> Wall.	6.6 to 8.2
<i>Calyptranthes pulchella</i> DC.	3.5 to 4.3	<i>Connarus perrottetii</i> (DC.) Planch.	3.4 to 4.3
<i>Campomanesia</i> sp.	3.5 to 3.8	<i>Conyza canadensis</i> (L.) Cronquist	6.4 to 6.7
<i>Capillipedium parviflorum</i> (R.Br.) Stapf	5.4 to 6.7	<i>Copaifera langsdorffii</i> Desf.	3.4 to 4.3
<i>Carex vesiculosa</i> Boott	6.6 to 8.2	<i>Corydalis chaerophylla</i> DC.	6.6 to 8.2
<i>Casearia stipitata</i> Mast. #	5.1 to 5.3	<i>Couepia recurva</i> Spruce ex Prance	3.8 to 5.8
<i>Cassytha filiformis</i> L.	3.8 to 4.2	<i>Critoniopsis floribunda</i> (Kunth) H.Rob.	3.8 to 5.8
<i>Castanopsis carlesii</i> (Hemsl.) Hayata	3 to 5.6	<i>Critoniopsis zamorensis</i> X. Haro & H.Rob.	3.8 to 5.8
<i>Castanopsis faberi</i> Hance	4.1 to 4.7	<i>Cupania scrobiculata</i> Rich.	3.4 to 4.3
<i>Castanopsis indica</i> (Roxb. ex Lindl.) A.DC.	6.6 to 8.2	<i>Cuscuta reflexa</i> Roxb.	6.6 to 8.2
<i>Castanopsis tribuloides</i> (Sm.) A.DC.	6.6 to 8.2	<i>Cyathea callosa</i> H. Christ#	4.4 to 5.3
<i>Cecropia andina</i> Cuatrec.	3.8 to 5.8	<i>Cyathea contaminans</i> (Wall. ex Hook.) Copel.	4.8 to 7.1
<i>Cecropia angustifolia</i> Trécul	3.8 to 5.8	<i>Cyathea lepifera</i> (J. Sm. ex Hook.) Copel.	3.7 to 5.6
<i>Cecropia distachya</i> Huber	3.5 to 4.3	<i>Cyathea loheri</i> H. Christ	4.7 to 5.7
<i>Ceiba speciosa</i> (A.St.-Hil.) Ravenna	3.7 to 4.3	<i>Cyathea philippinensis</i> Baker#	4.4 to 5.2
<i>Centella asiatica</i> (L.) Urb.	5.4 to 6.7	<i>Cynodon dactylon</i> (L.) Pers.	6.4 to 6.7
<i>Cephalomanes apiifolium</i> (C. Presl) K. Iwats.	4.4 to 5	<i>Cyrtandra phoenicolasia</i> Lauterb.	3.7 to 4.1
<i>Cerasus campanulata</i> (Maxim.) A.N. Vassiljeva	3 to 4.1	<i>Dacryodes nitens</i> Cuatrec.	3.4 to 4.3
<i>Cestrum schlechtendahlui</i> G.Don	3.5 to 5.8	<i>Daemonorops robusta</i> Warb. ex Becc.	4.9 to 7.3
<i>Chaetocarpus echinocarpus</i> (Baill.) Ducke	3.4 to 4.3	<i>Daphniphyllum pentandrum</i> Hayata	3.1 to 5.6
<i>Cheiloclinium cognatum</i> (Miers) A.C.Sm.	3.4 to 4.3	<i>Dasylepis racemosa</i> Oliv. #	5.1 to 5.4
<i>Chromolaena odorata</i> (L.) R.M.King & H.Rob.	6.6 to 8.2	<i>Decaspermum gracilentum</i> (Hance) Merr. & L.M.Perry	4.1 to 4.7
<i>Chrysophyllum lanatum</i> T.D.Penn.	3.5 to 5.8	<i>Dendropanax dentiger</i> (Harms) Merr.	3 to 4.1
<i>Cinchona hirsuta</i> Ruiz & Pav.	3.5 to 4.3	<i>Dendrophthoe pentandra</i> (L.) Miq.	3.8 to 4.2
<i>Cinnamomum camphora</i> (L.) J.Presl	3 to 4.1	<i>Desmodium multiflorum</i> DC.	6.6 to 8.2
<i>Cinnamomum subavenium</i> Miq.	3 to 4.1	<i>Dianella ensifolia</i> (L.) DC.	3.8 to 4.2
<i>Cissampelos pareira</i> L.	6.6 to 8.2	<i>Dichostemma glaucescens</i> Pierre	5.1 to 5.3
<i>Clematis montana</i> Buch.-Ham. ex DC.	6.6 to 8.2	<i>Dicranopteris linearis</i> (Burm. f.) Underw.	3.8 to 5.5
<i>Clethra revoluta</i> (Ruiz & Pav.) Spreng.	3.7 to 4.3	<i>Dictyocaryum lamarckianum</i> (Mart.) H.Wendl.	3.7 to 4.3
<i>Cleyera japonica</i> Thunb.	3.1 to 5.6	<i>Digitaria sanguinalis</i> (L.) Scop.	6.4 to 6.7
<i>Clinopodium piperitum</i> (D.Don) Murata	6.6 to 8.2	<i>Dioicodendron dioicum</i> (K.Schum. & K.Krause) Steyererm.	3.5 to 4.3
<i>Clusia ducu</i>	3.7 to 4.3	<i>Diospyros eriantha</i> Champ. ex Benth.	4.1 to 4.7

Appendix S2.4

Species	pH range	Species	pH range
<i>Diospyros gabunensis</i> Gürke	5.1 to 5.3	<i>Faidherbia albida</i> (Delile) A.Chev.	4.5 to 6.8
<i>Diospyros morrisiana</i> Hance	3 to 4.1	<i>Faramea bangii</i> Rusby	3.8 to 5.8
<i>Diospyros zenkeri</i> (Gürke) F.White	5.3 to 5.4	<i>Faramea coerulescens</i> K.Schum. & K.Krause	3.5 to 4.4
<i>Diplazium crenato-serratum</i> T. Moore [#]	3.7 to 4.1	<i>Faramea glandulosa</i> Poepp.	3.8 to 5.8
<i>Diplazium riparium</i> Holtum [#]	4 to 4.6	<i>Faramea uniflora</i> Dwyer & M.V.Hayden	3.8 to 5.8
<i>Diplospora dubia</i> (Lindl.) Masam.	3 to 5.6	<i>Fatoua pilosa</i> Gaudich.	6.4 to 6.7
<i>Diplostropis triloba</i> Gleason	3.4 to 4.3	<i>Ficus citrifolia</i> Mill.	3.8 to 5.8
<i>Dipsacus inermis</i> Wall.	6.6 to 8.2	<i>Ficus cuatrecasiana</i> Dugand	3.8 to 5.8
<i>Dipterocarpus sublamellatus</i> Foxw.	4.2 to 4.5	<i>Ficus fistulosa</i> Reinw. ex Blume	4.1 to 4.7
<i>Doryphora sassafras</i> Endl.	4.5 to 7	<i>Ficus insipida</i> Willd.	4.8 to 6.9
<i>Drimys granadensis</i> L.f.	3.5 to 4.4	<i>Ficus mucoso</i> Welw. ex Ficalho	5.3 to 5.4
<i>Drypetes bipindensis</i> (Pax) Hutch.	5.1 to 5.3	<i>Ficus tonduzii</i> Standl.	3.8 to 5.8
<i>Drypetes paxii</i> Hutch.	5.3 to 5.4	<i>Frangula granulosa</i> (Ruiz & Pav.) Grubov	3.5 to 4.3
<i>Drypetes staudtii</i> (Pax) Hutch.	4.9 to 5.3	<i>Fraxinus griffithii</i> C.B.Clarke	3 to 4.1
<i>Duchesnea indica</i> (Andrews) Focke	6.4 to 6.7	<i>Freziera campanulata</i> A.L. Weitzman [#]	3.5 to 4.4
<i>Dulacia inopiflora</i> (Miers) Kuntze	3.4 to 4.3	<i>Freziera karsteniana</i> (Szyszyl.) Kobuski	3.5 to 4.4
<i>Dussia</i> sp.	3.8 to 5.8	<i>Garcinia mannii</i> Oliv.	4.9 to 5.4
<i>Elaeagia obovata</i> Rusby	3.5 to 4.4	<i>Garcinia multiflora</i> Champ. ex Benth.	4.1 to 4.7
<i>Elaeagia pastoensis</i> L.E.Mora	3.5 to 4.4	<i>Gaultheria reticulata</i> Kunth	3.7 to 4.4
<i>Elaeocarpus japonicus</i> Siebold	3 to 4.1	<i>Geissanthus vanderwerffii</i> Pipoly	3.5 to 4.3
<i>Elaeocarpus sylvestris</i> (Lour.) Poir.	4.1 to 4.7	<i>Glochidion rubrum</i> Blume	3.7 to 5.6
<i>Elettariopsis kerbyi</i> R.M.Sm.	3.7 to 4.6	<i>Gloeospermum</i> sp.	3.5 to 5.8
<i>Elettariopsis stenosphon</i> (K.Schum.) B.L.Burt & R.M.Sm.	4 to 4.1	<i>Gnaphalium polycaulon</i> Pers.	6.4 to 6.7
<i>Emilia sonchifolia</i> (L.) DC. ex DC.	6.4 to 6.7	<i>Gordonia axillaris</i> (Roxb. ex Ker) Endl.	3 to 4.7
<i>Endlicheria griseosericea</i> Chanderb.	3.8 to 5.8	<i>Graffenrieda emarginata</i> (Ruiz & Pav.) Triana	3.8 to 5.8
<i>Endlicheria oreocola</i> Chanderb.	3.7 to 4.4	<i>Graffenrieda harlingii</i> Wurdack	3.5 to 4.3
<i>Engelhardtia roxburghiana</i> Lindl.	3 to 5.6	<i>Guapira</i> sp.	3.8 to 5.8
<i>Epipremnum falcifolium</i> Engl.	3.7 to 4.1	<i>Guarea kunthiana</i> A.Juss.	3.8 to 5.8
<i>Eriachne pallescens</i> R.Br.	3.8 to 4.2	<i>Guatteria blepharophylla</i> Mart.	3.4 to 4.3
<i>Erigeron annuus</i> (L.) Pers.	6.4 to 6.7	<i>Guatteria foliosa</i> Benth.	3.4 to 4.3
<i>Eschweilera sessilis</i> A.C.Sm.	3.5 to 4.3	<i>Guatteria schomburgkiana</i> Mart.	3.4 to 4.3
<i>Eugenia egensis</i> DC.	3.8 to 5.8	<i>Guzmania monostachia</i> (L.) Rusby ex Mez	5.9 to 6.4
<i>Euonymus laxiflorus</i> Champ. ex Benth.	3 to 4.1	<i>Handroanthus chrysanthus</i> (Jacq.) S.O.Grose	3.8 to 5.8
<i>Eurya hayatae</i> Yamam.	4.1 to 4.7	<i>Hedyosmum anisodorum</i> Todzia	3.7 to 4.3
<i>Eurya loquaiana</i> Dunn	3 to 5.6	<i>Hedyosmum translucidum</i> Cuatrec.	3.7 to 4.3
<i>Euterpe precatória</i> Mart.	3.7 to 4.3	<i>Heisteria</i> sp.	3.8 to 5.8
<i>Evodia merrillii</i> Kaneh. & Sasaki [#]	4.1 to 4.7		

Supporting information

Species	pH range	Species	pH range
<i>Helicia formosana</i> Hemsl.	3 to 5.6	<i>Ixonanthes reticulata</i> Jack [#]	3.8 to 4.2
<i>Helicostylis towarensis</i> (Klotzsch & H.Karst.) C.C.Berg	3.8 to 5.8	<i>Jacaranda copaia</i> (Aubl.) D.Don	3.4 to 4.3
<i>Heliocarpus americanus</i> L.	3.5 to 5.8	<i>Jasminum humile</i> L.	6.6 to 8.2
<i>Himatanthus sukuuba</i> (Spruce ex Müll.Arg.) Woodson	3.4 to 4.3	<i>Korthalsia celebica</i> Becc.	4.9 to 7.3
<i>Hirtella bullata</i> Benth.	3.4 to 4.3	<i>Kyllinga brevifolia</i> Rottb.	5.4 to 6.7
<i>Hirtella racemosa</i> Lam.	3.4 to 4.3	<i>Lacistema pubescens</i> Mart. [#]	3.4 to 4.3
<i>Homalomena ovata</i> Engl.	3.7 to 4.1	<i>Ladenbergia acutifolia</i> (Ruiz & Pav.) Klotzsch	3.8 to 5.8
<i>Hopea ferruginea</i> Parijs [#]	4.2 to 4.5	<i>Lagerstroemia subcostata</i> Koehne	3.7 to 5.6
<i>Hoya diversifolia</i> Blume [#]	3.8 to 4.2	<i>Laurocerasus phaeosticta</i> (Hance) C.K. Schneid.	3 to 4.7
<i>Hydrangea chinensis</i> Maxim.	3 to 4.1	<i>Lebruniodendron</i> sp.	4.9 to 5.3
<i>Hymenaea courbaril</i> L.	3.4 to 4.3	<i>Leeuwenbergia africana</i> Letouzey & N.Hallé	5.1 to 5.4
<i>Hymenophyllum meyenianum</i> Copel. [#]	4.7 to 5	<i>Leucaena leucocephala</i> (Lam.) de Wit	5.4 to 6.7
<i>Hymenostegia afzelii</i> (Oliv.) Harms	4.9 to 5.1	<i>Licania blackii</i> Prance	3.4 to 4.3
<i>Ilex ambovoica</i> Loes.	3.8 to 5.8	<i>Licania kunthiana</i> Hook.f.	3.4 to 4.3
<i>Ilex cochinchinensis</i> (Lour.) Loes.	4.1 to 4.7	<i>Licaria subsessilis</i> van der Werff [#]	3.7 to 4.4
<i>Ilex formosana</i> Maxim.	3 to 5.6	<i>Ligularia fischeri</i> (Ledeb.) Turcz.	6.6 to 8.2
<i>Ilex goshiensis</i> Hayata	3 to 4.1	<i>Ligustrum japonicum</i> Thunb.	3 to 4.1
<i>Ilex hippocrateoides</i> Kunth	3.7 to 4.3	<i>Lindera communis</i> Hemsl.	3.6 to 5.6
<i>Ilex lonicerifolia</i> Hayata	4.1 to 4.7	<i>Lindsaea parallelogramma</i> Alderw. [#]	4 to 4.1
<i>Ilex mitis</i> (L.) Radlk.	4.9 to 5.3	<i>Lithocarpus amygdalifolius</i> (Skan) Hayata	4.1 to 4.7
<i>Ilex rimbachii</i> Standl.	3.7 to 4.3	<i>Lithocarpus hancei</i> (Benth.) Rehder	3.7 to 5.6
<i>Ilex rotunda</i> Thunb.	3 to 4.1	<i>Litsea acuminata</i> (Teschner) Kosterm.	3 to 3.7
<i>Ilex scopulorum</i> Kunth	3.7 to 4.3	<i>Litsea acutivena</i> Hayata	4.1 to 4.7
<i>Ilex teratopsis</i> Loes.	3.7 to 4.3	<i>Lycopodiella cernua</i> (L.) Pic. Serm.	3.8 to 4.2
<i>Ilex triflora</i> Blume	4.1 to 4.7	<i>Lyonia ovalifolia</i> (Wall.) Drude	6.6 to 8.2
<i>Ilex uraiensis</i> Mori & Yamamoto	4.1 to 4.7	<i>Mabea fistulifera</i> Mart.	3.4 to 4.3
<i>Ilex weberlingii</i> Loizeau & Spichiger	3.7 to 4.3	<i>Machilus japonica</i> var. <i>kusanoi</i>	3.7 to 5.6
<i>Illicium anisatum</i> Gaertn. [#]	3 to 4.1	<i>Machilus thunbergii</i> Siebold & Zucc.	3 to 5.6
<i>Illicium arborescens</i> Hayata	3 to 5.6	<i>Macrocarpaea revoluta</i> (Ruiz & Pav.) Gilg	3.7 to 4.4
<i>Inga extra-nodis</i> T.D.Penn.	3.8 to 5.8	<i>Magnolia compressa</i> Maxim.	3 to 4.1
<i>Inga heterophylla</i> Willd.	3.4 to 4.3	<i>Magnolia kachirachirai</i> (Kaneh. & Yamam.) Dandy	4.1 to 4.7
<i>Inga laurina</i> (Sw.) Willd.	3.4 to 4.3	<i>Mallotus paniculatus</i> (Lam.) Müll.Arg.	4.1 to 4.7
<i>Inga marginata</i> Kunth	3.8 to 5.8	<i>Mapania graminea</i> Uittien	3.7 to 4.6
<i>Inga striata</i> Benth.	3.8 to 5.8	<i>Mapania monostachya</i> Uittien	3.7 to 4.1
<i>Inga thibaudiana</i> DC.	3.4 to 4.3	<i>Maprounea guianensis</i> Aubl.	3.4 to 4.3
<i>Isertia laevis</i> (Triana) Boom	3.8 to 5.8	<i>Mareyopsis longifolia</i> (Pax) Pax & K.Hoffm.	4.9 to 5.4
<i>Itea parviflora</i> Hemsl.	3.1 to 5.6		

Appendix S2.4

Species	pH range	Species	pH range
<i>Matayba arborescens</i> (Aubl.) Radlk.	3.4 to 4.3	<i>Morinda umbellata</i> L.	3.8 to 4.2
<i>Matayba inelegans</i> Radlk.	3.5 to 4.4	<i>Morus insignis</i> Bureau	3.8 to 5.8
<i>Mauria heterophylla</i> Kunth	3.8 to 5.8	<i>Mosla dianthera</i> (Buch.-Ham. ex Roxb.) Maxim.	6.4 to 6.7
<i>Maytenus macrocarpa</i> (Ruiz & Pav.) Briq.	3.8 to 5.8	<i>Musanga cecropioides</i> R.Br. ex Tedlie	5.1 to 5.4
<i>Mazus japonicus</i> (Thunb.) Kuntze	6.4 to 6.7	<i>Myrcia</i> sp.	3.5 to 4.3
<i>Melastoma malabathricum</i> L.	3.8 to 4.7	<i>Myrcia splendens</i> (Sw.) DC.	3.4 to 4.3
<i>Meliosma rhoifolia</i> Maxim.	3 to 5.6	<i>Myrcianthes</i> sp.	3.8 to 5.8
<i>Meliosma squamulata</i> Hance	3 to 4.1	<i>Myrciaria dubia</i> (Kunth) McVaugh	3.4 to 4.3
<i>Memecylon</i> sp.	4.9 to 5.3	<i>Myrica rubra</i> (Lour.) Siebold & Zucc.	3 to 5.6
<i>Meriania franciscana</i> C. Ulloa & Homeier [#]	3.8 to 5.8	<i>Myrsine coriacea</i> (Sw.) R.Br. ex Roem. & Schult.	3.5 to 4.3
<i>Meriania hexamera</i> Sprague	3.8 to 5.8	<i>Myrsine seguinii</i> H. Lév.	3 to 4.1
<i>Meriania rigida</i> (Benth.) Triana	3.5 to 4.3	<i>Myrsine semiserrata</i> Wall.	6.6 to 8.2
<i>Mesophlebion falcatilobum</i> Holttum [#]	3.7 to 4.1	<i>Nectandra cissiflora</i> Nees	3.4 to 4.3
<i>Miconia calophylla</i> (D. Don) Triana	3.5 to 4.3	<i>Nectandra cuspidata</i> Nees & Mart.	3.4 to 5.8
<i>Miconia capitellata</i> Cogn.	3.5 to 4.3	<i>Nectandra lineatifolia</i> (Ruiz & Pav.) Mez	3.8 to 5.8
<i>Miconia crebrillata</i> Wurdack	3.8 to 5.8	<i>Nectandra subbullata</i> Rohwer	3.8 to 5.8
<i>Miconia cuspidata</i> Mart. ex Naudin	3.4 to 4.3	<i>Neea</i> sp.	3.8 to 5.8
<i>Miconia dispar</i> Benth.	3.4 to 4.3	<i>Neolitsea aciculata</i> (Blume) Koidz.	3 to 4.1
<i>Miconia elaeagnoides</i> Cogn.	3.4 to 4.3	<i>Neolitsea hiiranensis</i> Tang S. Liu & J.C. Liao	4.1 to 4.7
<i>Miconia holosericea</i> (L.) DC.	3.4 to 4.3	<i>Nepenthes gracilis</i> Korth. [#]	3.8 to 4.2
<i>Miconia jahnii</i> Pittier	3.5 to 4.3	<i>Nepenthes rafflesiana</i> Jack [#]	3.8 to 4.2
<i>Miconia punctata</i> (Desr.) D. Don ex DC.	3.8 to 5.8	<i>Nephrolepis hirsutula</i> (G. Forst.) C. Presl	4.9 to 5.5
<i>Miconia pyrifolia</i> Naudin	3.4 to 4.3	<i>Ocotea aciphylla</i> (Nees & Mart.) Mez	3.7 to 4.4
<i>Miconia quadripora</i> Wurdack	3.8 to 5.8	<i>Ocotea benthamiana</i> Mez	3.7 to 4.4
<i>Miconia tetrasperma</i> Gleason	3.4 to 4.3	<i>Ocotea guianensis</i> Aubl.	3.4 to 4.3
<i>Miconia theizans</i> (Bonpl.) Cogn.	3.8 to 5.8	<i>Ocotea oblongo-obovata</i> (Nees) Rohwer	3.8 to 5.8
<i>Miconia tinifolia</i> Naudin	3.5 to 4.3	<i>Oldenlandia cristata</i> (Willd. ex Roem. & Schult.) ined.	3.8 to 4.2
<i>Microgramma percussa</i> (Cav.) de la Sota	5.9 to 6.4	<i>Omphalocarpum</i> sp.	5.1 to 5.8
<i>Microgramma piloselloides</i> (L.) Copel.	5.9 to 6.4	<i>Oplismenus undulatifolius</i> (Ard.) Roem. & Schult.	5.4 to 6.7
<i>Micropholis guyanensis</i> (A.DC.) Pierre	3.5 to 5.8	<i>Oreocnide pedunculata</i> (Shirai) Masam.	3.7 to 5.6
<i>Micropholis venulosa</i> (Mart. & Eichler ex Miq.) Pierre	3.4 to 4.3	<i>Oreopanax confusum</i> Marchal	3.8 to 5.8
<i>Microtropis japonica</i> (Franch. & Sav.) Hallier f.	4.1 to 4.7	<i>Oreopanax microflorus</i> Borchs.	3.8 to 5.8
<i>Minuartia guianensis</i> Aubl.	3.4 to 4.3	<i>Orites excelsa</i> R.Br. [#]	4.5 to 7
<i>Molineria latifolia</i> (Dryand. ex W.T.Aiton) Herb. ex Kurz	3.7 to 4.1	<i>Ormosia arborea</i> (Vell.) Harms	3.4 to 4.3
<i>Monodora tenuifolia</i> Benth.	4.9 to 5.3	<i>Osmanthus marginatus</i> (Champ. ex Benth.) Hemsl.	4.1 to 4.7
<i>Monstera adansonii</i> Schott	5.9 to 6.4	<i>Osmanthus matsumuranus</i> Hayata	3 to 3.7

Supporting information

Species	pH range	Species	pH range
<i>Ouratea discophora</i> Ducke	3.4 to 4.3	<i>Polyosma cunninghamii</i> Benn. [#]	4.5 to 7
<i>Oxalis corniculata</i> L.	5.4 to 6.7	<i>Pouteria austin-smithii</i> (Standl.) Cronquist	3.5 to 5.8
<i>Oxalis debilis</i> var. <i>corymbosa</i>	5.4 to 6.7	<i>Pouteria gardneri</i> (Mart. & Eichler ex Miq.) Baehni	3.4 to 4.3
<i>Palicourea angustifolia</i> Kunth	3.5 to 4.4	<i>Protium guianense</i> (Aubl.) Marchand	3.4 to 4.3
<i>Palicourea canarina</i> C.M.Taylor	3.8 to 5.8	<i>Protium unifoliolatum</i> Engl.	3.4 to 4.3
<i>Palicourea guianensis</i> Aubl.	3.5 to 3.8	<i>Prunopitys montana</i> (Humb. & Bonpl. ex Willd.) de Laub.	3.8 to 5.8
<i>Palicourea loxensis</i> C.M.Taylor	3.5 to 4.4	<i>Prunus africana</i> (Hook. f.) Kalkman	4.9 to 5.4
<i>Palicourea luteonivea</i> C.M.Taylor	3.8 to 5.8	<i>Prunus opaca</i> (Benth.) Walp.	3.5 to 4.3
<i>Palicourea stenosepala</i> Standl.	3.8 to 5.8	<i>Pseudolmedia macrophylla</i> Trécul	3.4 to 4.3
<i>Panda oleosa</i> Pierre	5.3 to 5.4	<i>Pseudolmedia rigida</i> (Klotzsch & H.Karst.) Cuatrec.	3.8 to 5.8
<i>Paspalum distichum</i> L.	5.4 to 6.7	<i>Psychotria asiatica</i> L.	4.1 to 4.7
<i>Paspalum scrobiculatum</i> L.	3.8 to 4.2	<i>Psychotria montivaga</i> C.M.Taylor	3.8 to 5.8
<i>Paspalum thunbergii</i> Kunth ex Steud.	6.4 to 6.7	<i>Ptyssiglottis psychotriifolia</i> (Stapf) B.Hansen [#]	3.7 to 4.1
<i>Pera coccinea</i> (Benth.) Müll.Arg.	3.4 to 4.3	<i>Purdiaea nutans</i> Planch.	3.7 to 4.4
<i>Persea areolatocostae</i> (C.K.Allen) van der Werff	3.7 to 4.4	<i>Pycnanthus angolensis</i> (Welw.) Warb.	5.1 to 5.8
<i>Persea ruizii</i> J.F.Macbr.	3.7 to 4.4	<i>Pyrenaria microcarpa</i> var. <i>microcarpa</i>	3 to 4.1
<i>Persea subcordata</i> (Ruiz & Pav.) Nees	3.7 to 4.4	<i>Quercus championii</i> Benth.	4.1 to 4.7
<i>Persea weberbaueri</i> Mez	3.7 to 4.4	<i>Quercus glauca</i> Thunb.	3 to 5.6
<i>Philodendron acuminatissimum</i> Engl.	5.9 to 6.4	<i>Quercus lanata</i> Sm.	6.6 to 8.2
<i>Philodendron hederaceum</i> (Jacq.) Schott	5.9 to 6.4	<i>Quercus longinux</i> Hayata	3 to 5.6
<i>Philodendron subhastatum</i> K.Krause	5.9 to 6.4	<i>Quercus pachyloma</i> Seemen	4.1 to 4.7
<i>Phyllanthus urinaria</i> L.	6.4 to 6.7	<i>Quercus semecarpifolia</i> Sm.	6.6 to 8.2
<i>Physalis angulata</i> var. <i>angulata</i>	6.4 to 6.7	<i>Quercus sessilifolia</i> Blume	3 to 4.1
<i>Pilea umbrosa</i> Blume	6.6 to 8.2	<i>Quiina yatuensis</i> J.V.Schneid. & Zizka	3.8 to 5.8
<i>Piper arboreum</i> Aubl.	3.8 to 5.8	<i>Rapanea capitellata</i> (Wall.) Mez	6.6 to 8.2
<i>Piper obliquum</i> Ruiz & Pav.	3.8 to 5.8	<i>Rhaphiolepis indica</i> var. <i>hiiranensis</i>	4.2 to 4.7
<i>Piper obtusilimum</i> C. DC.	3.8 to 5.8	<i>Rhaptopetalum</i> sp.	4.9 to 5.4
<i>Piper perareolatum</i> C. DC.	3.8 to 5.8	<i>Rhodamnia cinerea</i> Jack	3.8 to 4.2
<i>Piptocomia discolor</i> (Kunth) Pruski	3.7 to 5.8	<i>Rhododendron arboreum</i> Sm.	6.6 to 8.2
<i>Pittosporum</i> sp.	5.3 to 5.4	<i>Rhododendron latoucheae</i> Franch.	3 to 4.1
<i>Plagiostachys albiflora</i> Ridl.	3.7 to 4.1	<i>Rhodomyrtus tomentosa</i> (Aiton) Hassk.	3.8 to 4.2
<i>Plagiostachys strobilifera</i> (Baker) Ridl.	3.7 to 4.6	<i>Richeria grandis</i> Vahl	3.8 to 5.8
<i>Plantago major</i> L.	6.4 to 6.7	<i>Rinorea oblongifolia</i> (C.H.Wright) C.Marquand ex Chipp	5.1 to 5.3
<i>Pleopeltis bombycina</i> (Maxon) A.R. Sm.	5.9 to 6.4	<i>Rorippa indica</i> (L.) Hiern	6.4 to 6.7
<i>Ploiarium alternifolium</i> (Vahl) Melch.	3.8 to 4.2	<i>Rothmannia</i> sp.	5.1 to 5.8
<i>Podocarpus oleifolius</i> D.Don	3.5 to 4.3	<i>Ruagea glabra</i> Triana & Planch.	3.8 to 5.8
<i>Podocarpus rumphii</i> Blume	4.1 to 4.7		

Appendix S2.4

Species	pH range	Species	pH range
<i>Rubus biflorus</i> Buch.-Ham. ex Sm.	6.6 to 8.2	<i>Sorindeia</i> sp.	5.1 to 5.4
<i>Rudgea hospes</i> Standl. & Steyerl.	3.5 to 5.8	<i>Sphaerostephanos hirsutus</i> Holttum [#]	4.8 to 7.2
<i>Sacoglottis mattogrossensis</i> Malme	3.4 to 4.3	<i>Stachyphrynium borneense</i> Ridl.	4 to 4.1
<i>Sapium glandulosum</i> (L.) Morong	3.8 to 5.8	<i>Staurogyne jaheri</i> Bremek. [#]	3.7 to 4.1
<i>Saurauia tristyla</i> DC.	3.7 to 5.6	<i>Stilpnophyllum oellgaardii</i> L.Andersson	3.5 to 4.4
<i>Schefflera angulata</i> (Pav.) Harms	3.7 to 4.3	<i>Strobilanthes urticifolia</i> Wall. ex Kuntze	6.6 to 8.2
<i>Schefflera heptaphylla</i> (L.) Frodin	3.6 to 5.6	<i>Strobilanthes wallichii</i> Nees	6.6 to 8.2
<i>Schima superba</i> Gardner & Champ.	4.1 to 4.7	<i>Strombosia grandifolia</i> Hook.f. ex Benth.	5.1 to 5.4
<i>Schima wallichii</i> Choisy	3.8 to 4.2	<i>Strombosia pustulata</i> Oliv.	5.1 to 5.7
<i>Schismatoglottis calyptrata</i> (Roxb.) Zoll. & Moritzi	3.7 to 4.1	<i>Strombosia scheffleri</i> Engl.	5.1 to 5.3
<i>Schismatoglottis monoplacenta</i> M.Hotta	3.7 to 4.1	<i>Strombosiopsis tetrandra</i> Engl.	5.1 to 5.4
<i>Schlegelia darienensis</i> Sandwith	5.9 to 6.4	<i>Styphelia malayana</i> J.J.Sm. [#]	3.8 to 4.2
<i>Scindapsus pictus</i> Hassk.	4 to 4.1	<i>Styrax suberifolius</i> Hook. & Arn.	3.6 to 5.6
<i>Scleria biflora</i> Roxb.	3.8 to 4.2	<i>Styrax trichostemon</i> P.W.Fritsch [#]	3.5 to 4.4
<i>Sclerobium paniculatum</i> Vogel	3.5 to 3.8	<i>Symphonia globulifera</i> L.f.	5.1 to 5.7
<i>Scoparia dulcis</i> L.	6.4 to 6.7	<i>Symplocos bogotensis</i> Brand	3.5 to 4.4
<i>Selaginella delicatula</i> (Desv. ex Poir.) Alston	4.5 to 5.5	<i>Symplocos cochinchinensis</i> var. <i>laurina</i>	3.1 to 5.6
<i>Selinum wallichianum</i> (DC.) Raizada & H.O. Saxena	6.6 to 8.2	<i>Symplocos fuscata</i> B. Ståhl	3.5 to 4.4
<i>Sericanthe</i> sp.	5.3 to 5.4	<i>Symplocos lucida</i> (Thunb.) Siebold & Zucc.	3 to 4.1
<i>Setaria viridis</i> (L.) P.Beauv.	5.4 to 6.7	<i>Symplocos sumuntia</i> Buch.-Ham. ex D. Don	3 to 4.1
<i>Shorea gibbosa</i> Brandis [#]	4.2 to 4.5	<i>Symplocos wikstroemifolia</i> Hayata	3 to 4.1
<i>Shorea hopeifolia</i> (F.Heim) Symington [#]	4.2 to 4.5	<i>Syngonium crassifolium</i> (Engl.) Croat	5.9 to 6.4
<i>Shorea laevis</i> Ridl. [#]	4.2 to 4.5	<i>Synotis wallichii</i> (DC.) C.Jeffrey & Y.L.Chen	6.6 to 8.2
<i>Shorea lamellata</i> Foxw. [#]	4.2 to 4.5	<i>Synsepalum</i> sp.	5.1 to 5.7
<i>Shorea pauciflora</i> King [#]	4.2 to 4.5	<i>Syzygium buxifolium</i> Hook. & Arn.	3 to 4.7
<i>Sida rhombifolia</i> L.	5.4 to 6.7	<i>Syzygium euphlebium</i> (Hayata) Mori	4.1 to 4.7
<i>Simarouba amara</i> Aubl.	3.4 to 4.3	<i>Tabernaemontana crassa</i> Benth.	5.1 to 5.4
<i>Simira tinctoria</i> Aubl.	3.5 to 5.8	<i>Taenitis blechnoides</i> (Willd.) Sw.	3.8 to 4.2
<i>Siparuna aspera</i> (Ruiz & Pav.) A.DC.	3.5 to 5.8	<i>Tapirira guianensis</i> Aubl.	3.4 to 5.8
<i>Siparuna guianensis</i> Aubl.	3.4 to 4.3	<i>Tectaria barberi</i> (Hook.) Copel.	3.7 to 4.1
<i>Siparuna thecaphora</i> (Poepp. & Endl.) A.DC.	3.5 to 5.8	<i>Ternstroemia cleistogama</i> Kobuski	3.5 to 4.4
<i>Siphoneugena</i> sp.	3.5 to 4.3	<i>Ternstroemia gymnanthera</i> (Wight & Arn.) Bedd.	3 to 4.1
<i>Sloanea dasycarpa</i> (Benth.) Hemsl.	4.1 to 4.7	<i>Ternstroemia jelskii</i> (Szyszyl.) Melch.	3.5 to 4.4
<i>Sloanea robusta</i> Uittien	3.4 to 4.3	<i>Thalictrum foliolosum</i> DC.	6.6 to 8.2
<i>Smilax menispermoides</i> A.DC.	6.6 to 8.2	<i>Thyrsodium spruceanum</i> Benth.	3.4 to 4.3
<i>Solanum nutans</i> Ruiz & Pav.	3.5 to 5.8	<i>Timonius flavescens</i> (Jacq.) Baker	3.8 to 4.2
<i>Sonchus arvensis</i> L.	6.4 to 6.7		

Supporting information

Species	pH range	Species	pH range
<i>Torenia concolor</i> Lindl.	6.4 to 6.7	<i>Youngia japonica</i> (L.) DC.	6.4 to 6.7
<i>Torilis scabra</i> (Thunb.) DC.	5.4 to 6.7	<i>Zanthoxylum</i> sp.	5.1 to 5.4
<i>Tovomita weddeliana</i> Planch. & Triana	3.7 to 4.3	(b) Tropical and subtropical grassland, savanna, and shrubland	
<i>Triadica cochinchinensis</i> Lour.	4.1 to 4.7	<i>Acosmium dasycarpum</i> (Vogel) Yakovlev	4.5 to 4.9
<i>Tricalysia</i> sp.	5.4 to 5.5	<i>Acosmium subelegans</i> (Mohlenbr.) Yakovlev	4.9 to 5.3
<i>Trichilia micrantha</i> Benth.	3.4 to 4.3	<i>Aegiphila lhotzkiana</i> Cham.	4.7 to 4.8
<i>Trichomanes singaporianum</i> Alderw. #	3.7 to 4.6	<i>Allagoptera campestris</i> (Mart.) Kuntze	4.9 to 5.3
<i>Tridesmostemon omphalocarpoides</i> Engl.	5.1 to 5.8	<i>Allagoptera leucocalyx</i> (Drude) Kuntze	4.7 to 4.9
<i>Trilepisium madagascariense</i> DC.	5.3 to 5.4	<i>Anacardium humile</i> A.St.-Hil.	4.7 to 4.9
<i>Tristaniopsis obovata</i> (Benn.) Peter G. Wilson & J.T. Waterh.	3.8 to 4.2	<i>Anadenanthera peregrina</i> (L.) Speg.	4.5 to 6.1
<i>Trochodendron aralioides</i> Siebold & Zucc.	3 to 4.1	<i>Andira laurifolia</i> Benth.	5 to 5.3
<i>Turpinia formosana</i> Nakai	3.7 to 5.6	<i>Andropogon leucostachyus</i> Kunth	5 to 5.3
<i>Turpinia occidentalis</i> (Sw.) G. Don	3.5 to 5.8	<i>Annona crassiflora</i> Mart.	4.5 to 5.1
<i>Uvariadendron connivens</i> (Benth.) R.E. Fr.	4.9 to 5.7	<i>Annona warmingiana</i> Mello-Silva & Pirani	4.9 to 5.1
<i>Uvariadendron</i> sp.	4.9 to 5.3	<i>Anthraenantiaopsis perforata</i> (Nees) Parodi	4.9 to 5.1
<i>Uvariopsis congolana</i> (De Wild.) R.E. Fr.	4.9 to 5.3	<i>Aspidosperma parvifolium</i> A. DC.	4.5 to 6.1
<i>Vatica</i> sp.	4.2 to 4.5	<i>Aspilia leucoglossa</i> Malme	4.9 to 5.1
<i>Viburnum oliganthum</i> Batalin	3.8 to 5.8	<i>Axonopus comans</i> (Döll) Kuhl.	4.7 to 5.3
<i>Viola arcuata</i> Blume	6.4 to 6.7	<i>Axonopus pressus</i> (Steud.) Parodi	4.9 to 5.3
<i>Virola sebifera</i> Aubl.	3.4 to 4.3	<i>Bauhinia rufa</i> (Bong.) Steud.	4.5 to 4.7
<i>Viscum articulatum</i> Burm. f.	3.8 to 4.2	<i>Brachiaria decumbens</i> Stapf	5 to 5.3
<i>Vismia japurensis</i> Rchb.f.	3.4 to 4.3	<i>Byrsonima coccolobifolia</i> Kunth	4.5 to 4.8
<i>Vismia tomentosa</i> Ruiz & Pav.	3.8 to 5.8	<i>Byrsonima guillemiana</i> A. Juss.	4.9 to 5.1
<i>Vochysia ferruginea</i> Mart.	3.4 to 4.3	<i>Byttneria oblongata</i> Pohl	4.9 to 5.3
<i>Weinmannia elliptica</i> Kunth	3.7 to 4.4	<i>Campomanesia pubescens</i> (Mart. ex DC.) O. Berg	4.5 to 5.1
<i>Weinmannia fagaroides</i> Kunth	3.7 to 4.4	<i>Camptosema ellipticum</i> (Desv.) Burkart	4.9 to 5.1
<i>Weinmannia haenkeana</i> Engl.	3.7 to 4.4	<i>Caryocar brasiliense</i> A. St.-Hil.	4.5 to 4.8
<i>Weinmannia magnifolia</i> Cuatrec.	3.7 to 4.4	<i>Casearia sylvestris</i> Sw.	4.5 to 4.8
<i>Weinmannia ovata</i> Cav.	3.7 to 4.4	<i>Chresta sphaerocephala</i> DC.	4.7 to 4.9
<i>Weinmannia pinnata</i> L.	3.7 to 4.4	<i>Chromolaena squalida</i> (DC.) R.M. King & H. Rob.	4.7 to 4.9
<i>Weinmannia spruceana</i> Engl.	3.8 to 5.8	<i>Coccocypselum lymansmithii</i> Standl.	4.7 to 5.3
<i>Wendlandia formosana</i> Cowan	3.6 to 5.6	<i>Copaifera langsdorffii</i> Desf.	4.5 to 6.1
<i>Xanthium sibiricum</i> Patr. ex Widder	6.4 to 6.7	<i>Croton antisiphiliticus</i> Mart.	4.9 to 5.1
<i>Xylopia amazonica</i> R.E. Fr.	3.4 to 4.3	<i>Croton glandulosus</i> L.	4.7 to 5.3
<i>Xylopia benthamii</i> R.E. Fr.	3.4 to 4.3	<i>Cuphea carthagenensis</i> (Jacq.) J.F. Macbr.	4.9 to 5.1
<i>Xylopia frutescens</i> Aubl.	3.4 to 4.3		

Appendix S2.4

Species	pH range	Species	pH range
<i>Davilla elliptica</i> A.St.-Hil.	4.5 to 5.1	<i>Kielmeyera coriacea</i> Mart. & Zucc.	4.5 to 4.8
<i>Dimorphandra mollis</i> Benth.	4.5 to 4.9	<i>Lafoensia pacari</i> A.St.-Hil. [#]	4.5 to 4.7
<i>Diospyros hispida</i> A.DC.	4.5 to 5.1	<i>Lessingianthus bardanoides</i> (Less.) H.Rob.	4.7 to 4.9
<i>Drosera communis</i> A.St.-Hil.	4.7 to 5.3	<i>Luehea grandiflora</i> Mart.	4.5 to 6.1
<i>Duguetia furfuracea</i> (A.St.-Hil.) Saff.	4.7 to 4.9	<i>Lycopodiella cernua</i> (L.) Pic. Serm.	4.7 to 5.3
<i>Elionurus muticus</i> (Spreng.) Kuntze	4.7 to 5.3	<i>Machaerium acutifolium</i> Vogel	4.5 to 4.9
<i>Eragrostis articulata</i> (Schrank) Nees	4.9 to 5.1	<i>Manihot tripartita</i> (Spreng.) Müll.Arg.	4.7 to 4.9
<i>Eragrostis bahiensis</i> Roem. & Schult.	4.7 to 5.3	<i>Melinis repens</i> (Willd.) Zizka	4.9 to 5.1
<i>Erechtites hieracifolia</i> (L.) Raf.	5 to 5.3	<i>Miconia albicans</i> (Sw.) Steud.	4.5 to 4.7
<i>Eremanthus erythropappus</i> (DC.) MacLeish	4.5 to 4.9	<i>Miconia ferruginata</i> DC. [#]	4.5 to 4.8
<i>Eriosema crinitum</i> (Kunth) G.Don	4.9 to 5.1	<i>Mimosa amnis-atrici</i> Barneby [#]	4.5 to 4.9
<i>Eriosema longifolium</i> Benth.	4.9 to 5.1	<i>Mimosa gracilis</i> Benth.	4.9 to 5.1
<i>Eriotheca gracilipes</i> (K.Schum.) A.Robyns	4.5 to 4.8	<i>Myrcia tomentosa</i> (Aubl.) DC.	4.9 to 5.3
<i>Eriotheca pubescens</i> (Mart. & Zucc.) Schott & Endl.	4.5 to 4.8	<i>Myrcia uberavensis</i> O.Berg	4.9 to 5.3
<i>Erythroxylum campestre</i> A.St.-Hil.	4.5 to 4.9	<i>Ocimum</i> sp.	4.9 to 5.3
<i>Erythroxylum deciduum</i> A.St.-Hil.	4.9 to 5.1	<i>Ouratea acuminata</i> (DC.) Engl.	4.5 to 4.9
<i>Erythroxylum suberosum</i> A.St.-Hil.	4.5 to 5.1	<i>Ouratea nana</i> (A. St.-Hil.) Engl.	4.9 to 5.1
<i>Eugenia angustissima</i> O.Berg	4.9 to 5.1	<i>Ouratea spectabilis</i> (Mart. ex Engl.) Engl.	4.5 to 5.1
<i>Eugenia calycina</i> Cambess.	4.9 to 5.1	<i>Palicourea rigida</i> Kunth	4.5 to 4.9
<i>Eugenia complicata</i> O.Berg	5 to 5.3	<i>Panicum parvifolium</i> Lam.	5 to 5.3
<i>Eugenia livida</i> O.Berg	4.5 to 5.3	<i>Panicum rudgei</i> Roem. & Schult.	4.9 to 5.3
<i>Eugenia puniceifolia</i> (Kunth) DC.	4.5 to 4.8	<i>Paspalum dedeccae</i> Quarín	4.7 to 5.3
<i>Eugenia stictopetala</i> DC.	4.7 to 4.9	<i>Paspalum maculosum</i> Trin.	4.7 to 5.3
<i>Festuca subverticillata</i> (Pers.) E.B.Alexeev	4.7 to 5.3	<i>Paspalum pectinatum</i> Nees	4.9 to 5.1
<i>Froelichia procera</i> (Seub.) Pedersen	4.9 to 5.1	<i>Peltaea edouardii</i> (Hochr.) Krapov. & Cristobal	4.9 to 5.1
<i>Galactia decumbens</i> Hoehne	4.9 to 5.1	<i>Peltophorum dubium</i> (Spreng.) Taub.	4.5 to 6.1
<i>Galactia martii</i> DC.	4.9 to 5.3	<i>Phyllanthus niruri</i> L.	4.7 to 5.3
<i>Gaylussacia brasiliensis</i> (Spreng.) Meisn.	4.7 to 5.3	<i>Piptocarpha rotundifolia</i> (Less.) Baker	4.5 to 4.9
<i>Himatanthus obovatus</i> (Müll.Arg.) Woodson	4.7 to 4.8	<i>Platycyamus regnellii</i> Benth.	4.5 to 6.1
<i>Hovenia dulcis</i> Thunb.	4.5 to 6.1	<i>Pouteria ramiflora</i> (Mart.) Radlk.	4.5 to 4.9
<i>Hymenaea courbaril</i> L.	4.5 to 6.1	<i>Pouteria torta</i> (Mart.) Radlk.	4.5 to 4.9
<i>Hypoxis</i> sp.	4.7 to 5.3	<i>Pradosia brevipes</i> (Pierre) T.D.Penn.	4.9 to 5.1
<i>Hyptis adpressa</i> A.St.-Hil. ex Benth.	4.9 to 5.1	<i>Psidium australe</i> Cambess.	4.9 to 5.3
<i>Hyptis pulchella</i> Briq.	4.7 to 5.3	<i>Psidium grandifolium</i> Mart. ex DC.	4.9 to 5.1
<i>Hyptis villosa</i> Pohl ex Benth.	4.9 to 5.1	<i>Psidium laruotteanum</i> Cambess.	4.5 to 5.1
<i>Jacaranda mimosifolia</i> D.Don	4.5 to 6.1	<i>Psidium rufum</i> Mart. ex DC.	4.9 to 5.1
		<i>Qualea grandiflora</i> Mart.	4.5 to 4.8

Supporting information

Species	pH range	Species	pH range
<i>Qualea parviflora</i> Mart.	4.7 to 4.8	<i>Conocarpus erectus</i> L.	4.1 to 7.1
<i>Rhynchospora globosa</i> (Kunth) Roem. & Schult.	4.7 to 5.3	<i>Derris trifoliata</i> Lour.	4.1 to 6.5
<i>Rhynchospora leucostachys</i> Boeckeler	4.7 to 5.3	<i>Halimodendron halodendron</i> (Pall.) Voss	4.1 to 7.1
<i>Roupala montana</i> Aubl.	4.5 to 4.7	<i>Heritiera littoralis</i> Aiton	3.6 to 7.1
<i>Rourea induta</i> var. <i>induta</i> [#]	4.5 to 5.1	<i>Nypa fruticans</i> Wurmb	3.4 to 7.1
<i>Salacia micrantha</i> (Mart. ex Schult.) G. Don	4.9 to 5.3	<i>Pandanus candelabrum</i> P.Beauv.	3.4 to 7.1
<i>Schinus terebinthifolia</i> Raddi	4.5 to 6.1	<i>Pandanus odorifer</i> (Forssk.) Kuntze	4.1 to 7.1
<i>Schizachyrium tenerum</i> Nees	4.7 to 5.3	<i>Phoenix reclinata</i> Jacq.	3.9 to 7.1
<i>Sclerolobium</i> sp.	4.5 to 4.7	<i>Raphia hookeri</i> G.Mann & H.Wendl.	3.6 to 7.1
<i>Senna macranthera</i> (Collad.) H.S.Irwin & Barneby	4.5 to 6.1	<i>Rhizophora apiculata</i> Blume	3.4 to 7.2
<i>Senna multijuga</i> (Rich.) H.S.Irwin & Barneby	4.5 to 6.1	<i>Rhizophora harrisonii</i> Leechm.	3.4 to 7.1
<i>Serjania cissooides</i> Radlk. [#]	4.9 to 5.1	<i>Rhizophora mangle</i> L.	3.6 to 6.9
<i>Sisyrinchium vaginatum</i> Spreng.	4.7 to 5.3	<i>Rhizophora mucronata</i> Lam.	4.1 to 7.1
<i>Solanum lycocarpum</i> A. St.-Hil.	4.5 to 4.9	<i>Rhizophora racemosa</i> G.Mey.	3.9 to 6.9
<i>Stachytarpheta linearis</i> Moldenke	4.7 to 5.3	<i>Salsola pellucida</i> Litv.	3.4 to 7
<i>Stryphnodendron adstringens</i> (Mart.) Coville	4.5 to 4.9	<i>Sonneratia alba</i> Sm.	4.3 to 7.1
<i>Syagrus flexuosa</i> (Mart.) Becc.	4.9 to 5.1	<i>Taraxacum mongolicum</i> Hand.-Mazz.	3.6 to 6
<i>Tabebuia aurea</i> (Silva Manso) Benth. & Hook.f. ex S.Moore	4.5 to 4.8	(d) Tropical and subtropical dry broadleaf forest	
<i>Tabebuia ochracea</i> A.H. Gentry	4.5 to 5.1	<i>Acacia gaumeri</i> S.F.Blake	6.9 to 7.3
<i>Tetrapollinia caeruleascens</i> (Aubl.) Maguire & B.M.Boom	4.7 to 5.3	<i>Acacia polyphylla</i> DC.	5.5 to 6.5
<i>Trachypogon</i> sp.	4.7 to 5.3	<i>Adelia oaxacana</i> (Müll.Arg.) Hemsl.	7 to 7.3
<i>Trema micrantha</i> (L.) Blume	4.5 to 6.1	<i>Aegiphila sellowiana</i> Cham.	5.5 to 6.5
<i>Tristachya leiostachya</i> Nees	4.9 to 5.1	<i>Albizia niopoides</i> (Benth.) Burkart	5.5 to 6.5
<i>Waltheria communis</i> A.St.-Hil.	4.9 to 5.1	<i>Aloysia virgata</i> (Ruiz & Pav.) Juss.	5.5 to 6.5
<i>Wedelia macedoi</i> H.Rob. [#]	4.9 to 5.1	<i>Anadenanthera colubrina</i> (Vell.) Brenan	5.5 to 6.5
<i>Xyris</i> sp.	4.7 to 5.3	<i>Apeiba tibourbou</i> Aubl.	5.5 to 6.5
(c) Mangrove		<i>Ardisia escallonioides</i> Schltld. & Cham.	6.9 to 7.1
<i>Acanthus ilicifolius</i> L.	3.4 to 7.1	<i>Aspidosperma olivaceum</i> Müll.Arg.	5.5 to 6.5
<i>Acrostichum speciosum</i> (Fée) C. Presl	4.1 to 7.1	<i>Aspidosperma subincanum</i> Mart. ex A.DC.	5.5 to 6.5
<i>Avicennia germinans</i> (L.) L.	3.9 to 6.9	<i>Astrocasia tremula</i> (Griseb.) G.L.Webster	6.9 to 7.5
<i>Avicennia marina</i> (Forssk.) Vierh.	4.1 to 6.9	<i>Astronium fraxinifolium</i> Schott	5.5 to 6.5
<i>Bassia prostrata</i> (L.) Beck	3.6 to 6	<i>Attalea phalerata</i> Mart. ex Spreng.	5.5 to 6.5
<i>Bruguiera gymnorhiza</i> (L.) Lam.	4.3 to 7.2	<i>Bauhinia divaricata</i> L.	6.9 to 7.3
<i>Bruguiera parviflora</i> (Roxb.) Wight & Arn. ex Griff.	4.1 to 7.1	<i>Bauhinia unguolata</i> L.	5.5 to 6.5
<i>Ceriops tagal</i> (Perr.) C.B.Rob.	3.4 to 7.2	<i>Bourreria pulchra</i> (Millsp.) Millsp. ex Green.	6.9 to 7.6
		<i>Brosimum alicastrum</i> Sw.	6.9 to 8.5

Appendix S2.4

Species	pH range	Species	pH range
<i>Bunchosia swartziana</i> Griseb.	6.9 to 7.6	<i>Eugenia bimarginata</i> DC.	5.5 to 6.5
<i>Bursera schlechtendalii</i> Engl.	7 to 7.3	<i>Eugenia buxifolia</i> Lam.	6.9 to 7.6
<i>Bursera simaruba</i> (L.) Sarg.	6.9 to 7.6	<i>Eugenia florida</i> DC.	5.5 to 6.5
<i>Caesalpinia gaumeri</i> Greenm.	6.9 to 7.3	<i>Eugenia moraviana</i> O.Berg	5.5 to 6.5
<i>Caesalpinia velutina</i> (Britton & Rose) Standl.	6.9 to 7.2	<i>Eupatorium</i> sp.	5.5 to 6.5
<i>Campomanesia velutina</i> (Cambess.) O.Berg	5.5 to 6.5	<i>Exostema caribaeum</i> (Jacq.) Schult.	6.9 to 7.6
<i>Casearia corymbosa</i> Kunth	7 to 7.3	<i>Ficus</i> sp.	6.9 to 7.2
<i>Casearia gossypiosperma</i> Briq.	5.5 to 6.5	<i>Genipa americana</i> L.	5.5 to 6.5
<i>Casearia mariquitensis</i> Kunth	5.5 to 6.5	<i>Guarea guidonia</i> (L.) Sleumer	5.5 to 6.5
<i>Casearia sylvestris</i> Sw.	5.5 to 6.5	<i>Guarea macrophylla</i> Vahl	5.5 to 6.5
<i>Cecropia pachystachya</i> Trécul	5.5 to 6.5	<i>Guazuma ulmifolia</i> Lam.	5.5 to 6.5
<i>Cedrela fissilis</i> Vell.	5.5 to 6.5	<i>Guettarda combsii</i> Urb.	6.9 to 7
<i>Cedrela odorata</i> L.	7.3 to 8.5	<i>Guettarda elliptica</i> Sw.	7 to 7.3
<i>Celtis iguanaea</i> (Jacq.) Sarg.	5.5 to 7.5	<i>Guettarda gaumeri</i> Standl.	6.9 to 7.1
<i>Chloroleucon mangense</i> var. <i>leucospermum</i>	6.9 to 7.6	<i>Gymnanthes lucida</i> Sw.	6.9 to 7.6
<i>Chomelia ribesoides</i> Benth. ex A.Gray	5.5 to 6.5	<i>Gymnopodium floribundum</i> Rolfe	6.9 to 7.3
<i>Coccoloba cozumelensis</i> Hemsl.	6.9 to 7.1	<i>Hampea trilobata</i> Standl.	6.9 to 7.1
<i>Coccoloba spicata</i> Lundell	6.9 to 7.1	<i>Handroanthus impetiginosus</i> (Mart. ex DC.) Mattos	5.5 to 6.5
<i>Cochlospermum vitifolium</i> (Willd.) Spreng.	5.7 to 7	<i>Havardia albicans</i> (Kunth) Britton & Rose	7 to 7.3
<i>Colubrina elliptica</i> (Sw.) Brizicky & W.L.Stern	7.2 to 7.3	<i>Hybanthus yucatanensis</i> Millsp.	7.5 to 7.6
<i>Colubrina greggii</i> S.Watson	7 to 7.3	<i>Hymenaea courbaril</i> L.	5.5 to 6.5
<i>Cordia alliodora</i> (Ruiz & Pav.) Oken	5.5 to 6.5	<i>Inga pinetorum</i> Pittier	5.7 to 6.3
<i>Cordia gerascanthus</i> L.	6.9 to 7.6	<i>Inga vera</i> Willd.	5.5 to 6.5
<i>Cosmocalyx spectabilis</i> Standl.	6.9 to 7.6	<i>Jacaranda jasminoides</i> (Thunb.) Sandwith	5.5 to 6.5
<i>Croton oerstedianus</i> Müll.Arg.	7.5 to 7.6	<i>Jatropha gaumeri</i> Greenm.	6.9 to 7.3
<i>Croton reflexifolius</i> Kunth	6.9 to 7.5	<i>Krugiodendron ferreum</i> (Vahl) Urb.	6.9 to 7.6
<i>Cupania vernalis</i> Cambess.	5.5 to 6.5	<i>Lonchocarpus guillemineanus</i> (Tul.) Malme	5.5 to 6.5
<i>Dialium guianense</i> (Aubl.) Sandwith	7.3 to 8.5	<i>Lonchocarpus rugosus</i> Benth.	6.9 to 7
<i>Dilodendron bipinnatum</i> Radlk.	5.5 to 6.5	<i>Lonchocarpus yucatanensis</i> Pittier	6.9 to 7.3
<i>Diospyros anisandra</i> S.F.Blake	7 to 7.6	<i>Luehea speciosa</i> Willd.	6.9 to 7.1
<i>Diospyros tetrasperma</i> Sw.	6.9 to 7.2	<i>Lysiloma latisiliquum</i> (L.) Benth.	6.9 to 7.3
<i>Diphysa carthagenensis</i> Jacq.	6.9 to 7.3	<i>Machaerium aculeatum</i> Raddi	5.5 to 6.5
<i>Drypetes lateriflora</i> (Sw.) Krug & Urb.	6.9 to 7.6	<i>Machaerium paraguariense</i> Hassl.	5.5 to 6.5
<i>Ehretia tinifolia</i> L.	7 to 7.5	<i>Machaerium stipitatum</i> (DC.) Vogel	5.5 to 6.5
<i>Erythroxylum rotundifolium</i> Lunan	6.9 to 7.2	<i>Machaerium villosum</i> Vogel	5.5 to 6.5
<i>Eugenia axillaris</i> (Sw.) Willd.	6.9 to 7.6	<i>Machaonia lindeniana</i> Baill.	7.1 to 7.2
		<i>Machura tinctoria</i> (L.) D.Don ex Steud.	5.5 to 6.5

Supporting information

Species	pH range	Species	pH range
<i>Malmea depressa</i> (Baill.) R.E. Fr.	6.9 to 7.6	<i>gaumeri</i> (Pittier) T.D.Penn.	
<i>Malpighia glabra</i> L.	7 to 7.1	<i>Spondias mombin</i> L.	6.9 to 8.5
<i>Manilkara chicle</i> (Pittier) Gilly	7.3 to 8.5	<i>Swietenia macrophylla</i> King	7.3 to 8.5
<i>Manilkara zapota</i> (L.) P.Royen	6.9 to 8.5	<i>Tabebuia ochracea</i> A.H. Gentry	5.5 to 6.5
<i>Maytenus pittieriana</i> Steyerm.	5.5 to 6.5	<i>Tabebuia rosealba</i> (Ridl.) Sandwith	5.5 to 6.5
<i>Melicoccus oliviformis</i> Kunth	6.9 to 7.6	<i>Terminalia phaeocarpa</i> Eichler [#]	5.5 to 6.5
<i>Mimosa bahamensis</i> Benth.	7 to 7.3	<i>Thouinia paucidentata</i> Radlk.	6.9 to 7.6
<i>Myracrodruon urundeuva</i> Allemão	5.5 to 6.5	<i>Trichilia catigua</i> A.Juss.	5.5 to 6.5
<i>Myrcia splendens</i> (Sw.) DC.	5.5 to 6.5	<i>Trichilia pallida</i> Sw.	5.5 to 6.5
<i>Myrcia tomentosa</i> (Aubl.) DC.	5.5 to 6.5	<i>Urera baccifera</i> (L.) Gaudich.	7.5 to 7.6
<i>Myrsine umbellata</i> Mart.	5.5 to 6.5	<i>Vitex gaumeri</i> Greenm.	6.9 to 8.5
<i>Nectandra coriacea</i> (Sw.) Griseb.	6.9 to 7.6	<i>Zanthoxylum riedelianum</i> Engl.	5.5 to 6.5
<i>Neea psychotrioides</i> Donn. Sm.	7 to 7.5	<i>Zuelania guidonia</i> (Sw.) Britton & Millsp.	6.9 to 7.6
<i>Neomillspaughia emarginata</i> (H. Gross) S.F. Blake	6.9 to 7.2	(e) Flooded grassland and savanna	
<i>Parmentiera aculeata</i> (Kunth) Seem.	7 to 7.2	<i>Bulbostylis cardiocarpoides</i> Cherm.	5.3 to 6.9
<i>Phyllanthus acuminatus</i> Vahl	5.5 to 6.5	<i>Bulbostylis coleotricha</i> (Hochst. ex A.Rich.) C.B. Clarke	5.3 to 6.9
<i>Pinus caribaea</i> var. <i>hondurensis</i>	5.7 to 6.3	<i>Cyperus compressus</i> L.	5.3 to 6.9
<i>Pinus oocarpa</i> Schiede	5.7 to 6.3	<i>Cyperus cyperoides</i> (L.) Kuntze	5.3 to 6.9
<i>Piptadenia gonoacantha</i> (Mart.) J.F. Macbr.	5.5 to 6.5	<i>Cyperus denudatus</i> L.f.	5.3 to 6.9
<i>Piscidia piscipula</i> (L.) Sarg.	6.9 to 7.6	<i>Cyperus difformis</i> L.	5.3 to 6.9
<i>Pithecellobium dulce</i> (Roxb.) Benth.	7 to 7.3	<i>Cyperus digitatus</i> subsp. <i>auricomus</i> (Sieber ex Spreng.) Kük.	5.3 to 6.9
<i>Platypodium elegans</i> Vogel	5.5 to 6.5	<i>Cyperus iria</i> L.	5.3 to 6.9
<i>Pouteria torta</i> (Mart.) Radlk.	5.5 to 6.5	<i>Cyperus papyrus</i> L.	5.3 to 6.9
<i>Protium copal</i> (Schltdl. & Cham.) Engl.	7.3 to 8.5	<i>Cyperus pectinatus</i> Vahl	5.3 to 6.9
<i>Psidium sartorianum</i> (O.Berg) Nied.	5.5 to 7.1	<i>Fuirena umbellata</i> Rottb.	5.3 to 6.9
<i>Quercus oleoides</i> Schltdl. & Cham.	5.7 to 6.3	<i>Mouriri guianensis</i> Aubl.	5.9 to 6.6
<i>Randia obcordata</i> S.Watson	7 to 7.3	<i>Pseudobombax</i> sp.	5.9 to 6.6
<i>Rhamnidium elaeocarpum</i> Reissek	5.5 to 6.5	<i>Salacia elliptica</i> (Mart.) G.Don	5.9 to 6.6
<i>Rhamnus humboldtiana</i> Willd. ex Schult.	7.1 to 7.6	<i>Trichilia catigua</i> A.Juss.	5.9 to 6.6
<i>Rollinia sylvatica</i> (A. St.-Hil.) Martius	5.5 to 6.5	<i>Triplaris americana</i> L.	5.9 to 6.6
<i>Sabal mauritiiformis</i> (H.Karst.) Griseb. & H.Wendl.	7.3 to 8.5	<i>Vitex cymosa</i> Bertero ex Spreng.	5.9 to 6.6
<i>Schizolobium parahyba</i> (Vell.) S.F. Blake	7.3 to 8.5	<i>Vochysia divergens</i> Pohl [#]	5.9 to 6.6
<i>Sebastiania tuerckheimiana</i> (Pax & K.Hoffm.) Lundell	7.3 to 8.5	(f) Desert and xeric shrubland	
<i>Semialarium mexicanum</i> (Miers) Mennega	6.9 to 7.6	<i>Abutilon angulatum</i> (Guill. & Perr.) Mast.	7 to 8
<i>Senna racemosa</i> (Mill.) H.S.Irwin & Barneby	7 to 7.3	<i>Abutilon fruticosum</i> Guill. & Perr.	6.6 to 7.5
<i>Sideroxylon foetidissimum</i> subsp.	6.9 to 7.3		

Appendix S2.4

Species	pH range	Species	pH range
<i>Abutilon pannosum</i> (G.Forst.) Schldl.	7.3 to 9.3	<i>Artemisia ordosica</i> Krasch.	7.4 to 8.6
<i>Abutilon ramosum</i> (Cav.) Guill. & Perr.	7 to 8	<i>Arthrocnemum macrostachyum</i> (Moric.) K.Koch	7.3 to 8.3
<i>Acacia cochliacantha</i> Willd.	5.1 to 6.9	<i>Asparagus natalensis</i> (Baker) J.-P.Lebrun & Stork	7 to 8
<i>Acacia constricta</i> A.Gray	5.2 to 7.5	<i>Astragalus hamosus</i> L.	6.6 to 9.4
<i>Acacia farnesiana</i> (L.) Willd.	5.1 to 6.8	<i>Atriplex barclayana</i> (Benth.) D.Dietr.	6.2 to 7.7
<i>Acacia grandicornuta</i> Gerstner	7 to 8	<i>Atriplex canescens</i> (Pursh) Nutt.	6.6 to 7
<i>Acacia robusta</i> Burch.	7 to 8	<i>Atriplex crassifolia</i> Ledeb.	7.7 to 7.9
<i>Acacia tortilis</i> (Forssk.) Hayne	6.2 to 9.3	<i>Atriplex leucoclada</i> Boiss.	7.3 to 7.7
<i>Acalypha indica</i> L.	7 to 8	<i>Atriplex polycarpa</i> (Torr.) S.Watson	6.9 to 7.3
<i>Acanthospermum hispidum</i> DC.	7 to 8	<i>Baccharis</i> sp.	5.2 to 6.4
<i>Aeluropus lagopoides</i> (L.) Thwaites	6.2 to 9.7	<i>Barleria elegans</i> S.Moore	7 to 8
<i>Aeluropus littoralis</i> (Gouan) Parl.	6.3 to 9.7	<i>Barleria prionitis</i> L.	7 to 8
<i>Aerva javanica</i> (Burm.f.) Juss. ex Schult.	6.2 to 9.4	<i>Bassia dasyphylla</i> (Fisch. & C.A.Mey.) Kuntze	7.4 to 7.6
<i>Agave cerulata</i> Trel.	6.6 to 7.7	<i>Bassia muricata</i> (L.) Asch.	7.4 to 7.7
<i>Agave deserti</i> Engelm.	6.2 to 7.7	<i>Bassia prostrata</i> (L.) Beck	7.3 to 7.6
<i>Agave kerchovei</i> Lem.	7.4 to 7.5	<i>Beaucarnea gracilis</i> Lem.	7.4 to 7.5
<i>Agave marmorata</i> Roetzl	7.2 to 7.5	<i>Bidens biternata</i> (Lour.) Merr. & Sherff	7 to 8
<i>Agave salmiana</i> Otto ex Salm-Dyck	7.2 to 7.4	<i>Bidens pilosa</i> L.	7 to 8
<i>Agave triangularis</i> Jacobi	7.2 to 7.4	<i>Blepharis ciliaris</i> (L.) B.L.Burtt	6.2 to 9.3
<i>Agriophyllum montasirii</i> El Gazzar	7.1 to 8.3	<i>Breonadia salicina</i> (Vahl) Hepper & J.R.I.Wood	7 to 8
<i>Agriophyllum squarrosum</i> (L.) Moq.	7.4 to 7.6	<i>Bridelia cathartica</i> Bertol.	7 to 8
<i>Alhagi maurorum</i> Medik.	7.2 to 8.5	<i>Buddleja</i> sp.	7.4 to 7.5
<i>Alhagi sparsifolia</i> Shap.	6.4 to 9.7	<i>Bursera fagaroides</i> (Kunth) Engl.	7.2 to 7.4
<i>Aloe vera</i> (L.) Burm.f.	6.2 to 9.3	<i>Cakile arabica</i> Velen.	7.1 to 7.9
<i>Amaranthus viridis</i> L.	6.7 to 7	<i>Calliandra eriophylla</i> Benth.	7.2 to 7.5
<i>Ambrosia camphorata</i> (Greene) W.W.Payne	6.2 to 7.7	<i>Calligonum comosum</i> L'Hér.	7.2 to 8.3
<i>Ambrosia chenopodiifolia</i> (Benth.) W.W.Payne	6.9 to 7.7	<i>Calotropis procera</i> (Aiton) Dryand.	5.6 to 9.4
<i>Ambrosia deltoidea</i> (Torr.) W.W.Payne	6.6 to 8.7	<i>Caragana korshinskii</i> Kom.	7.4 to 7.6
<i>Ambrosia dumosa</i> (A.Gray) W.W.Payne	7.6 to 8.6	<i>Caralluma penicillata</i> (Deflers) N.E.Br.	7.3 to 9.3
<i>Anabasis articulata</i> (Forssk.) Moq.	6.6 to 9.4	<i>Cardiospermum halicacabum</i> L.	7 to 8
<i>Anabasis setifera</i> Moq.	7.3 to 7.5	<i>Carnegiea gigantea</i> (Engelm.) Britton & Rose	6.6 to 8.7
<i>Anthemis melampodina</i> Delile	7.1 to 7.9	<i>Carthamus oxyacanthus</i> M.Bieb.	7.4 to 7.7
<i>Apocynum venetum</i> L.	6.4 to 9.8	<i>Cassia abbreviata</i> Oliv.	7 to 8
<i>Argemone ochroleuca</i> Sweet	7 to 8	<i>Cassia italica</i> (Mill.) Lam. ex F.W.Andrews	6.2 to 8.5
<i>Aristida adscensionis</i> L.	7 to 8	<i>Cassytha filiformis</i> L.	7 to 8
<i>Arnebia hispidissima</i> (Lehm.) A.DC.	7.2 to 8.3	<i>Catharanthus roseus</i> (L.) G.Don	7 to 8
<i>Artemisia monosperma</i> Delile	6.6 to 9.2		

Supporting information

Species	pH range	Species	pH range
<i>Cenchrus ciliaris</i> L.	7.7 to 7.9	<i>Cylindropuntia cholla</i> (F.A.C.Weber) F.M.Knuth	6.6 to 7
<i>Centaurea aegyptiaca</i> L.	6.7 to 9.2	<i>Cylindropuntia molesta</i> (Brandege) F.M.Knuth	6.2 to 7.7
<i>Centaurea pallescens</i> Delile	6.7 to 9.4	<i>Cynodon dactylon</i> (L.) Pers.	7 to 9.5
<i>Centella asiatica</i> (L.) Urb.	7 to 8	<i>Cyperus conglomeratus</i> Rottb.	6.3 to 9.7
<i>Cercidium microphyllum</i> (Torr.) Rose & I.M.Johnst.	6.6 to 8.7	<i>Cyperus difformis</i> L.	8.1 to 8.5
<i>Chenopodium album</i> L.	7.4 to 7.6	<i>Cyperus rotundus</i> L.	7.7 to 9.5
<i>Chloris barbata</i> Sw.	6.7 to 7.5	<i>Cyperus sexangularis</i> Nees	7 to 8
<i>Chloris gayana</i> Kunth	7 to 8	<i>Dalea</i> sp.	7.2 to 7.4
<i>Chloris roxburghiana</i> Schult.	7 to 8	<i>Dasyliion</i> sp.	7.2 to 7.4
<i>Cissampelos mucronata</i> A.Rich.	7 to 8	<i>Desmostachya bipinnata</i> (L.) Stapf	7.7 to 9.8
<i>Cissus quadrangularis</i> L.	7.9 to 8.5	<i>Deverra tortuosa</i> DC.	6.7 to 9.4
<i>Cissus rotundifolia</i> Vahl	7 to 8	<i>Dichrostachys cinerea</i> (L.) Wight & Arn.	7 to 8
<i>Citrullus colocynthis</i> (L.) Schrad.	6.4 to 9.4	<i>Diospyros mespiliiformis</i> Hochst. ex A.DC.	7 to 8
<i>Cleistogenes songorica</i> (Roshev.) Ohwi	7.4 to 7.6	<i>Dipterygium glaucum</i> Decne.	6.2 to 9.3
<i>Cleome amblyocarpa</i> Barratte & Murb.	6.6 to 9.4	<i>Dodonaea viscosa</i> Jacq.	5.2 to 6.4
<i>Cleome monophylla</i> L.	7 to 8	<i>Echinocactus platyacanthus</i> Link & Otto	7.4 to 7.5
<i>Cleome viscosa</i> L.	7.5 to 7.8	<i>Echinocereus engelmannii</i> (Parry ex Engelm.) Lem.	6.2 to 7.7
<i>Combretum apiculatum</i> Sond.	7 to 8	<i>Echinochloa colona</i> (L.) Link	8.1 to 9.5
<i>Combretum erythrophyllum</i> (Burch.) Sond.	7 to 8	<i>Echinops polyceras</i> Boiss.	7.1 to 8.3
<i>Combretum hereroense</i> Schinz	7 to 8	<i>Echinops spinosissimus</i> Turra	6.6 to 9.4
<i>Combretum imberbe</i> Wawra	7 to 8	<i>Ehretia amoena</i> Klotzsch	7 to 8
<i>Combretum microphyllum</i> Klotzsch	7 to 8	<i>Encelia</i> sp.	6.2 to 7.7
<i>Combretum mossambicense</i> (Klotzsch) Engl.	7 to 8	<i>Ephedra aspera</i> Engelm. ex S.Watson	6.2 to 7.7
<i>Commelina diffusa</i> Burm.f.	7 to 8	<i>Eragrostis heteromera</i> Stapf	7 to 8
<i>Corchorus depressus</i> (L.) Stocks	6.2 to 9.3	<i>Eragrostis minor</i> Host	7.4 to 7.6
<i>Corchorus trilocularis</i> L.	7.2 to 7.3	<i>Eragrostis superba</i> Peyr.	7 to 8
<i>Cordia curassavica</i> (Jacq.) Roem. & Schult.	5.2 to 6.4	<i>Eremobium aegyptiacum</i> (Spreng.) Asch. ex Boiss.	7.1 to 8.3
<i>Cordia monoica</i> Roxb.	7 to 8	<i>Ericameria brachylepis</i> (A.Gray) H.M.Hall	6.2 to 7.6
<i>Coriandrum sativum</i> L.	7.3 to 7.6	<i>Eriogonum fasciculatum</i> Benth.	6.2 to 7.7
<i>Cornulaca aucheri</i> Moq.	7.1 to 7.9	<i>Eriogonum scalare</i> S.Watson	6.6 to 7
<i>Cornulaca monacantha</i> Delile	6.6 to 9.4	<i>Erodium glaucophyllum</i> (L.) L'Hér.	6.8 to 9.4
<i>Cressa cretica</i> L. [#]	6.3 to 9.7	<i>Erodium oxyrhinchum</i> subsp. <i>bryoniifolium</i> (Boiss.) Schönb.-Tem.	7.1 to 8.3
<i>Crotalaria aegyptiaca</i> Benth.	6.6 to 9.4	<i>Escontria chiotilla</i> (A.A.Weber ex K.Schum.) Rose	5.2 to 6.9
<i>Croton ciliatoglanduliferus</i> Ortega [#]	5.1 to 7.5	<i>Euclea divinorum</i> Hiern	7 to 8
<i>Cryptolepis obtusa</i> K.Schum.	7 to 8	<i>Euclea natalensis</i> A.DC.	7 to 8
<i>Cylindropuntia acanthocarpa</i> (Engelm. & J.M.Bigelow) F.M.Knuth	6.6 to 8.7		

Appendix S2.4

Species	pH range	Species	pH range
<i>Euphorbia heterophylla</i> L.	7 to 8	<i>Hyphaene coriacea</i> Gaertn.	7 to 8
<i>Euphorbia hirta</i> L.	7 to 8	<i>Ifloga spicata</i> (Forssk.) Sch.Bip.	7.4 to 8.3
<i>Euphorbia inarticulata</i> Schweinf.	6.2 to 9.3	<i>Indigofera arrecta</i> A.Rich.	7 to 8
<i>Eysenhardtia polystachya</i> (Ortega) Sarg.	5.1 to 6.8	<i>Indigofera filipes</i> Harv.	7 to 8
<i>Fagonia bruguieri</i> DC.	6.4 to 9.3	<i>Indigofera spinosa</i> Forssk.	6.2 to 9.3
<i>Fagonia indica</i> Burm.f.	6.8 to 8.3	<i>Iphiona mucronata</i> (Forssk.) Asch. & Schweinf.	6.7 to 9.2
<i>Farsetia aegyptia</i> Turra	6.6 to 9.4	<i>Ipomoea biflora</i> (L.) Pers.	7 to 8
<i>Ferocactus flavovirens</i> (Scheidw.) Britton & Rose	7.4 to 7.5	<i>Ipomoea wolcottiana</i> subsp. <i>wolcottiana</i>	7.4 to 7.5
<i>Ferocactus gracilis</i> H.E.Gates	6.2 to 7.7	<i>Jasminum fluminense</i> Vell.	7 to 8
<i>Flueggea virosa</i> (Roxb. ex Willd.) Royle	7 to 8	<i>Jatropha cuneata</i> Wiggins & Rollins	7.2 to 8.7
<i>Forestiera</i> sp.	7.4 to 7.5	<i>Juncus rigidus</i> Desf.	7.2 to 7.7
<i>Fouquieria columnaris</i> (C.Kellogg) Kellogg ex Curran	6.2 to 7.7	<i>Justicia flava</i> (Vahl) Vahl	7 to 8
<i>Fouquieria splendens</i> Engelm.	6.2 to 7.6	<i>Karelinia caspia</i> (Pall.) Less.	6.4 to 10
<i>Gardenia volkensii</i> K.Schum.	7 to 8	<i>Kochia indica</i> Wight	7.1 to 7.7
<i>Gastrocotyle hispida</i> (Forssk.) Bunge	6.7 to 9.4	<i>Krameria erecta</i> Willd. ex Schult.	6.6 to 7
<i>Glinus lotoides</i> L.	5.3 to 8.3	<i>Krameria grayi</i> Rose & Painter	6.6 to 8.7
<i>Glycyrrhiza inflata</i> Batalin	6.4 to 9.6	<i>Kraussia floribunda</i> Harv.	7 to 8
<i>Gomphrena pringlei</i> J.M.Coult. & Fisher	6.1 to 6.9	<i>Kyphocarpa angustifolia</i> (Moq.) Lopr.	7 to 8
<i>Gomphrena serrata</i> L.	6.1 to 6.9	<i>Lagenaria siceraria</i> (Molina) Standl.	7 to 8
<i>Grewia damine</i> Gaertn.	7 to 8	<i>Lamourouxia rhinanthifolia</i> Kunth	5.1 to 6.8
<i>Grewia flavescens</i> Juss.	7 to 8	<i>Lantana camara</i> L.	7 to 8
<i>Grewia villosa</i> Willd.	7 to 8	<i>Larrea tridentata</i> (Sessé & Moc. ex DC.) Coville	6.2 to 8.7
<i>Gymnosporia senegalensis</i> (Lam.) Loes.	7 to 8	<i>Launaea capitata</i> (Spreng.) Dandy	7.1 to 7.9
<i>Halimodendron halodendron</i> (Pall.) Voss	6.4 to 10	<i>Launaea mucronata</i> (Forssk.) Muschl.	7.1 to 8.3
<i>Halostachys belangeriana</i> (Moq.) Botsch.	6.4 to 9.7	<i>Leonotis nepetifolia</i> (L.) R.Br.	7 to 8
<i>Haloxylon salicornicum</i> (Moq.) Bunge ex Boiss.	7.3 to 8.3	<i>Leptadenia pyrotechnica</i> (Forssk.) Decne.	7.3 to 9.3
<i>Hechtia</i> sp.	7.2 to 7.5	<i>Leucophyllum</i> sp.	7.2 to 7.4
<i>Hedysarum scoparium</i> Fisch. & C.A.Mey.	7.4 to 7.6	<i>Limeum sulcatum</i> (Klotzsch) Hutch.	7 to 8
<i>Heliotropium arbainense</i> Fresen. #	6.2 to 9.3	<i>Lippia graveolens</i> Kunth	6.1 to 7.5
<i>Heliotropium bacciferum</i> Forssk.	6.2 to 9.3	<i>Lippia javanica</i> (Burm.f.) Spreng.	7 to 8
<i>Heliotropium luteum</i> Poir. #	6.6 to 9.4	<i>Lolium persicum</i> Boiss. & Hohen.	7.4 to 7.7
<i>Heliotropium ovalifolium</i> Forssk.	7 to 8	<i>Lophocereus schottii</i> (Engelm.) Britton & Rose	6.6 to 8.7
<i>Hexinia polydichotoma</i> (Ostenf.) H.L.Yang	6.8 to 7.8	<i>Ludwigia octovalvis</i> (Jacq.) P.H.Raven	7 to 8
<i>Hibiscus surattensis</i> L.	7 to 8	<i>Lycium pallidum</i> Miers	8.1 to 8.8
<i>Hordeum vulgare</i> L.	7.1 to 7.7	<i>Lycium ruthenicum</i> Murray	6.1 to 10.1
		<i>Lycium shawii</i> Roem. & Schult.	7.9 to 9.1
		<i>Malva parviflora</i> L.	7.3 to 7.7

Supporting information

Species	pH range	Species	pH range
<i>Melhantha forbesii</i> Planch. ex Mast.	7 to 8	<i>Phalaris minor</i> Retz.	7.4 to 7.7
<i>Melia azedarach</i> L.	7 to 8	<i>Philenoptera violacea</i> (Klotzsch) Schrire	7 to 8
<i>Mimosa aculeaticarpa</i> Ortega	5.2 to 6.4	<i>Phoenix dactylifera</i> L.	7.1 to 7.6
<i>Mimosa adenantheroides</i> (M.Martens & Galeotti) Benth.	5.1 to 6.8	<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	6.4 to 9.7
<i>Mimosa borealis</i> A.Gray	5.2 to 6.4	<i>Phragmites mauritianus</i> Kunth	7 to 8
<i>Mimosa calcicola</i> Robinson	7.4 to 7.5	<i>Phyllanthus reticulatus</i> Poir.	7 to 8
<i>Mimosa lacerata</i> Rose	7.2 to 7.4	<i>Piqueria trinervia</i> Cav.	5.2 to 6.4
<i>Mimosa luisana</i> Brandegee	6.1 to 7.5	<i>Plantago boissieri</i> Hausskn. & Bornm. #	7.1 to 8.3
<i>Mimosa polyantha</i> Benth.	6.1 to 6.9	<i>Pluchea dioscoridis</i> (L.) DC.	7 to 8
<i>Mimosa purpusii</i> Brandegee	7.2 to 7.4	<i>Plumbago zeylanica</i> L.	7 to 8
<i>Momordica balsamina</i> L.	7 to 8	<i>Plumeria rubra</i> L.	5.1 to 6.8
<i>Morkillia mexicana</i> (DC.) Rose & Painter	7.4 to 7.5	<i>Poa angustifolia</i> L.	7.4 to 7.6
<i>Myrtillocactus geometrizans</i> (Mart. ex Pfeiff.) Console	7.4 to 7.5	<i>Polygonum argyrocoleon</i> Steud. ex Kunze	7.3 to 7.8
<i>Neobuxbaumia tetetzo</i> (F.A.C.Weber ex K.Schum.) Backeb.	7.4 to 7.5	<i>Populus euphratica</i> Olivier	6.1 to 10.5
<i>Nitraria sibirica</i> Pall.	6.4 to 9.8	<i>Prosopis glandulosa</i> Torr.	6.2 to 7.6
<i>Nolina longifolia</i> (Karw. ex Schult. & Schult.f.) Hemsl.	7.2 to 7.4	<i>Prosopis juliflora</i> (Sw.) DC.	6.2 to 7.9
<i>Ochna natalitia</i> (Meisn.) Walp.	7 to 8	<i>Prosopis laevigata</i> (Willd.) M.C.Johnst.	5.1 to 6.8
<i>Ochradenus baccatus</i> Delile #	6.6 to 9.4	<i>Psammochloa villosa</i> (Trin.) Bor	7.4 to 7.6
<i>Ochthochloa compressa</i> (Forssk.) Hilu	7.7 to 7.9	<i>Pseudosmodium multifolium</i> Rose	7.4 to 7.5
<i>Oligomeris linifolia</i> (Vahl) J.F. Macbr.	7.1 to 7.8	<i>Pulicaria crispa</i> Sch.Bip.	6.6 to 9.4
<i>Olneya tesota</i> A.Gray	6.6 to 8.7	<i>Randia capitata</i> DC.	5.2 to 6.4
<i>Opuntia decumbens</i> Salm-Dyck	6.1 to 6.9	<i>Reichardia tingitana</i> (L.) Roth	6.6 to 9.4
<i>Opuntia pilifera</i> F.A.C. Weber	6.1 to 7.4	<i>Rhanterium epapposum</i> Oliv.	7.5 to 8.3
<i>Opuntia streptacantha</i> Lem.	5.1 to 6.8	<i>Ruellia patula</i> Jacq.	7 to 8
<i>Opuntia velutina</i> F.A.C. Weber	6.1 to 6.9	<i>Salsola baryosma</i> (Schult.) Dandy	7.2 to 7.7
<i>Orobancha aegyptiaca</i> Pers.	7.3 to 7.7	<i>Salsola kali</i> L.	7.4 to 9.7
<i>Pachycereus pringlei</i> (S.Watson) Britton & Rose	6.6 to 7	<i>Salsola pellucida</i> Litv.	7.4 to 9
<i>Pachycormus discolor</i> (Benth.) Coville	7.3 to 7.7	<i>Salsola schweinfurthii</i> Solms	7.2 to 8.2
<i>Panicum repens</i> L.	7.3 to 9.3	<i>Salvadora persica</i> L. #	6.2 to 9.7
<i>Panicum turgidum</i> Forssk.	6.2 to 9.3	<i>Sarcobatus vermiculatus</i> (Hook.) Torr.	9.6 to 9.7
<i>Parkinsonia praecox</i> (Ruiz & Pav.) Hawkins	7.4 to 7.5	<i>Schismus barbatus</i> (L.) Thell.	7.1 to 7.7
<i>Paspalum distichum</i> L.	8.5 to 9.5	<i>Schmidtia pappophoroides</i> Steud. ex J.A.Schmidt	7 to 8
<i>Pavetta catophylla</i> K.Schum.	7 to 8	<i>Schoenoplectiella roylei</i> (Nees) Lye	8.1 to 8.5
<i>Pavetta lanceolata</i> Eckl.	7 to 8	<i>Senecio flavus</i> (Decne.) Sch.Bip.	7.3 to 7.6
<i>Peganum harmala</i> L.	7.7 to 7.9	<i>Senecio praecox</i> (Cav.) DC.	5.2 to 6.4
<i>Penstemon</i> sp.	5.2 to 6.4	<i>Senna alexandrina</i> Mill.	7.9 to 9.1
		<i>Senna holosericea</i> (Fresen.) Greuter	7 to 7.6

Appendix S2.4

Species	pH range	Species	pH range
<i>Senna italica</i> Mill.	6.2 to 8.6	<i>Tetraena qatariensis</i> (Hadidi) Beier & Thulin. [#]	7.1 to 8.3
<i>Senna occidentalis</i> (L.) Link	7 to 8	<i>Themeda triandra</i> Forssk.	7 to 8
<i>Senna uniflora</i> (Mill.) H.S.Irwin & Barneby	5.1 to 6.8	<i>Thunbergia neglecta</i> Sond. [#]	7 to 8
<i>Sesamum alatum</i> Thonn.	7 to 8	<i>Tragus australianus</i> S.T.Blake	7 to 8
<i>Sida cordifolia</i> L.	7 to 8	<i>Trema orientalis</i> (L.) Blume	7 to 8
<i>Sida spinosa</i> L.	7 to 8	<i>Tribulus arabicus</i> Hosni [#]	7.5 to 8.3
<i>Simmondsia chinensis</i> (Link) C.K. Schneid.	6.2 to 8	<i>Tribulus terrestris</i> L.	7 to 8
<i>Solanum carolinense</i> L. [#]	7 to 8	<i>Tricholaena monachne</i> (Trin.) Stapf & C.E.Hubb.	7 to 8
<i>Solanum seaforthianum</i> Andrews	7 to 8	<i>Tridax procumbens</i> (L.) L.	7 to 8
<i>Sonchus oleraceus</i> (L.) L.	7.3 to 8.1	<i>Triumfetta bogotensis</i> DC.	7 to 8
<i>Sorghum bicolor</i> (L.) Moench	7 to 8	<i>Urochloa mosambicensis</i> (Hack.) Dandy	7 to 8
<i>Spirostachys africana</i> Sond.	7 to 8	<i>Vangueria infausta</i> Burch.	7 to 8
<i>Sporobolus ioclados</i> (Trin.) Nees	9 to 9.5	<i>Verbena litoralis</i> var. <i>brasiliensis</i>	7 to 8
<i>Sporobolus pyramidalis</i> P.Beauv.	7 to 8	<i>Vernonia glabra</i> (Steetz) Vatke	7 to 8
<i>Sporobolus spicatus</i> (Vahl) Kunth	6.2 to 9.7	<i>Vitex harveyana</i> H.Pearson	7 to 8
<i>Sporobolus virginicus</i> (L.) Kunth	6.3 to 8.7	<i>Waltheria indica</i> L.	7 to 8
<i>Stenocereus pruinosus</i> (Otto ex Pfeiff.) Buxb.	6.1 to 6.9	<i>Xanthium strumarium</i>	7 to 8
<i>Stenocereus stellatus</i> (Pfeiff.) Riccob.	5.1 to 6.8	<i>Yucca periculosa</i> Baker	7.2 to 7.4
<i>Stenocereus thurberi</i> (Engelm.) Buxb.	6.6 to 8.7	<i>Zapoteca</i> sp.	7.4 to 7.5
<i>Stipa caucasica</i> Schmalh.	7.4 to 7.6	<i>Zilla spinosa</i> (L.) Prantl [#]	6.6 to 9.4
<i>Stipa speciosa</i> Trin. & Rupr.	6.6 to 7	<i>Ziziphus spina-christi</i> (L.) Willd.	7.3 to 9.3
<i>Stipagrostis ciliata</i> (Desf.) De Winter	7.3 to 8.3	<i>Zygophyllum coccineum</i> L. [#]	6.6 to 9.4
<i>Stipagrostis plumosa</i> Munro ex T.Anderson	6.2 to 8.5	<i>Zygophyllum simplex</i> L.	6.6 to 9.4
<i>Suaeda fruticosa</i> Forssk. ex J.F.Gmel.	5.8 to 8.3		
<i>Suaeda monoica</i> Forssk. [#]	6.2 to 9.7	(g) Mediterranean forest, woodland, and scrub	
<i>Suaeda vermiculata</i> Forssk. ex J.F.Gmel.	7.1 to 7.7	<i>Aegilops neglecta</i> Req. ex Bertol.	6.5 to 6.7
<i>Tagetes minuta</i> L.	7 to 8	<i>Atractylis humilis</i> L.	8 to 8.3
<i>Tamarix aphylla</i> (L.) H.Karst.	6.3 to 9.7	<i>Aulax umbellata</i> (Thunb.) R.Br.	5.3 to 5.6
<i>Tamarix hispida</i> Willd.	6.4 to 9.7	<i>Bellis sylvestris</i> Cirillo	6.4 to 6.7
<i>Tamarix leptostachya</i> Bunge	6.4 to 10	<i>Brachypodium retusum</i> (Pers.) P.Beauv.	6.5 to 8
<i>Tamarix mannifera</i> Kotschy ex Bunge [#]	6.3 to 9.7	<i>Bromus rubens</i> L.	6.5 to 8.3
<i>Tamarix ramosissima</i> Ledeb.	6.1 to 10.5	<i>Buxus sempervirens</i> L.	7.4 to 8.5
<i>Taraxacum mongolicum</i> Hand.-Mazz.	7.7 to 8.4	<i>Calopsis hyalina</i> (Mast.) H.P.Linder	5.4 to 5.6
<i>Tecoma stans</i> (L.) Juss. ex Kunth	5.1 to 6.8	<i>Dactylis glomerata</i> L.	6.5 to 6.7
<i>Tephrosia purpurea</i> (L.) Pers.	6.2 to 9.3	<i>Echinospartum horridum</i> (M.Vahl) Rothm.	7.4 to 8.5
<i>Terminalia sericea</i> Burch. ex DC.	7 to 8	<i>Elegia verreauxii</i> Mast.	4.9 to 5.5
		<i>Erica labialis</i> Salisb.	5.4 to 5.5

Supporting information

Species	pH range	Species	pH range
<i>Erica lutea</i> P.J.Bergius	5.4 to 5.5	<i>Aegopodium podagraria</i> L.	4.5 to 6.3
<i>Genista scorpius</i> (L.) DC.	7.4 to 8.5	<i>Aesculus hippocastanum</i> L.	3.1 to 6.2
<i>Ischyrolepis leptoclados</i> (Mast.) H.P.Linder	7.7 to 7.8	<i>Ageratina altissima</i> (L.) R.M.King & H.Rob.	3.8 to 5.1
<i>Juniperus communis</i> L.	7.4 to 8.5	<i>Agrostis canina</i> L.	2.9 to 6.4
<i>Leucadendron meridianum</i> T.M.Salter ex I.Williams [#]	7.7 to 7.9	<i>Agrostis capillaris</i> L.	2.9 to 6.3
<i>Leucadendron xanthoconus</i> K. Schum.	5.4 to 5.9	<i>Agrostis curtisii</i> Kerguelen	4.2 to 5.6
<i>Linum strictum</i> L.	6.5 to 6.7	<i>Agrostis stolonifera</i> L.	3.4 to 9.4
<i>Metalasia muricata</i> (L.) D.Don	5.9 to 6.2	<i>Agrostis vinealis</i> Schreb.	4.2 to 5.8
<i>Mimetes cucullatus</i> R. Br.	4.9 to 5.5	<i>Aira praecox</i> L.	4.3 to 6
<i>Mimetes saxatilis</i> E.Phillips [#]	7.8 to 7.9	<i>Ajuga pyramidalis</i> L.	4 to 7.2
<i>Pinus sylvestris</i> L.	7.4 to 8.5	<i>Ajuga reptans</i> L.	3.1 to 6.4
<i>Populus nigra</i> L.	6.4 to 8.6	<i>Alliaria petiolata</i> (M.Bieb.) Cavara & Grande	3.1 to 8.4
<i>Populus tremula</i> L.	6.4 to 8.6	<i>Allium oleraceum</i> L.	4.5 to 5.1
<i>Protea compacta</i> R. Br.	5.4 to 5.7	<i>Allium tricoccum</i> Sol.	4.7 to 5.1
<i>Protea susanna</i> E.Phillips [#]	5.4 to 6.2	<i>Alnus glutinosa</i> (L.) Gaertn.	4.1 to 6
<i>Quercus faginea</i> Lam.	6.4 to 8.6	<i>Alnus incana</i> (L.) Moench	3.5 to 4.1
<i>Santolina chamaecyparissus</i> L.	8 to 8.3	<i>Alopecurus geniculatus</i> L.	6.2 to 9.2
<i>Senecio vulgaris</i> L.	6.5 to 6.7	<i>Alopecurus pratensis</i> L.	5.8 to 6.6
<i>Willdenowia rugosa</i> Esterh.	5.9 to 6.1	<i>Ambrosia artemisiifolia</i> L.	5.3 to 5.5
(h) Temperate broadleaf mixed forest		<i>Amelanchier arborea</i> (F. Michx.) Fernald	3.8 to 4.5
<i>Acalypha virginica</i> var. <i>rhomboidea</i>	3.9 to 4.4	<i>Amphicarpaea bracteata</i> (L.) Fernald	3.8 to 4.5
<i>Acer campestre</i> L.	3.3 to 8.7	<i>Anemone hepatica</i> L.	4.7 to 6.1
<i>Acer negundo</i> L.	5.9 to 7.8	<i>Anemone nemorosa</i> L.	3.1 to 8.7
<i>Acer pensylvanicum</i> L.	4.1 to 5.9	<i>Anemone sylvestris</i> L.	4.1 to 4.5
<i>Acer platanoides</i> L.	3.1 to 6.4	<i>Anemonella thalictroides</i> (L.) Spach	3.8 to 4.5
<i>Acer pseudoplatanus</i> L.	2.4 to 8.7	<i>Angelica sylvestris</i> L.	4.9 to 6.6
<i>Acer rubrum</i> L.	3.3 to 6.9	<i>Antennaria dioica</i> (L.) Gaertn.	3.1 to 5.8
<i>Acer saccharinum</i> L.	6.6 to 7.8	<i>Anthericum ramosum</i> L.	4 to 7.3
<i>Acer saccharum</i> Marshall	3.6 to 8.2	<i>Anthoxanthum odoratum</i> L.	2.9 to 7.2
<i>Acer saccharum</i> subsp. <i>nigrum</i> (F.Michx.) Desmarais	4.7 to 5.1	<i>Anthriscus sylvestris</i> (L.) Hoffm.	4.5 to 7.7
<i>Acer spicatum</i> Lam.	4.1 to 5.9	<i>Arabidopsis thaliana</i> (L.) Heynh.	4.2 to 5.2
<i>Achillea millefolium</i> L.	3.1 to 9.2	<i>Arabis hirsuta</i> (L.) Scop.	4.1 to 4.5
<i>Actaea racemosa</i> L.	3.8 to 4.5	<i>Aralia nudicaulis</i> L.	4.4 to 4.8
<i>Adiantum pedatum</i> L.	4.2 to 5.1	<i>Arisaema triphyllum</i> (L.) Schott	3.8 to 5.1
<i>Adoxa moschatellina</i> L.	3.1 to 8	<i>Aristolochia serpentaria</i> L.	3.8 to 4.5
<i>Aegonychon purpurea-coeruleum</i> Holub.	3.3 to 6.3	<i>Arnica montana</i> L.	3.1 to 5.9
		<i>Arrhenatherum elatius</i> (L.) P.Beauv. ex J.Presl & C.Presl.	4.8 to 7.8

Appendix S2.4

Species	pH range	Species	pH range
<i>Artemisia vulgaris</i> L.	6.2 to 9.2	<i>Calamagrostis epigeios</i> (L.) Roth	4.3 to 7.9
<i>Arthraxon hispidus</i> (Thunb.) Makino	3.9 to 4.4	<i>Calamagrostis villosa</i> (Chaix) J.F.Gmel.	3.5 to 6.2
<i>Arum cylindraceum</i> Gasp.	6.5 to 7.5	<i>Callionia canadensis</i> (L.) Greene	3.8 to 4.5
<i>Arum maculatum</i> L.	3.1 to 8.7	<i>Calluna vulgaris</i> (L.) Hull	2.9 to 5.9
<i>Asarum canadense</i> L.	4.2 to 5.1	<i>Caltha palustris</i> L.	6.7 to 8.3
<i>Asarum europaeum</i> L.	4.6 to 4.8	<i>Calystegia sepium</i> (L.) R. Br.	4.6 to 5.3
<i>Asplenium platyneuron</i> (L.) Britton, Sterns & Poggenb.	5.3 to 5.5	<i>Campanula persicifolia</i> L.	3.7 to 7.3
<i>Asplenium trichomanes</i> L.	4.7 to 8.7	<i>Campanula rapunculoides</i> L.	3.3 to 6.3
<i>Aster</i> sp.	4.7 to 5.1	<i>Campanula rotundifolia</i> L.	3.1 to 6.5
<i>Astragalus glycyphyllos</i> L.	3.7 to 4.4	<i>Campanula trachelium</i> L.	5.1 to 8.7
<i>Athyrium filix-femina</i> (L.) Roth	3.1 to 6.3	<i>Cardamine concatenata</i> (Michx.) O.Schwarz	4.7 to 5.1
<i>Atriplex patula</i> L.	6.4 to 8.9	<i>Cardamine diphylla</i> (Michx.) Alph.Wood	4.7 to 5.1
<i>Atriplex prostrata</i> Boucher ex DC.	6.1 to 9.3	<i>Cardamine flexuosa</i> With.	5.1 to 6.6
<i>Atriplex sagittata</i> Borkh.	6.2 to 9.2	<i>Cardamine maxima</i> (Nutt.) Alph.Wood	4.7 to 5.1
<i>Atropa belladonna</i> L.	5.2 to 8.4	<i>Cardamine pratensis</i> L.	3.1 to 6.6
<i>Avena sativa</i> L.	6.2 to 9.2	<i>Carex albursina</i> E.Sheld.	4.7 to 5.1
<i>Betula alleghaniensis</i> Britton	4.1 to 5.9	<i>Carex appalachica</i> J.M.Webber & P.W.Ball	4.7 to 5.1
<i>Betula lenta</i> L.	3.3 to 5.2	<i>Carex arenaria</i> L.	4.4 to 5.8
<i>Betula nigra</i> L.	6.6 to 7.8	<i>Carex brizoides</i> L.	4.3 to 4.4
<i>Betula papyrifera</i> Marshall	3.6 to 5.9	<i>Carex caryophyllea</i> Latourr.	4.3 to 5.9
<i>Betula pendula</i> Roth	3.1 to 7.9	<i>Carex communis</i> L.H.Bailey	4.7 to 5.1
<i>Betula populifolia</i> Marshall	3.4 to 4.1	<i>Carex cuprina</i> (Sándor ex Heuff.) Nendtv. ex A.Kern.	6.2 to 8.6
<i>Betula pubescens</i> Ehrh.	2.9 to 6	<i>Carex digitalis</i> Willd.	3.8 to 4.5
<i>Bidens tripartita</i> L.	6.2 to 9.2	<i>Carex digitata</i> L.	3.7 to 5.9
<i>Bolboschoenus maritimus</i> (L.) Palla	4.5 to 9.3	<i>Carex distans</i> L.	6.2 to 8.6
<i>Bossekia odorata</i> (L.) Greene	4.7 to 5.1	<i>Carex echinata</i> Murray	4.1 to 5.3
<i>Botrychium virginianum</i> (L.) Sw.	3.8 to 5.1	<i>Carex flacca</i> Schreb.	4.3 to 8
<i>Brachyelytrum erectum</i> (Schreb.) P.Beauv.	3.8 to 4.5	<i>Carex frankii</i> Kunth	3.9 to 4.4
<i>Brachypodium pinnatum</i> (L.) P.Beauv.	4 to 7.8	<i>Carex hirta</i> L.	3.7 to 6.3
<i>Brachypodium sylvaticum</i> (Huds.) P.Beauv.	3.3 to 8.4	<i>Carex hitchcockiana</i> Dewey	4.7 to 5.1
<i>Brassica napus</i> L.	6.2 to 9.2	<i>Carex hostiana</i> DC.	3.1 to 6.4
<i>Briza media</i> L.	4.3 to 5.9	<i>Carex humilis</i> Leyss.	3.7 to 4.5
<i>Bromus benekenii</i> (Lange) Trimen	3.3 to 7.3	<i>Carex laxiflora</i> Lam.	4.7 to 5.1
<i>Bromus ramosus</i> Huds.	5.2 to 8.4	<i>Carex leporina</i> L.	3.1 to 6
<i>Bromus sterilis</i> L.	5.6 to 6.5	<i>Carex montana</i> L.	3.7 to 7.3
<i>Buddleja davidii</i> Franch.	4.7 to 5.2	<i>Carex muricata</i> L.	3.5 to 7.3
<i>Calamagrostis arundinacea</i> (L.) Roth	3.3 to 6.5		

Supporting information

Species	pH range	Species	pH range
<i>Carex nigra</i> (L.) Reichard	2.5 to 6.4	<i>Chaerophyllum temulum</i> L.	3.3 to 8
<i>Carex pallescens</i> L.	4 to 6	<i>Chelidonium majus</i> L.	5.1 to 5.3
<i>Carex panicea</i> L.	3.1 to 6.4	<i>Chenopodium album</i> L.	6.2 to 9.2
<i>Carex pedunculata</i> Muhl. ex Willd.	4.7 to 5.1	<i>Chenopodium glaucum</i> L.	6.2 to 9.2
<i>Carex pendula</i> Huds.	4.9 to 8.4	<i>Chenopodium polyspermum</i> L.	4.7 to 8.4
<i>Carex pensylvanica</i> Lam.	3.4 to 4.1	<i>Chenopodium rubrum</i> L.	5.2 to 8.6
<i>Carex pilulifera</i> L.	2.9 to 7	<i>Chimaphila maculata</i> (L.) Pursh	3.8 to 4.5
<i>Carex pilulifera</i> subsp. <i>pilulifera</i>	4.1 to 6.4	<i>Chrysosplenium oppositifolium</i> L.	3.1 to 5.5
<i>Carex plantaginea</i> Lam.	4.7 to 5.1	<i>Cinna arundinacea</i> L.	3.9 to 4.4
<i>Carex platyphylla</i> J.Carey	4.7 to 5.1	<i>Circaea lutetiana</i> L.	3.1 to 8.4
<i>Carex pseudocyperus</i> L.	4.7 to 5.2	<i>Cirsium arvense</i> (L.) Scop.	5.1 to 9.3
<i>Carex remota</i> L.	3.1 to 6.3	<i>Cirsium dissectum</i> (L.) Hill	3.1 to 6.4
<i>Carex riparia</i> subsp. <i>riparia</i>	3.8 to 4.5	<i>Cirsium palustre</i> (L.) Coss. ex Scop.	4.7 to 6.4
<i>Carex spicata</i> Huds.	5.2 to 8.4	<i>Claytonia caroliniana</i> Michx.	4.7 to 5.1
<i>Carex sylvatica</i> Huds.	3.1 to 8.7	<i>Claytonia virginica</i> L.	3.8 to 4.5
<i>Carex tribuloides</i> Wahlenb.	3.9 to 4.4	<i>Clematis recta</i> L.	4.1 to 4.5
<i>Carex vulpinoidea</i> Michx.	3.9 to 4.4	<i>Clinopodium vulgare</i> L.	3.3 to 6.3
<i>Carex willdenowii</i> Willd.	3.8 to 4.5	<i>Comarum palustre</i> L.	4.7 to 6.4
<i>Carpinus betulus</i> L.	2.4 to 8	<i>Commelina communis</i> L.	3.9 to 6.4
<i>Carpinus caroliniana</i> Walter	3.8 to 5.5	<i>Conopodium majus</i> (Gouan) Loret	5.1 to 6.6
<i>Carya alba</i> (L.) Nutt. ex Elliott	4.5 to 8	<i>Convallaria majalis</i> L.	3.1 to 6.8
<i>Carya cordiformis</i> (Wangenh.) K.Koch	3.8 to 5.1	<i>Convolvulus arvensis</i> L.	6.5 to 8.9
<i>Carya glabra</i> (Mill.) Sweet	3.8 to 4.9	<i>Conyza canadensis</i> (L.) Cronquist	6.2 to 9.2
<i>Carya glabra</i> var. <i>odorata</i>	4.3 to 4.9	<i>Cornus alternifolia</i> L.f.	4.5 to 8.2
<i>Carya texana</i> Buckley	4.5 to 8	<i>Cornus florida</i> L.	3.8 to 6.1
<i>Castanea sativa</i> Mill.	3.1 to 5.5	<i>Cornus mas</i> L.	4 to 4.5
<i>Caulophyllum thalictroides</i> (L.) Michx.	4.2 to 5.1	<i>Cornus sanguinea</i> L.	3.3 to 8.7
<i>Celtis occidentalis</i> L.	6.6 to 7.8	<i>Corydalis intermedia</i> (L.) Méral	4.8 to 8
<i>Centaurea jacea</i> L.	2.9 to 5.9	<i>Corylus avellana</i> L.	3.1 to 8.7
<i>Centaurea scabiosa</i> L.	6 to 6.9	<i>Corynephorus canescens</i> (L.) P.Beauv.	4.4 to 5.8
<i>Centaurea stoebe</i> L.	6.2 to 9.2	<i>Cotoneaster integerrimus</i> Medik.	4 to 4.5
<i>Centaurium erythraea</i> Rafn	4.7 to 5.2	<i>Crataegus laevigata</i> (Poir.) DC.	2.6 to 8.7
<i>Cephalanthera damasonium</i> (Mill.) Druce	5.2 to 8.4	<i>Crataegus monogyna</i> Jacq.	3.1 to 8.7
<i>Cerastium fontanum</i> Baumg.	3.1 to 6	<i>Cunila origanoides</i> (L.) Britton	3.8 to 4.2
<i>Cerastium fontanum</i> subsp. <i>vulgare</i> (Hartm.) Greuter & Burdet.	6.2 to 9.2	<i>Cyperus strigosus</i> L.	3.9 to 4.4
<i>Cercis canadensis</i> L.	3.8 to 8.2	<i>Cystopteris bulbifera</i> (L.) Bernh.	4.7 to 5.1
<i>Chaerophyllum hirsutum</i> L.	4.9 to 5.8	<i>Cystopteris fragilis</i> (L.) Bernh.	4.7 to 5.1

Appendix S2.4

Species	pH range	Species	pH range
<i>Cytisus scoparius</i> (L.) Link	2.9 to 5.6	<i>Empetrum nigrum</i> L.	3.1 to 5.6
<i>Daboecia cantabrica</i> (Huds.) K.Koch	4.2 to 5.6	<i>Epilobium angustifolium</i> L.	3.1 to 6.3
<i>Dactylis glomerata</i> L.	2.5 to 8	<i>Epilobium hirsutum</i> L.	5.1 to 5.9
<i>Dactylorhiza maculata</i> (L.) Soó	2.9 to 6.4	<i>Epilobium montanum</i> L.	4.4 to 5.5
<i>Danthonia decumbens</i> (L.) DC.	2.9 to 6.4	<i>Epilobium palustre</i> L.	6.2 to 9.2
<i>Danthonia spicata</i> (L.) Roem. & Schult.	3.8 to 5.6	<i>Equisetum palustre</i> L.	2.9 to 6.4
<i>Daphne mezereum</i> L.	5.5 to 8.7	<i>Equisetum sylvaticum</i> L.	4.3 to 5.8
<i>Daucus carota</i> L.	4.3 to 5.9	<i>Erica tetralix</i> L.	2.9 to 6.4
<i>Demstaedtia punctilobula</i> (Michx.) T. Moore	4.7 to 5.1	<i>Eriophorum angustifolium</i> Honck.	3.1 to 5.6
<i>Deparia acrostichoides</i> (Sw.) M. Kato	4.7 to 5.1	<i>Erythronium americanum</i> Ker Gawl.	4.7 to 5.1
<i>Deschampsia cespitosa</i> (L.) P.Beauv.	2.4 to 8.9	<i>Euonymus europaeus</i> L.	4.1 to 8.7
<i>Deschampsia flexuosa</i> (L.) Trin.	2.9 to 6.3	<i>Euphorbia amygdaloides</i> L.	3.3 to 8.4
<i>Desmodium glutinosum</i> (Willd.) Alph.Wood	3.8 to 4.5	<i>Euphorbia cyparissias</i> L.	4 to 4.4
<i>Desmodium nudiflorum</i> (L.) DC.	3.8 to 4.5	<i>Eurybia divaricata</i> (L.) G.L.Nesom	3.8 to 5.1
<i>Desmodium paniculatum</i> (L.) DC.	5.3 to 5.5	<i>Eurybia macrophylla</i> (L.) Cass.	5.5 to 5.6
<i>Dicentra</i> sp.	4.7 to 5.1	<i>Fagus grandifolia</i> Ehrh.	3.3 to 6.9
<i>Dictamnus albus</i> L.	4.1 to 4.5	<i>Fagus sylvatica</i> L.	3.1 to 7.9
<i>Diervilla lonicera</i> Mill.	4.4 to 5.6	<i>Fallopia cilinodis</i> (Michx.) Holub	4.6 to 5.1
<i>Digitalis purpurea</i> L.	4.2 to 5.6	<i>Fallopia convolvulus</i> (L.) Á.Löve	3.3 to 6.6
<i>Digitaria sanguinalis</i> (L.) Scop.	3.9 to 4.4	<i>Festuca arundinacea</i> Schreb.	6.2 to 8.6
<i>Diodia virginiana</i> L.	3.9 to 4.4	<i>Festuca arundinacea</i> var. <i>spuria</i>	3.9 to 4.4
<i>Dioscorea villosa</i> L.	3.8 to 4.5	<i>Festuca gigantea</i> (L.) Vill.	4.4 to 6.6
<i>Diospyros virginiana</i> L.	5.3 to 5.5	<i>Festuca heterophylla</i> Lam.	3.7 to 7.3
<i>Drosera intermedia</i> Hayne	3.9 to 5.4	<i>Festuca ovina</i> L.	2.9 to 7.3
<i>Drosera rotundifolia</i> L.	3.9 to 5.4	<i>Festuca pratensis</i> Huds.	6.2 to 9.2
<i>Dryopteris carthusiana</i> (Will.) H.P. Fuchs	2.4 to 6.3	<i>Festuca rubra</i> L.	2.9 to 9.3
<i>Dryopteris dilatata</i> (Hoffm.) A. Gray	2.4 to 5.5	<i>Festuca rupicola</i> Heuff.	4.1 to 7.7
<i>Dryopteris filix-mas</i> (L.) Schott	3.1 to 8.7	<i>Ficaria verna</i> Huds.	3.1 to 8.7
<i>Dryopteris goldiana</i> (Hook. ex Goldie) A. Gray	4.7 to 5.1	<i>Filipendula rubra</i> (Hill) B.L. Rob.	5.5 to 6.9
<i>Dryopteris intermedia</i> (Muhl. ex Willd.) A. Gray	4.7 to 5.1	<i>Filipendula ulmaria</i> (L.) Maxim.	3.7 to 6.6
<i>Dryopteris marginalis</i> (L.) A. Gray	4.7 to 5.1	<i>Fragaria vesca</i> L.	3.7 to 8.7
<i>Eleocharis multicaulis</i> (Sm.) Desv.	4.1 to 5.3	<i>Fragaria virginiana</i> Duchesne	4.4 to 4.6
<i>Elephantopus carolinianus</i> Raeusch.	3.9 to 4.4	<i>Fragaria viridis</i> Duch. #	3.3 to 7.3
<i>Elymus caninus</i> (L.) L.	3.3 to 7.7	<i>Frangula dodonei</i> Ard.	2.4 to 8
<i>Elymus hystrix</i> L.	4.7 to 5.1	<i>Fraxinus americana</i> L.	3.8 to 8.2
<i>Elymus repens</i> (L.) Gould	6.1 to 9.3	<i>Fraxinus excelsior</i> L.	3.1 to 8.4
		<i>Fraxinus pennsylvanica</i> Marshall	6.6 to 7.8

Supporting information

Species	pH range	Species	pH range
<i>Gagea lutea</i> (L.) Ker Gawl.	4.1 to 7.5	<i>Hieracium lachenalii</i>	3.7 to 7.3
<i>Galeopsis bifida</i> Boenn.	2.4 to 7.3	<i>Hieracium maculatum</i> Schrank	3.7 to 4.2
<i>Galeopsis tetrahit</i> L.	3.1 to 6.6	<i>Hieracium murorum</i> L.	2.5 to 7.3
<i>Galium aparine</i> L.	3.1 to 8	<i>Hieracium pilosella</i> L.	2.9 to 6.2
<i>Galium boreale</i> L.	4 to 7.3	<i>Hieracium piloselloides</i> Vill.	4.7 to 5.6
<i>Galium circaezans</i> Michx.	3.8 to 4.5	<i>Hieracium sabaudum</i> L.	3.1 to 6.5
<i>Galium concinnum</i> Torr. & A.Gray	4.2 to 4.5	<i>Hieracium tridentatum</i> (Fr.) Fr.	4.5 to 5.1
<i>Galium odoratum</i> (L.) Scop.	3.2 to 8.7	<i>Hieracium umbellatum</i> L.	2.5 to 5.9
<i>Galium palustre</i> L.	4.7 to 6.4	<i>Hieracium vulgatum</i> Fr.	4.8 to 5.1
<i>Galium saxatile</i> L.	2.9 to 5.9	<i>Hierochloa australis</i> (Schrad.) Roem. & Schult.	3.7 to 4.2
<i>Galium saxatile</i> var. <i>saxatile</i>	3.5 to 6	<i>Holcus lanatus</i> L.	2.9 to 7.2
<i>Galium sylvaticum</i> L.	3.7 to 7.3	<i>Holcus mollis</i> L.	2.9 to 6.3
<i>Galium triflorum</i> Michx.	3.8 to 5.1	<i>Hordehymus europaeus</i> (L.) Jess. ex Harz	3.3 to 5.5
<i>Galium uliginosum</i> L.	4.7 to 6.4	<i>Hordeum vulgare</i> L.	6.2 to 9.2
<i>Galium verum</i> L.	4.3 to 5.9	<i>Hyacinthoides non-scripta</i> (L.) Chouard ex Rothm.	5.1 to 6.6
<i>Gaultheria procumbens</i> L.	3.4 to 5.6	<i>Hydrangea arborescens</i> L.	3.8 to 4.5
<i>Gaylussacia baccata</i> (Wangenh.) K.Koch	3.5 to 6	<i>Hydrocotyle vulgaris</i> L.	3.9 to 6.4
<i>Genista anglica</i> L.	2.9 to 5.9	<i>Hydrophyllum virginianum</i> L. #	4.6 to 5.1
<i>Genista pilosa</i> L.	2.9 to 5.8	<i>Hypericum hirsutum</i> L.	3.3 to 8.4
<i>Gentiana pneumonanthe</i> L.	3.1 to 6.4	<i>Hypericum humifusum</i> L.	4.7 to 5.2
<i>Geranium columbinum</i> L.	4.2 to 5.2	<i>Hypericum maculatum</i> Crantz	4.5 to 5.1
<i>Geranium maculatum</i> L.	3.8 to 4.5	<i>Hypericum perforatum</i> L.	3.3 to 8.4
<i>Geranium robertianum</i> L.	3.1 to 8.4	<i>Hypericum pulchrum</i> L.	3.1 to 6.3
<i>Geranium sylvaticum</i> L.	4.5 to 6.3	<i>Hypochaeris maculata</i> L.	4.5 to 5.1
<i>Geum canadense</i> Jacq.	4.7 to 5.1	<i>Hypochoeris radicata</i> L.	4 to 4.4
<i>Geum urbanum</i> L.	3.1 to 8.4	<i>Ilex aquifolium</i> L.	3.1 to 6.3
<i>Glandora prostrata</i> (Loisel.) D.C.Thomas	4.2 to 5.6	<i>Impatiens noli-tangere</i> L.	4.6 to 4.8
<i>Glechoma hederacea</i> L.	3.1 to 8.4	<i>Impatiens parviflora</i> DC.	3.3 to 7.7
<i>Grossularia cynosbati</i> (L.) Mill. #	4.7 to 5.1	<i>Jasione montana</i> L.	4.4 to 5.8
<i>Gymnocarpium dryopteris</i> (L.) Newman	4.2 to 6	<i>Juglans nigra</i> L.	5.9 to 6.1
<i>Halimium alyssoides</i> K.Koch#	4.2 to 5.6	<i>Juncus acutiflorus</i> Ehrh. ex Hoffm.	3.9 to 6.4
<i>Hamamelis virginiana</i> L.	3.8 to 4.5	<i>Juncus alpinoarticulatus</i> Chaix	4.7 to 6.4
<i>Hedera helix</i> L.	3.1 to 8.7	<i>Juncus articulatus</i> L.	4.7 to 8.3
<i>Helianthus divaricatus</i> L.	3.8 to 4.5	<i>Juncus bufonius</i> L.	4.7 to 6.6
<i>Helictotrichon pubescens</i> (Huds.) Schult. & Schult.f.	4.7 to 5.1	<i>Juncus bulbosus</i> L.	4.1 to 5.3
<i>Hepatica nobilis</i> Mill.	3.7 to 7.7	<i>Juncus compressus</i> Jacq.	6.1 to 9.3
<i>Heracleum sphondylium</i> L.	3.1 to 6.6	<i>Juncus conglomeratus</i> L.	3.1 to 6.4

Appendix S2.4

Species	pH range	Species	pH range
<i>Juncus effusus</i> L.	2.9 to 8.4	<i>Luzula luzuloides</i> (Lam.) Dandy & Wilmott	4 to 6.5
<i>Juncus squarrosus</i> L.	2.9 to 5.9	<i>Luzula multiflora</i> (Ehrh.) Lej.	2.9 to 6.2
<i>Juncus tenuis</i> Willd.	3.9 to 4.4	<i>Luzula multiflora</i> subsp. <i>multiflora</i>	5.8 to 6
<i>Juniperus communis</i> L.	4.1 to 4.6	<i>Luzula pilosa</i> (L.) Willd.	3.1 to 8.4
<i>Juniperus virginiana</i> L.	5.8 to 8	<i>Lycopodiella inundata</i> (L.) Holub	3.9 to 5.4
<i>Knautia maxima</i> (L.) Coult.	3.1 to 5.9	<i>Lycopodium clavatum</i> L.	3.8 to 4.9
<i>Kummerowia stipulacea</i> (Maxim.) Makino	5.3 to 5.5	<i>Lysimachia maritima</i> (L.) Galasso, Banfi & Soldano	3.4 to 9.4
<i>Lactuca serriola</i> L.	6.1 to 9.3	<i>Lysimachia nemorum</i> L. #	3.1 to 5.5
<i>Lamium purpureum</i> L.	5.7 to 7.2	<i>Lysimachia nummularia</i> L. #	3.9 to 4.4
<i>Laportea canadensis</i> (L.) Wedd.	4.2 to 5.1	<i>Lysimachia vulgaris</i> L.	3.1 to 6.4
<i>Lapsana communis</i> L.	4.5 to 8.4	<i>Lythrum salicaria</i> L.	4.7 to 6.4
<i>Larix decidua</i> Mill.	3.5 to 6	<i>Maianthemum bifolium</i> (L.) F.W.Schmidt	3.1 to 6.3
<i>Lathyrus linifolius</i> (Reichard) Bassler	4 to 5.5	<i>Maianthemum canadense</i> Desf.	3.4 to 5.1
<i>Lathyrus niger</i> (L.) Bernh.	3.7 to 7.3	<i>Maianthemum racemosum</i> (L.) Link	3.8 to 5.1
<i>Lathyrus pratensis</i> L.	4.5 to 7.7	<i>Malus sylvestris</i> Mill.	3.7 to 5
<i>Lathyrus vernus</i> (L.) Bernh.	3.7 to 7.7	<i>Matricaria matricarioides</i> (Less.) Porter	5.8 to 6.6
<i>Lembotropis nigricans</i> (L.) Griseb.	4 to 6.5	<i>Medicago lupulina</i> L.	6.2 to 8.6
<i>Leontodon autumnalis</i> L.	6.2 to 8.6	<i>Melampyrum cristatum</i> L. #	4 to 4.4
<i>Leontodon hispidus</i> L.	4.3 to 5.9	<i>Melampyrum nemorosum</i> L.	5.1 to 5.7
<i>Lepidium ruderales</i> L.	6.2 to 9.2	<i>Melampyrum pratense</i> L.	3.7 to 7.3
<i>Ligustrum vulgare</i> L.	3.3 to 6.3	<i>Melampyrum sylvaticum</i> L. #	4.7 to 4.8
<i>Lilium martagon</i> L.	7 to 7.7	<i>Melica nutans</i> L.	3.3 to 8.9
<i>Lindera benzoin</i> (L.) Blume	3.8 to 4.5	<i>Melica uniflora</i> Retz.	3.1 to 8.7
<i>Linum catharticum</i> L.	4.3 to 5.9	<i>Melilotus dentatus</i> (Waldst. & Kit.) Pers.	6.2 to 8.6
<i>Liquidambar styraciflua</i> L.	5.3 to 5.5	<i>Melittis melissophyllum</i> L.	3.3 to 6.3
<i>Liriodendron tulipifera</i> L.	3.3 to 8.2	<i>Mentha aquatica</i> L.	4.7 to 8.3
<i>Lobelia siphilitica</i> L.	5.3 to 5.5	<i>Mercurialis perennis</i> L.	3.3 to 8.4
<i>Lolium perenne</i> L.	5.8 to 8.1	<i>Microstegium vimineum</i> (Trin.) A.Camus	5.3 to 6.1
<i>Lonicera japonica</i> #	2.4 to 8.7	<i>Milium effusum</i> L.	3.1 to 8.7
<i>Lonicera oblata</i> #	7 to 7.7	<i>Mitchella repens</i> L.	4.4 to 4.6
<i>Lonicera xylosteum</i> Thunb.	5.3 to 6.6	<i>Mitella diphylla</i> L. #	4.7 to 5.1
<i>Lotus corniculatus</i> L.	4.2 to 5.9	<i>Moehringia trinervia</i> (L.) Clairv.	3.1 to 7.7
<i>Lotus maritimus</i> L.	6.2 to 8.6	<i>Molinia caerulea</i> (L.) Moench	2.4 to 6.4
<i>Lotus pedunculatus</i> Cav.	4.7 to 6.4	<i>Monarda fistulosa</i> L.	3.8 to 4.5
<i>Lotus tenuis</i> Waldst. & Kit.	6.2 to 8.6	<i>Morus rubra</i> L.	5.9 to 6.1
<i>Luzula campestris</i> (L.) DC.	2.5 to 6.4	<i>Mycelis muralis</i> (L.) Dumort.	3.3 to 7.3
<i>Luzula forsteri</i> (Sm.) DC.	4.8 to 5.1		

Supporting information

Species	pH range	Species	pH range
<i>Myosotis sylvatica</i> Ehrh. ex Hoffm.	6.2 to 7.5	<i>Phalaris arundinacea</i> L.	4.8 to 8.6
<i>Nardus stricta</i> L.	2.9 to 5.9	<i>Phaseolus polystachios</i> (L.) Britton & al.	3.9 to 4.4
<i>Narthecium ossifragum</i> (L.) Huds.	3.9 to 6.4	<i>Phegopteris hexagonoptera</i> (Michx.) Fée	3.8 to 4.5
<i>Neottia nidus-avis</i> (L.) Rich.	5.5 to 8.7	<i>Phleum pratense</i> L.	4.7 to 5.1
<i>Neottia ovata</i> (L.) Bluff & Fingerh.	5.5 to 6.4	<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	3.1 to 9.4
<i>Nyssa sylvatica</i> Marshall	3.8 to 4.5	<i>Phyteuma spicatum</i> L.	4.3 to 8
<i>Odontites vulgaris</i> Moench	6.2 to 8.6	<i>Picea abies</i> (L.) H.Karst.	3.5 to 6.9
<i>Orchis mascula</i> (L.) L.	5.5 to 8.7	<i>Pilea pumila</i> (L.) A. Gray	3.8 to 4.5
<i>Orchis purpurea</i> Huds.	5.5 to 8.7	<i>Pimpinella saxifraga</i> L.	4.3 to 5.9
<i>Ornithogalum umbellatum</i> L.	5.5 to 6.4	<i>Pinus banksiana</i> Lamb.	4 to 4.8
<i>Ornithopus perpusillus</i> L.	4.4 to 5.8	<i>Pinus echinata</i> Mill.	4.5 to 8
<i>Oryzopsis asperifolia</i> Michx.	4.4 to 5.6	<i>Pinus resinosa</i> Aiton	3.7 to 4.8
<i>Oryzopsis racemosa</i> (Sm.) Ricker ex Hitchc.	4.7 to 5.1	<i>Pinus rigida</i> Mill.	3.4 to 4.1
<i>Osmorhiza aristata</i> (Thunb.) Rydb.	4.6 to 5.1	<i>Pinus strobus</i> L.	3.4 to 8.2
<i>Ostrya virginiana</i> (Mill.) K.Koch	3.6 to 5.9	<i>Pinus sylvestris</i> L.	3.6 to 6.5
<i>Oxalis acetosella</i> L.	3.1 to 6.6	<i>Plantago intermedia</i> DC.	3.4 to 9.4
<i>Oxalis corniculata</i> L.	3.9 to 4.4	<i>Plantago lanceolata</i> L.	2.9 to 6.4
<i>Oxalis stricta</i> L.	3.9 to 4.4	<i>Plantago major</i> L.	5.2 to 9.2
<i>Oxydendrum arboreum</i> (L.) DC.	3.3 to 5.3	<i>Platanus occidentalis</i> L.	6.6 to 7.8
<i>Padus avium</i> var. <i>avium</i>	4.2 to 5	<i>Poa angustifolia</i> L.	3.3 to 9.2
<i>Panax quinquefolius</i> L.	4.7 to 5.1	<i>Poa annua</i> L.	5.1 to 6.6
<i>Panicum anceps</i> Michx.	3.9 to 4.4	<i>Poa cuspidata</i> Nutt.	3.8 to 4.5
<i>Panicum boscii</i> Poir.	3.8 to 4.5	<i>Poa nemoralis</i> L.	3.1 to 8.7
<i>Panicum dichotomum</i> L.	3.8 to 4.5	<i>Poa pratensis</i> L.	2.9 to 7.3
<i>Paris quadrifolia</i> L.	3.1 to 8	<i>Poa trivialis</i> L.	3.1 to 8.9
<i>Parnassia palustris</i> <i>Parnassia palustris</i> L.	4.7 to 6.4	<i>Polycodium stamineum</i> (L.) Greene	3.8 to 4.5
<i>Parthenocissus quinquefolia</i> (L.) Planch.	3.8 to 5.1	<i>Polygala serpyllifolia</i> Hosé	3.1 to 5.9
<i>Pedicularis canadensis</i> L.	4.7 to 4.8	<i>Polygala vulgaris</i> L.	4.3 to 5.9
<i>Pedicularis nodosa</i> Pennell [#]	2.9 to 6.4	<i>Polygonatum biflorum</i> (Walter) Elliott	3.8 to 4.8
<i>Pennisetum glaucum</i> (L.) R.Br.	3.9 to 4.4	<i>Polygonatum multiflorum</i> (L.) All.	3.1 to 8.7
<i>Persicaria amphibia</i> (L.) Delarbre	6.7 to 8.3	<i>Polygonatum odoratum</i> (Mill.) Druce	4 to 5.4
<i>Persicaria bistorta</i> (L.) Samp.	3.1 to 6.3	<i>Polygonatum pubescens</i> (Willd.) Pursh	4.7 to 5.1
<i>Persicaria hydropiperoides</i> (Michx.) Small	3.9 to 4.4	<i>Polygonatum verticillatum</i> (L.) All.	4.5 to 4.9
<i>Persicaria lapathifolia</i> (L.) Delarbre	6.2 to 9.2	<i>Polygonum aviculare</i> L.	6.2 to 9.2
<i>Persicaria maculosa</i> Gray	4 to 8.4	<i>Polypodium vulgare</i> L.	4.5 to 5.5
<i>Persicaria pensylvanica</i> (L.) M. Gómez	3.9 to 4.4	<i>Polystichum acrostichoides</i> (Michx.) Schott	3.8 to 5.1
<i>Persicaria virginiana</i> (L.) Gaertn.	5.9 to 6.1	<i>Populus alba</i> L.	3.1 to 5.5

Appendix S2.4

Species	pH range	Species	pH range
<i>Populus tremula</i> L.	3.1 to 7.2	<i>Ranunculus auricomus</i> L.	4.1 to 7.7
<i>Populus tremula</i> subsp. <i>grandidentata</i> (Michx.) A. Löve & D. Löve	3.3 to 5.6	<i>Ranunculus bulbosus</i> L.	4.3 to 5.9
<i>Potentilla anserina</i> L.	4.7 to 9.3	<i>Ranunculus flammula</i> L.	4.7 to 6.4
<i>Potentilla argentea</i> L.	4.2 to 5.2	<i>Ranunculus polyanthemos</i> L.	4.8 to 7.3
<i>Potentilla erecta</i> (L.) Raeusch.	2.9 to 6.4	<i>Ranunculus repens</i> L.	4.7 to 8.6
<i>Potentilla reptans</i> L.	6.7 to 8.3	<i>Rhamnus cathartica</i> L.	4 to 4.5
<i>Potentilla sterilis</i> (L.) Garcke	3.1 to 8.7	<i>Rhinanthus minor</i> L. #	4.3 to 5.9
<i>Prenanthes</i> sp.	4.7 to 5.1	<i>Rhynchospora alba</i> (L.) Vahl	3.9 to 5.4
<i>Primula scandinavica</i> Brum#	3.1 to 8.4	<i>Rhynchospora fusca</i> (L.) W.T.Aiton	4.1 to 5.3
<i>Primula veris</i> L.	4 to 8.4	<i>Ribes alpinum</i> L.	5.5 to 8.7
<i>Prunus avium</i> (L.) L.	3.1 to 7.7	<i>Ribes rubrum</i> L.	3.7 to 6.3
<i>Prunus serotina</i> Ehrh.	3.1 to 8.2	<i>Ribes uva-crispa</i> L.	4.4 to 8.7
<i>Prunus spinosa</i> L.	3.7 to 8.7	<i>Robinia pseudoacacia</i> L.	3.8 to 8.2
<i>Pseuderanthemum longifolium</i> (G. Forst.) Guilaumin	4.2 to 5.6	<i>Rorippa islandica</i> (Oeder) Borbás	6.2 to 9.2
<i>Pteridium aquilinum</i> (L.) Kuhn	2.4 to 6.3	<i>Rosa arvensis</i> Huds.	4.3 to 8.7
<i>Puccinellia distans</i> (Jacq.) Parl.	3.4 to 9.4	<i>Rosa canina</i> L.	3.3 to 8
<i>Pulmonaria obscura</i> Dumort. #	3.7 to 5	<i>Rosa carolina</i> L.	3.8 to 4.5
<i>Pulmonaria officinalis</i> L. #	4.5 to 5.4	<i>Rosa multiflora</i> Thunb.	6.1 to 6.4
<i>Pyrethrum corymbosum</i> (L.) Scop.	3.7 to 7.3	<i>Rubus allegheniensis</i> Porter#	4.4 to 5.6
<i>Pyrus pyraeaster</i> (L.) Du Roi	4 to 4.4	<i>Rubus caesius</i> L.	4.3 to 8.7
<i>Quercus alba</i> L.	3.4 to 8.2	<i>Rubus fruticosus</i> L.	2.4 to 8
<i>Quercus coccinea</i> Münchh.	3.8 to 4.5	<i>Rubus idaeus</i> L.	2.4 to 8
<i>Quercus ellipsoidalis</i> E.J.Hill	4.4 to 4.8	<i>Rubus occidentalis</i> L.	4.7 to 5.1
<i>Quercus ilicifolia</i> Wangenh.	3.7 to 3.8	<i>Rubus saxatilis</i> L.	4.2 to 6.2
<i>Quercus marilandica</i> (L.) Münchh.	4.5 to 8	<i>Rumex acetosa</i> L.	2.9 to 7.2
<i>Quercus michauxii</i> Nutt.	3.8 to 8.2	<i>Rumex acetosella</i> L.	2.9 to 6.3
<i>Quercus muehlenbergii</i> Engelm.	5.8 to 8	<i>Rumex obtusifolius</i> L.	5.1 to 6.6
<i>Quercus petraea</i> (Matt.) Liebl.	3.1 to 7.7	<i>Rumex sanguineus</i> L.	4.2 to 4.4
<i>Quercus pubescens</i> Willd.	4.1 to 4.5	<i>Ruscus aculeatus</i> L.	4.8 to 5.1
<i>Quercus robur</i> L.	3.1 to 6.2	<i>Salicornia europaea</i> L.	3.4 to 9.4
<i>Quercus rubra</i> L.	3.1 to 8.2	<i>Salix aurita</i> L.	4.1 to 5.3
<i>Quercus semecarpifolia</i> Sm.	4 to 7.5	<i>Salix caprea</i> L.	3.8 to 7.9
<i>Quercus serrata</i> Murray	4.9 to 5.7	<i>Salix caroliniana</i> Michx. #	3.1 to 6.4
<i>Quercus stellata</i> Wangenh.	4.5 to 8	<i>Salix myrsinites</i> L. #	6.6 to 7.8
<i>Quercus velutina</i> Lam.	3.8 to 8	<i>Sambucus nigra</i> L.	3.1 to 7.6
<i>Ranunculus abortivus</i> L.	4.7 to 5.1	<i>Sambucus racemosa</i> L.	4 to 6.5
<i>Ranunculus acris</i> L.	4.5 to 6.4	<i>Sanguinaria canadensis</i> L.	4.2 to 5.1

Supporting information

Species	pH range	Species	pH range
<i>Sanguisorba minor</i> Scop.	4.3 to 5.9	<i>Stellaria graminea</i> L.	3.1 to 7.7
<i>Sanicula elata</i> Buch.-Ham. ex D. Don	3.7 to 7.2	<i>Stellaria longifolia</i> (L.) Vill.	4.5 to 8
<i>Sassafras albidum</i> (Nutt.) Nees	3.3 to 7.2	<i>Stellaria media</i> L.	3.3 to 6.3
<i>Saxifraga virginiana</i> Michx.	4.7 to 5.1	<i>Stellaria nemorum</i> Ehrh. ex Retz.	4.7 to 6.4
<i>Schoenoplectus tabernaemontani</i> (C.C.Gmel.) Palla	6.2 to 8.6	<i>Stellaria uliginosa</i> Murray	4.7 to 5.8
<i>Scorzonera humilis</i> L.	3.1 to 5.6	<i>Succisa pratensis</i> Moench [#]	2.9 to 6.4
<i>Scrophularia nodosa</i> L. [#]	3.1 to 7.2	<i>Symphyotrichum lateriflorum</i> (L.) A.Löve & D.Löve	3.9 to 4.4
<i>Scutellaria galericulata</i> L.	5.5 to 8.9	<i>Symphyotrichum pilosum</i> (Willd.) G.L.Nesom	3.9 to 4.4
<i>Sedum maximum</i> (L.) Suter	4.1 to 4.5	<i>Tanacetum vulgare</i> L.	7.5 to 7.9
<i>Sedum telephium</i> L.	3.7 to 6.3	<i>Taraxacum officinale</i> Webb	3.9 to 8.9
<i>Senecio leucanthemifolius</i> subsp. <i>vernalis</i> (Waldst. & Kit.) Greuter	6.2 to 8.9	<i>Taraxacum vulgare</i> (Lam.) Schrank	5.1 to 5.5
<i>Senecio ovatus</i> Willd.	3.7 to 6.3	<i>Teucrium chamaedrys</i> L.	4.1 to 4.5
<i>Serratula tinctoria</i> L.	4 to 6.5	<i>Teucrium scorodonia</i> L.	3.1 to 6.3
<i>Setaria faberi</i> R.A.W.Herrm.	6.1 to 6.6	<i>Thalictrum dioicum</i> L.	4.7 to 5.1
<i>Silene acaulis</i> (L.) Clairv.	4.5 to 5.3	<i>Tiarella cordifolia</i> L.	4.2 to 5.1
<i>Silene dioica</i> (L.) Greuter & Burdet	6.7 to 8.3	<i>Tilia americana</i> L.	4.1 to 8
<i>Silene nutans</i> L.	3.8 to 8	<i>Tilia cordata</i> Mill.	4.8 to 5.1
<i>Silene rupestris</i> L.	4.2 to 5.2	<i>Tilia platyphyllos</i> Scop.	5.5 to 8.7
<i>Silene viscaria</i> (L.) Jess.	4 to 6.5	<i>Torilis japonica</i> (Houtt.) DC.	3.3 to 6.6
<i>Smilax glauca</i> Walter	3.8 to 6.1	<i>Toxicodendron radicans</i> (L.) Kuntze	3.8 to 4.5
<i>Smilax rotundifolia</i> L.	3.8 to 4.5	<i>Triadenum japonicum</i> (Blume) Makino	4.6 to 5.3
<i>Solanum dulcamara</i> L.	4.7 to 5.1	<i>Trichophorum alpinum</i> (L.) Pers.	4.3 to 7.2
<i>Solanum panduriforme</i> E. Mey. [#]	3.9 to 4.4	<i>Trichophorum cespitosum</i> (L.) Hartm.	3.1 to 7.2
<i>Solidago caesia</i> L.	3.8 to 5.1	<i>Trientalis europaea</i> L.	2.4 to 5.8
<i>Solidago flexicaulis</i> L.	4.7 to 5.1	<i>Trifolium arvense</i> L.	4.2 to 5.2
<i>Solidago rugosa</i> Mill.	4.7 to 5.1	<i>Trifolium fragiferum</i> L.	6.2 to 8.6
<i>Solidago virgaurea</i> L.	4 to 6.5	<i>Trifolium medium</i> L.	4.5 to 5.1
<i>Sonchus arvensis</i> L.	5.2 to 8.9	<i>Trifolium pratense</i> L.	3.1 to 5.9
<i>Sonchus oleraceus</i> (L.) L.	3.4 to 9.4	<i>Trifolium repens</i> L.	6.2 to 9.2
<i>Sorbus aria</i> Crantz	4 to 6.5	<i>Triglochin maritima</i> L.	3.4 to 9.4
<i>Sorbus aucuparia</i> L.	2.4 to 8	<i>Trillium erectum</i> L.	4.7 to 5.1
<i>Sorbus torminalis</i> (L.) Crantz	4 to 4.4	<i>Trillium grandiflorum</i> (Michx.) Salisb.	4.2 to 4.5
<i>Spergula morisonii</i> Boreau	4.2 to 5.2	<i>Tripolium pannonicum</i> (Jacq.) Dobroc.	3.4 to 9.4
<i>Spergularia marina</i> (L.) Besser	3.4 to 9.4	<i>Triticum aestivum</i> L.	6.5 to 8.9
<i>Stachys officinalis</i> (L.) Trevis.	4.3 to 5.9	<i>Tsuga canadensis</i> (L.) Carrière	3.5 to 6.1
<i>Stachys sylvatica</i> L.	3.1 to 8.4	<i>Tussilago farfara</i> L.	6 to 7.5
<i>Stellaria borealis</i> L.	4.5 to 5.1	<i>Ulmus alata</i> Michx.	5.3 to 5.5

Appendix S2.4

Species	pH range	Species	pH range
<i>Ulmus glabra</i> Huds.	3.3 to 8	<i>Viola tricolor</i> L.	4.2 to 5.2
<i>Ulmus minor</i> Mill.	3.3 to 6.3	<i>Vitis</i> sp.	3.8 to 4.5
<i>Ulmus rubra</i> Muhl.	3.8 to 8	<i>Xanthium strumarium</i>	3.9 to 4.4
<i>Urtica dioica</i> L.	3.1 to 8.4		
<i>Uvularia perfoliata</i> L.	3.8 to 4.5	(i) Temperate grassland, savanna, and shrubland	
<i>Uvularia sessilifolia</i> L.	4.7 to 5.1	<i>Acer negundo</i> L.	4.9 to 6.3
<i>Vaccinium corymbosum</i> L.	3.5 to 4.1	<i>Acer saccharinum</i> L.	4.9 to 6.3
<i>Vaccinium myrtillus</i> L.	2.4 to 8.5	<i>Achillea millefolium</i> L.	3.3 to 8.7
<i>Vaccinium stenophyllum</i> Steud.	3.4 to 5.6	<i>Aesculus glabra</i> Willd.	4.9 to 5.1
<i>Vaccinium vitis-idaea</i> L.	3.1 to 5.6	<i>Agoseris glauca</i> (Pursh) Raf.	4.1 to 6.4
<i>Valeriana jatamansi</i> [#]	3.7 to 6.3	<i>Agriophyllum squarrosum</i> (L.) Moq.	4.4 to 7.6
<i>Valeriana repens</i> L.	3.3 to 6.3	<i>Agropyron</i> sp.	4.1 to 6.4
<i>Valerianella locusta</i> (L.) Betcke	7.2 to 8	<i>Agrostis canina</i> L.	3.3 to 6.2
<i>Verbascum thapsus</i> L.	5.2 to 8.4	<i>Agrostis capillaris</i> L.	3.3 to 9.1
<i>Vernonia altissima</i> Nutt.	3.9 to 4.4	<i>Agrostis mertensii</i> Trin.	4.4 to 5.8
<i>Veronica chamaedrys</i> L.	3.7 to 8.9	<i>Agrostis stolonifera</i> L.	4.4 to 8.1
<i>Veronica hederifolia</i> L.	3.1 to 8	<i>Agrostis vinealis</i> Schreb.	4.3 to 6.1
<i>Veronica montana</i> L.	3.1 to 8.4	<i>Aira praecox</i> L.	4.3 to 6.1
<i>Veronica officinalis</i> L.	3.1 to 7.2	<i>Alchemilla glaucescens</i> Wallr.	4.5 to 8.7
<i>Viburnum acerifolium</i> Gueldenst. ex Ledeb. [#]	3.8 to 5.1	<i>Alchemilla vulgaris</i> L.	5 to 5.1
<i>Viburnum lantana</i> L. [#]	5.5 to 8.7	<i>Allium barszczewskii</i> Lipsky	5 to 7
<i>Viburnum opulus</i> L.	4.1 to 8.7	<i>Allium mongolicum</i> Regel	7.3 to 7.6
<i>Vicia cracca</i> L.	3.1 to 7.2	<i>Alopecurus pratensis</i> L.	5 to 7
<i>Vicia sepium</i> L.	3.3 to 8.7	<i>Alyssum alyssoides</i> (L.) L.	4.5 to 9.1
<i>Vinca minor</i> L.	3.1 to 6.3	<i>Andromeda polifolia</i> L.	4.4 to 5.8
<i>Vincetoxicum hirundinaria</i> Medik.	4.1 to 8.4	<i>Andropogon gerardii</i> Vitman	7.6 to 7.8
<i>Viola blanda</i> Salisb. [#]	3.1 to 5.9	<i>Anemone nemorosa</i> L.	3.3 to 5.7
<i>Viola calcarata</i> Vill. [#]	4.7 to 5.1	<i>Anemone pratensis</i> L.	4.5 to 9.1
<i>Viola canadensis</i> L.	4.7 to 5.1	<i>Antennaria dioica</i> (L.) Gaertn.	4.4 to 5.8
<i>Viola collina</i> Besser	3.3 to 6.3	<i>Anthericum liliago</i> L.	4.5 to 9.1
<i>Viola mirabilis</i> L.	3.3 to 6.3	<i>Anthoxanthum odoratum</i> L.	3.3 to 8.7
<i>Viola odorata</i> L.	3.3 to 8	<i>Anthriscus sylvestris</i> (L.) Hoffm.	5.2 to 8.7
<i>Viola palmata</i> L.	3.8 to 4.5	<i>Anthyllis montana</i> L.	6.9 to 7
<i>Viola palustris</i> L.	4.7 to 6.4	<i>Anthyllis vulneraria</i> L.	4.5 to 9.1
<i>Viola reichenbachiana</i> Jord. ex Boreau	3.3 to 7.7	<i>Anthyllis vulneraria</i> subsp. <i>alpestris</i> (Hegetschw.) Asch. & Graebn.	5 to 5.1
<i>Viola riviniana</i> Rehb.	3.3 to 8.7	<i>Arctostaphylos alpina</i> (L.) Spreng. [#]	4.4 to 5.8
<i>Viola rotundifolia</i> Hook. [#]	4.7 to 5.1	<i>Arenaria serpyllifolia</i> L.	4.5 to 9.1

Supporting information

Species	pH range	Species	pH range
<i>Aristida adscensionis</i> L.	7.3 to 7.6	<i>Carex caryophyllea</i> Latourr.	3.3 to 8.7
<i>Arnica montana</i> L.	5 to 5.1	<i>Carex dioica</i> L.	4.4 to 5.8
<i>Arrhenatherum elatius</i> (L.) P.Beauv. ex J.Presl & C.Presl.	3.3 to 9.1	<i>Carex flacca</i> Schreb.	3.3 to 5.7
<i>Artemisia campestris</i> L.	3.2 to 9.1	<i>Carex glacialis</i> Mack.	4.4 to 5.8
<i>Artemisia halodendron</i> Turcz. ex Besser	4.4 to 8.1	<i>Carex heterostachya</i> Bunge	5 to 7
<i>Artemisia sieversiana</i> Ehrh.	4.1 to 7.6	<i>Carex nigra</i> (L.) Reichard	4.6 to 6.4
<i>Asperula tinctoria</i> L.	5.6 to 8.7	<i>Carex panicea</i> L.	4.6 to 6.2
<i>Astragalus alpinus</i> L.	4.4 to 5.8	<i>Carex pseudocyperus</i> L.	4.6 to 6.2
<i>Astragalus andaulgensis</i> B.Fedtsch.	5 to 7	<i>Carex riparia</i> Curtis	4.6 to 6.2
<i>Astragalus norvegicus</i> Grauer	4.4 to 5.8	<i>Carex rostrata</i> Stokes	4.6 to 6.2
<i>Bartsia alpina</i> L.	4.4 to 5.8	<i>Carex rupestris</i> All.	4.4 to 5.8
<i>Bassia dasyphylla</i> (Fisch. & C.A.Mey.) Kuntze	7 to 7.5	<i>Carex sempervirens</i> Vill.	5 to 5.1
<i>Betula nana</i> L.	4.4 to 5.8	<i>Carex stricta</i> Lam.	4.1 to 8.1
<i>Betula nigra</i> L.	5.4 to 6.3	<i>Carex turkestanica</i> Regel	5 to 7
<i>Botrychium dusenii</i> Alston	4.4 to 5.8	<i>Carex vaginata</i> Tausch	4.4 to 5.8
<i>Bouteloua curtipendula</i> (Michx.) Torr.	7.6 to 7.8	<i>Carex viridula</i> subsp. <i>oedocarpa</i> (Andersson) B.Schmid	5.1 to 5.7
<i>Briza media</i> L.	3.3 to 8.7	<i>Carya cordiformis</i> (Wangenh.) K.Koch	4.9 to 6.3
<i>Bromus erectus</i> Huds.	6 to 6.7	<i>Carya laciniosa</i> (F.Michx.) G.Don	4.9 to 6.3
<i>Bromus hordeaceus</i> L.	4.3 to 6.1	<i>Carya texana</i> Buckley	7.6 to 7.8
<i>Bromus inermis</i> Leyss.	5 to 7	<i>Ceanothus americanus</i> L.	4.4 to 7.8
<i>Bupleurum baldense</i> Turra	6 to 6.7	<i>Celtis occidentalis</i> L.	4.9 to 6.3
<i>Bupleurum falcatum</i> L.	5 to 7	<i>Centaurea jacea</i> L.	5.2 to 8.7
<i>Calamagrostis epigeios</i> (L.) Roth	2.6 to 7.9	<i>Centaurea nigra</i> L.	3.3 to 5.7
<i>Calluna vulgaris</i> (L.) Hull	3.3 to 7.2	<i>Centaurea ovina</i> Pall. ex Willd.	5 to 7
<i>Caltha palustris</i> L.	4.4 to 6.2	<i>Centaurea scabiosa</i> L.	5.6 to 8.7
<i>Campanula barbata</i> L.	5 to 5.1	<i>Centaurium erythraea</i> Rafn	4.3 to 5.4
<i>Campanula glomerata</i> L.	5 to 7	<i>Cerastium alpinum</i> L.	4.4 to 5.8
<i>Campanula persicifolia</i> L.	4.5 to 8.7	<i>Cerastium arvense</i> L.	5 to 7
<i>Campanula rotundifolia</i> L.	3.3 to 8.7	<i>Cerastium fontanum</i> Baumg.	3.3 to 8.7
<i>Caragana microphylla</i> Lam.	4.1 to 7.6	<i>Cerastium semidecandrum</i> L.	4.5 to 9.1
<i>Carex acuta</i> L.	4.6 to 6.2	<i>Chamorchis alpina</i> (L.) Rich.	4.4 to 5.8
<i>Carex arenaria</i> L.	4.5 to 9.1	<i>Chenopodium album</i> L.	4.3 to 6.1
<i>Carex atrata</i> L.	4.4 to 5.8	<i>Chenopodium glaucum</i> L.	7.3 to 7.6
<i>Carex atrofusca</i> Schkuhr	4.4 to 5.8	<i>Cicer songaricum</i> DC.	5 to 7
<i>Carex bigelowii</i> Torr. ex Schwein.	4.4 to 5.8	<i>Cirsium arvense</i> (L.) Scop.	3.3 to 6.1
<i>Carex canescens</i> L.	4.6 to 6.2	<i>Cirsium dissectum</i> (L.) Hill	4.6 to 6.5
<i>Carex capillaris</i> L.	4.4 to 5.8	<i>Cirsium palustre</i> (L.) Coss. ex Scop.	3.3 to 6.7

Appendix S2.4

Species	pH range	Species	pH range
<i>Cladium mariscoides</i> (Muhl.) Torr.	4.1 to 8.1	<i>Equisetum variegatum</i> Schleich. ex F. Weber & D. Mohr	4.4 to 6.4
<i>Cleistogenes squarrosa</i> (Trin. ex Ledeb.) Keng	7.3 to 7.6	<i>Eragrostis pilosa</i> (L.) P.Beauv.	7.3 to 7.6
<i>Conopodium majus</i> (Gouan) Loret	3.3 to 5.7	<i>Erica cinerea</i> L.	4.3 to 6.1
<i>Convolvulus arvensis</i> L.	5 to 7	<i>Erica tetralix</i> L.	4.1 to 4.3
<i>Convolvulus lineatus</i> L.	5 to 7	<i>Erigeron uniflorus</i> L.	4.4 to 5.8
<i>Corispermum macrocarpum</i> Bunge ex Maxim.	7 to 7.6	<i>Eryngium campestre</i> L.	6 to 6.6
<i>Cornus drummondii</i> C.A.Mey.	7.5 to 8.1	<i>Euphorbia corollata</i> L.	7.6 to 7.8
<i>Cornus racemosa</i> Lam.	4.4 to 8.1	<i>Euphorbia esula</i> L.	7 to 7.6
<i>Corynephorus canescens</i> (L.) P.Beauv.	4.5 to 9.1	<i>Euphorbia humifusa</i> Willd.	7.3 to 7.6
<i>Crepis capillaris</i> (L.) Wallr.	5.4 to 6.1	<i>Euphrasia frigida</i> Pugsley	4.4 to 5.8
<i>Crepis paludosa</i> (L.) Moench	4.4 to 5.8	<i>Euphrasia karataviensis</i> Govor.	5 to 7
<i>Crucianella angustifolia</i> L.	6.2 to 6.7	<i>Euphrasia officinalis</i> L. #	4.3 to 5.4
<i>Cunila origanoides</i> (L.) Britton	4.1 to 7.8	<i>Euphrasia stricta</i> D.Wolff ex J.F.Lehm.	6.5 to 7.7
<i>Cynanchum thesioides</i> (Frey) K.Schum.	7 to 7.6	<i>Festuca beckeri</i> (Hack.) Trautv.	4.5 to 9.1
<i>Cynosurus cristatus</i> L.	4.9 to 7.1	<i>Festuca gautieri</i> (Hack.) K.Richt.	7.3 to 7.4
<i>Cytisus scoparius</i> (L.) Link	5 to 6.6	<i>Festuca nigrescens</i> Lam.	5.4 to 6
<i>Dactylis glomerata</i> L.	3.3 to 8.7	<i>Festuca ovina</i> L.	3.3 to 8.7
<i>Dalea purpurea</i> Vent.	7.6 to 7.8	<i>Festuca rubra</i> L.	3.3 to 9.1
<i>Danthonia spicata</i> (L.) Roem. & Schult.	7.6 to 7.8	<i>Festuca trachyphylla</i> Hack. #	4.5 to 9.1
<i>Delphinium confusum</i> Popov	5 to 7	<i>Festuca valesiaca</i> Schleich. ex Gaudin	5 to 7
<i>Deschampsia cespitosa</i> (L.) P.Beauv.	3.3 to 8.1	<i>Festuca vivipara</i> (L.) Sm.	4.4 to 5.8
<i>Deschampsia flexuosa</i> (L.) Trin.	3.3 to 7.2	<i>Filago pyramidata</i> L.	6 to 6.7
<i>Dianthus longicaulis</i> L.	4.5 to 9.1	<i>Filipendula vulgaris</i> Moench	4.5 to 8.7
<i>Dianthus superbus</i> L.	5 to 7	<i>Fragaria moschata</i> Duchesne #	5.6 to 8.7
<i>Diapensia lapponica</i> L.	4.4 to 5.8	<i>Fragaria vesca</i> L.	4.5 to 8.7
<i>Digitalis parviflora</i> Jacq.	5 to 5.2	<i>Fraxinus americana</i> L.	7.6 to 7.8
<i>Digitaria ciliaris</i> (Retz.) Koeler	4.4 to 7.6	<i>Fraxinus pennsylvanica</i> Marshall	4.9 to 6.4
<i>Doellingeria umbellata</i> (Mill.) Nees	4.4 to 8.1	<i>Galatella chromopappa</i> Novopokr.	5 to 7
<i>Drosera rotundifolia</i> L.	5.1 to 5.3	<i>Galium aparine</i> L.	4.4 to 7
<i>Dryas octopetala</i> L.	4.4 to 5.8	<i>Galium boreale</i> L.	4.5 to 8.7
<i>Echinacea pallida</i> (Nutt.) Nutt.	7.6 to 7.8	<i>Galium estebanii</i> Sennen	5 to 5.2
<i>Eleocharis palustris</i> (L.) Roem. & Schult.	4.6 to 6.2	<i>Galium mollugo</i> L.	5 to 6.7
<i>Eleocharis palustris</i> var. <i>vigens</i>	4.1 to 4.9	<i>Galium saxatile</i> L.	3.3 to 6.1
<i>Elytrigia repens</i> Desv.	5 to 7	<i>Galium verum</i> L.	4.5 to 9.1
<i>Empetrum nigrum</i> L.	4.4 to 5.8	<i>Genista anglica</i> L.	5.1 to 5.3
<i>Epilobium angustifolium</i> L.	3.3 to 8.1	<i>Genista sagittalis</i> L.	5 to 6.7
<i>Equisetum fluviatile</i> L.	4.6 to 6.2	<i>Gentiana nivalis</i> L.	4.4 to 5.8

Supporting information

Species	pH range	Species	pH range
<i>Gentiana pneumonanthe</i> L.	5 to 5.2	<i>Juncus bulbosus</i> L.	4.6 to 6.2
<i>Gentiana purpurea</i> L.	5 to 5.1	<i>Juncus effusus</i> L.	6.5 to 6.9
<i>Gentianella amarella</i> (L.) Harry Sm.	4.4 to 5.8	<i>Juncus filiformis</i> L.	4.6 to 6.2
<i>Gentianopsis virgata</i> (Raf.) Holub	4.4 to 8.1	<i>Juncus trifidus</i> L.	4.4 to 5.8
<i>Geranium collinum</i> Stephan ex Willd.	5 to 7	<i>Juniperus communis</i> L.	4.4 to 5.8
<i>Geranium molle</i> L.	4.3 to 6.1	<i>Juniperus virginiana</i> L.	7.6 to 7.8
<i>Geranium sylvaticum</i> L.	4.4 to 8.1	<i>Knautia maxima</i> (L.) Coult.	4.5 to 8.7
<i>Glandora diffusa</i> (Lag.) D.C.Thomas	5 to 6.7	<i>Koeleria glauca</i> (Spreng.) DC.	4.5 to 9.1
<i>Globularia cordifolia</i> L.	6.9 to 7	<i>Koeleria macrantha</i> (Ledeb.) Schult.	5.4 to 7
<i>Glyceria fluitans</i> (L.) R.Br.	4.6 to 6.2	<i>Koeleria micrathera</i> (Desv.) Griseb.	5 to 7
<i>Helenium autumnale</i> L.	4.4 to 6	<i>Koeleria vallesiana</i> (Honck.) Bertol. ex Schult.	6.2 to 6.7
<i>Helianthemum croceum</i> (Cav.) Losa & Rivas Goday	4.5 to 8.7	<i>Lathyrus linifolius</i> (Reichard) Bassler	4.5 to 7.2
<i>Helianthemum oelandicum</i> [#]	6.9 to 7.4	<i>Lathyrus pratensis</i> L.	4.5 to 8.7
<i>Helianthemum oelandicum</i> (Desf.) Pers.	6.2 to 6.7	<i>Leontodon hispidus</i> L.	3.3 to 5.7
<i>Helianthus divaricatus</i> L.	7.6 to 7.8	<i>Leontodon taraxacoides</i> (Vill.) Willd. ex Mérat	6 to 6.7
<i>Helianthus giganteus</i> L.	4.4 to 8.1	<i>Lespedeza capitata</i> Michx.	7.6 to 7.8
<i>Helichrysum arenarium</i> (L.) Moench	3.2 to 9.1	<i>Lespedeza davurica</i> (Laxm.) Schindl.	7 to 7.6
<i>Helictotrichon bromoides</i> (Gouan) C.E.Hubb.	6.2 to 6.7	<i>Leucanthemum vulgare</i> (Vaill.) Lam.	4.5 to 8.7
<i>Helictotrichon marginatum</i> (Lowe) Röser	5 to 6.7	<i>Libanotis schrenkiana</i> C.A. Mey. ex Schischk.	5 to 7
<i>Helictotrichon pratense</i> (L.) Pilg.	4.5 to 8.7	<i>Ligularia macrophylla</i> (Ledeb.) DC.	5 to 7
<i>Hieracium echinoides</i> Lumn.	5 to 7	<i>Linaria vulgaris</i> Mill.	7.3 to 7.6
<i>Hieracium pilosella</i> L.	3.3 to 5.7	<i>Lithospermum canescens</i> (Michx.) Lehm.	4.4 to 8.1
<i>Hieracium umbellatum</i> L.	4.5 to 8.7	<i>Lobelia kalmii</i> L.	4.1 to 4.9
<i>Hieracium virosum</i> Pall.	5 to 7	<i>Lotus corniculatus</i> L.	3.3 to 8.7
<i>Holcus lanatus</i> L.	3.3 to 6.2	<i>Luzula campestris</i> (L.) DC.	3.3 to 8.7
<i>Holcus mollis</i> L.	3.3 to 5.7	<i>Luzula multiflora</i> subsp. <i>frigida</i> (Buchenau) V.I.Krecz.	4.4 to 5.8
<i>Hydrocotyle vulgaris</i> L.	5.2 to 5.8	<i>Luzula spicata</i> (L.) DC.	4.4 to 5.8
<i>Hypericum elongatum</i> Ledeb.	5 to 7	<i>Luzula sudetica</i> (Willd.) Schult.	4.4 to 5.8
<i>Hypericum perforatum</i> L.	4.5 to 8.7	<i>Lycopus americanus</i> Muhl. ex W.P.C.Barton	4.4 to 8.1
<i>Hypericum scabrum</i> L.	5 to 7	<i>Maianthemum stellatum</i> (L.) Link	4.4 to 8.1
<i>Iris halophila</i> var. <i>sogdiana</i>	5 to 7	<i>Malva moschata</i> L.	6 to 6.2
<i>Ixeris chinensis</i> (Thunb. ex Thunb.) Nakai	7 to 8.1	<i>Manfreda virginica</i> (L.) Salisb. ex Rose	7.6 to 7.8
<i>Ixiolirion tataricum</i> (Pall.) Schult. & Schult.f.	5 to 7	<i>Medicago falcata</i> L.	4.5 to 9.1
<i>Juglans nigra</i> L.	4.9 to 5.5	<i>Medicago lupulina</i> L.	4.3 to 8.7
<i>Juncus acutiflorus</i> Ehrh. ex Hoffm.	4.6 to 6.2	<i>Medicago ruthenica</i> (L.) Ledeb.	4.1 to 8.1
<i>Juncus bufonius</i> L.	4.3 to 6.1	<i>Molinia caerulea</i> (L.) Moench	3.3 to 8.1

Appendix S2.4

Species	pH range	Species	pH range
<i>Muhlenbergia glomerata</i> (Willd.) Trin.	7.5 to 8.1	<i>Platanus occidentalis</i> L.	4.9 to 6.3
<i>Muhlenbergia mexicana</i> (L.) Trin.	4.1 to 6	<i>Poa alpina</i> L.	4.4 to 5.8
<i>Myosotis scorpioides</i> L.	4.6 to 6.2	<i>Poa angustifolia</i> L.	5 to 7
<i>Myosotis sylvatica</i> Ehrh. ex Hoffm.	5 to 7	<i>Poa annua</i> L.	4.3 to 6.1
<i>Nardus stricta</i> L.	3.3 to 6.2	<i>Poa bulbosa</i> L.	5 to 7
<i>Nepeta mariae</i> Regel	5 to 7	<i>Poa compressa</i> L.	6 to 6.2
<i>Nepeta nuda</i> subsp. <i>nuda</i>	5 to 7	<i>Poa humilis</i> Ehrh. ex Hoffm.	4.5 to 8.7
<i>Nummularia quadriflora</i> (Sims) Farw.	7.4 to 7.9	<i>Poa pratensis</i> L.	3.3 to 9.1
<i>Omalotheca norvegica</i> (Gunnerus) Sch.Bip. & F.W.Schultz	4.4 to 5.8	<i>Poa pratensis</i> subsp. <i>pratensis</i>	4.5 to 8.7
<i>Origanum vulgare</i> subsp. <i>gracile</i> (K.Koch) Letsw.	5 to 7	<i>Poa trivialis</i> L.	4.6 to 6.2
<i>Orobanche coerulescens</i> Stephan ex Willd.	4.4 to 7.5	<i>Polygala comosa</i> Schkuhr	5 to 7
<i>Orobanche elatior</i> Sutton	5 to 7	<i>Polygala serpyllifolia</i> Hosé	5.1 to 5.3
<i>Ostrya virginiana</i> (Mill.) K.Koch	4.1 to 4.9	<i>Polygala vulgaris</i> L.	4.5 to 7.2
<i>Oxyria digyna</i> (L.) Hill	4.4 to 5.8	<i>Populus deltoides</i> W. Bartram ex Marshall	5.4 to 6.3
<i>Oxytropis aulicatisensis</i> Vved.	5 to 7	<i>Potentilla argentea</i> L.	4.5 to 8.7
<i>Parnassia palustris</i> <i>Parnassia palustris</i> L.	4.4 to 7.3	<i>Potentilla bifurca</i> var. <i>major</i>	5 to 7
<i>Parthenocissus quinquefolia</i> (L.) Planch.	4.5 to 7.8	<i>Potentilla crantzii</i> (Crantz) Beck ex Fritsch	4.4 to 5.8
<i>Pedicularis lapponica</i> L. #	4.1 to 7.5	<i>Potentilla erecta</i> (L.) Raeusch.	3.3 to 8.1
<i>Pedicularis nodosa</i> Pennell#	5.1 to 5.3	<i>Potentilla fruticosa</i> L.	4.1 to 6
<i>Pedicularis oederi</i> Vahl	4.4 to 5.8	<i>Potentilla neumanniana</i> Rchb.	5 to 6.7
<i>Pedicularis sylvatica</i> L. #	4.4 to 5.8	<i>Potentilla pedata</i> Nestl.	5 to 7
<i>Persicaria vivipara</i> (L.) Ronse Decr.	4.4 to 5.8	<i>Potentilla verna</i> L. #	5.2 to 8.7
<i>Petrorhagia alpina</i> (Hablitz) P.W.Ball & Heywood	5 to 7	<i>Primula veris</i> L.	5 to 8.7
<i>Phleum alpinum</i> L.	4.4 to 5.8	<i>Prunella vulgaris</i> L.	3.3 to 7
<i>Phleum phleoides</i> (L.) H.Karst.	4.5 to 9.1	<i>Pseudolysimachion spurium</i> (L.) Rauschert	5 to 7
<i>Phleum pratense</i> L.	4.5 to 8.7	<i>Pteridium aquilinum</i> (L.) Kuhn	3.3 to 5.7
<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	4.7 to 5.3	<i>Pycnanthemum virginianum</i> (L.) T.Durand & B.D.Jacks. ex B.L.Rob. & Fernald	4.1 to 8.1
<i>Phyllodoce caerulea</i> (L.) Bab.	4.4 to 5.8	<i>Quercus alba</i> L.	7.6 to 7.8
<i>Physostegia virginiana</i> (L.) Benth.	7.6 to 7.8	<i>Quercus bicolor</i> Willd.	4.9 to 5.9
<i>Pilosella officinarum</i> Vaill. #	4.5 to 9.1	<i>Quercus coccinea</i> Münchh.	4.4 to 7.8
<i>Pilosella peleteriana</i> (Mérat) F.W.Schultz & Sch.Bip. #	4.5 to 8.7	<i>Quercus macrocarpa</i> Michx.	4.9 to 5.5
<i>Pimpinella saxifraga</i> L.	3.3 to 8.7	<i>Quercus palustris</i> Münchh.	4.9 to 6.3
<i>Pimpinella tragiium</i> Vill. #	6.2 to 6.7	<i>Quercus stellata</i> Wangenh.	4.1 to 4.9
<i>Pinguicula vulgaris</i> L.	4.4 to 5.8	<i>Quercus velutina</i> Lam.	4.1 to 4.9
<i>Plantago lanceolata</i> L.	3.3 to 8.7	<i>Ranunculus acris</i> L.	3.3 to 8.7
<i>Plantago media</i> L.	6.1 to 8.7	<i>Ranunculus bulbosus</i> L.	3.3 to 8.7

Supporting information

Species	pH range	Species	pH range
<i>Ranunculus flammula</i> L.	4.6 to 6.2	<i>Silene legionensis</i> Lag.	6.2 to 6.7
<i>Ranunculus polyanthemos</i> L.	4.5 to 8.7	<i>Silene viscaria</i> (L.) Jess.	4.5 to 8.7
<i>Rhinanthus minor</i> L. #	4.4 to 5.8	<i>Silphium integrifolium</i> Michx.	4.1 to 8.1
<i>Rhus aromatica</i> Aiton	7.6 to 7.8	<i>Silphium perfoliatum</i> L.	7.1 to 7.7
<i>Rhus glabra</i> L.	7.6 to 7.8	<i>Smilax bona-nox</i> L.	4.4 to 7.8
<i>Rhynchospora alba</i> (L.) Vahl	5.1 to 5.5	<i>Solidago nemoralis</i> Aiton	7.6 to 7.8
<i>Rhynchospora fusca</i> (L.) W.T.Aiton	5.4 to 5.6	<i>Solidago ohioensis</i> Riddell	4.4 to 8.1
<i>Rosa canina</i> L.	6.2 to 6.7	<i>Solidago speciosa</i> A.Gray	7.6 to 7.8
<i>Rubus occidentalis</i> L.	4.4 to 8.1	<i>Solidago virgaurea</i> L.	4.4 to 7
<i>Rudbeckia hirta</i> L.	4.1 to 4.9	<i>Sorghastrum nutans</i> (L.) Nash	7.6 to 7.8
<i>Rumex acetosa</i> L.	3.3 to 8.7	<i>Stachys betoniciflora</i> Rupr.	5 to 7
<i>Rumex acetosella</i> L.	4.3 to 9.1	<i>Stellaria borealis</i> L.	4.5 to 8.7
<i>Sagina saginoides</i> (L.) H.Karst.	4.4 to 5.8	<i>Stellaria longifolia</i> (L.) Vill.	4.3 to 6.1
<i>Salix gordejewii</i> Y.L. Chang & Skvortsov	7 to 7.6	<i>Succisa pratensis</i> Moench#	5.6 to 6
<i>Salix hastata</i> L.	4.4 to 5.8	<i>Symphyotrichum firmum</i> (Nees) G.L.Nesom	7.1 to 7.7
<i>Salix lanata</i> L.	4.4 to 5.8	<i>Symphyotrichum oblongifolium</i> (Nutt.) G.L.Nesom	7.6 to 7.8
<i>Salix phyllitfolia</i> L. #	4.4 to 5.8	<i>Symphyotrichum oolentangiense</i> (Riddell) G.L.Nesom	7.5 to 8.1
<i>Salix repens</i> L. #	4.4 to 5.8	<i>Symphyotrichum patens</i> (Aiton) G.L.Nesom	7.6 to 7.8
<i>Salix reticulata</i> L.	4.4 to 5.8	<i>Taraxacum montanum</i> (C.A.Mey.) DC.	5 to 7
<i>Salsola collina</i> Pall.	7 to 7.6	<i>Taraxacum officinale</i> Webb	4.3 to 6.1
<i>Saposhnikovia divaricata</i> (Turcz.) Schischk.	7 to 7.6	<i>Teucrium chamaedrys</i> L.	6.2 to 6.7
<i>Saussurea alpina</i> (L.) DC.	4.4 to 5.8	<i>Teucrium pyrenaicum</i> L.	6.2 to 6.7
<i>Saxifraga aizoides</i> L.	4.4 to 5.8	<i>Thalictrum alpinum</i> L.	4.4 to 5.8
<i>Scaligeria setacea</i> (Schrenk) Korovin	5 to 7	<i>Thalictrum dasycarpum</i> Fisch., C.A.Mey. & Avé-Lall.	4.1 to 6
<i>Schizachyrium scoparium</i> (Michx.) Nash	4.4 to 8.1	<i>Thalictrum minus</i> L.	5 to 7.6
<i>Schmaltzia copallinum</i> (L.) Small	7.6 to 7.8	<i>Thymus mastigophorus</i> Lacaita	6.2 to 6.7
<i>Scleranthus perennis</i> L.	4.5 to 9.1	<i>Thymus nervosus</i> J.Gay ex Coste	7.3 to 7.4
<i>Scorzonera turkestanica</i> Franch.	5 to 7	<i>Thymus pulegioides</i> L.	5 to 6.7
<i>Sedum acre</i> L.	4.5 to 9.1	<i>Thymus serpyllum</i> L.	4.5 to 9.1
<i>Sedum forsterianum</i> Sm.	5 to 6.7	<i>Tiedemannia rigida</i> (L.) J.M. Coult. & Rose	4.4 to 8.1
<i>Selaginella selaginoides</i> (L.) P. Beauv. ex Mart. & Schrank	4.4 to 5.8	<i>Tofieldia pusilla</i> (Michx.) Pers.	4.4 to 5.8
<i>Senecio jacobaea</i> L.	4.3 to 6.1	<i>Tragopogon</i> sp.	5 to 7
<i>Seseli libanotis</i> (L.) Koch	6 to 6.7	<i>Trichophorum cespitosum</i> (L.) Hartm.	4 to 4.2
<i>Seseli mucronatum</i> (Schrenk) Pimenov & Sdobnina	5 to 7	<i>Trifolium alpinum</i> L.	5 to 5.1
<i>Sesleria albicans</i> Kit.	7.3 to 7.4	<i>Trifolium dubium</i> Sibth.	4.3 to 6.1
<i>Setaria viridis</i> (L.) P.Beauv.	7 to 7.6	<i>Trifolium medium</i> L.	4.5 to 8.7
<i>Silene himalayensis</i> (L.) Jacq.	4.4 to 5.8		

Appendix S2.4

Species	pH range	Species	pH range
<i>Trifolium pratense</i> L.	4.5 to 8.7	<i>Agrostis stolonifera</i> L.	3.5 to 6.7
<i>Trifolium repens</i> L.	4.3 to 8.7	<i>Ajuga reptans</i> L.	3.3 to 7.8
<i>Trifolium striatum</i> L.	5 to 6.7	<i>Andromeda polifolia</i> L.	3.3 to 5.3
<i>Tripleurospermum maritimum</i> subsp. <i>inodorum</i> (L.)	4.3 to 6.1	<i>Anemone blanda</i> Schott & Kotschy	5.1 to 7.4
<i>Trisetum spicatum</i> (L.) K.Richt.	4.4 to 5.8	<i>Anemone nemorosa</i> L.	3.5 to 6.7
<i>Turritis glabra</i> L.	5 to 7	<i>Anthoxanthum odoratum</i> L.	4.6 to 6.5
<i>Typha angustifolia</i> L.	4.1 to 6	<i>Aremonia agrimonoides</i> (L.) DC.	5.1 to 7.4
<i>Ulmus alata</i> Michx.	7.6 to 7.8	<i>Arnica cordifolia</i> Hook.	6.4 to 8.2
<i>Ulmus americana</i> L.	4.9 to 6.3	<i>Asarum europaeum</i> L.	3.3 to 7.8
<i>Vaccinium myrtillus</i> L.	4.4 to 5.8	<i>Asperula gunnii</i> Hook.f.	4.6 to 4.8
<i>Vaccinium uliginosum</i> L.	4.4 to 5.8	<i>Asplenium ramosum</i> L.	3.3 to 7.8
<i>Vaccinium vitis-idaea</i> L.	4.4 to 5.8	<i>Aster bellidiflorus</i> (L.) Scop.	3.3 to 7.8
<i>Veronica alpina</i> L.	4.4 to 5.8	<i>Athyrium filix-femina</i> (L.) Roth	3.3 to 7.8
<i>Veronica arvensis</i> L.	4.5 to 8.7	<i>Balsamorhiza sagittata</i> (Pursh) Nutt.	7 to 8.2
<i>Veronica chamaedrys</i> L.	4.5 to 8.7	<i>Betula pubescens</i> Ehrh.	3.3 to 5.3
<i>Veronica officinalis</i> L.	4.5 to 7.2	<i>Blechnum spicant</i> (L.) Sm.	3.3 to 7.8
<i>Vicia cracca</i> L.	4.5 to 8.7	<i>Brachypodium pinnatum</i> (L.) P.Beauv.	7.4 to 8.1
<i>Vicia sativa</i> L.	5.4 to 6.1	<i>Brachypodium sylvaticum</i> (Huds.) P.Beauv.	6.9 to 7.4
<i>Vicia tenuifolia</i> Roth	5 to 7	<i>Buphthalmum salicifolium</i> L.	3.3 to 7.8
<i>Viola biflora</i> L.	4.4 to 5.8	<i>Calamagrostis arundinacea</i> (L.) Roth	3.5 to 6.1
<i>Viola blanda</i> Salisb.	4.4 to 8.1	<i>Calamagrostis epigeios</i> (L.) Roth	3.3 to 7.8
<i>Viola blandiformis</i> Nakai [#]	5 to 5.1	<i>Calamagrostis quadriseta</i> (Labill.) Spreng.	4.6 to 4.8
<i>Viola canina</i> L. [#]	6.3 to 8.1	<i>Calamagrostis rubescens</i> Buckley	6.4 to 8.2
<i>Viola riviniana</i> Rehb.	4.1 to 5.7	<i>Calamagrostis villosa</i> (Chaix) J.F.Gmel.	3.1 to 6.7
<i>Ziziphora clinopodioides</i> Lam.	5 to 7	<i>Calluna vulgaris</i> (L.) Hull	3.3 to 5.3
(j) Temperate coniferous forest		<i>Caltha palustris</i> L.	3.1 to 6.7
<i>Abies alba</i> Mill.	3.3 to 7.8	<i>Campanula glomerata</i> subsp. <i>glomerata</i>	3.3 to 7.8
<i>Abies cephalonica</i> Loudon	5.1 to 8.3	<i>Cardamine astoniae</i> I.Thomps.	4.6 to 4.8
<i>Acaena novae-zelandiae</i> Kirk [#]	4.6 to 4.8	<i>Cardamine pratensis</i> L.	4.7 to 6.7
<i>Acer hyrcanum</i> Fisch. & C.A.Mey.	7.2 to 7.4	<i>Cardamine trifolia</i> L.	3.5 to 6.1
<i>Achillea millefolium</i> L.	4.6 to 6.5	<i>Carduus defloratus</i> L.	3.3 to 7.8
<i>Aciphylla simplicifolia</i> (F.Muell.) Benth.	4.6 to 4.8	<i>Carex appressa</i> R.Br.	4.6 to 4.8
<i>Actaea spicata</i> L.	3.3 to 7.8	<i>Carex brachystachys</i> Schrank	3.3 to 7.8
<i>Adenostyles alliariae</i> (Gouan) A.Kern.	3.6 to 7.8	<i>Carex brizoides</i> L.	3.1 to 6.7
<i>Adenostyles alpina</i> (L.) Bluff & Fingerh.	3.3 to 7.8	<i>Carex davalliana</i> Sm.	3.3 to 6.7
<i>Agrostis capillaris</i> L.	3.3 to 7.8	<i>Carex digitata</i> L.	3.3 to 7.8
		<i>Carex echinata</i> Murray	3.1 to 6.7

Supporting information

Species	pH range	Species	pH range
<i>Carex flava</i> L.	4.7 to 6.7	<i>Elymus spicatus</i> (Pursh) Gould	7 to 8.2
<i>Carex humilis</i> Leyss.	3.3 to 7.8	<i>Empetrum nigrum</i> L.	3.3 to 5.3
<i>Carex leporina</i> L.	3.3 to 7.5	<i>Empetrum nigrum</i> subsp. <i>hermaphroditum</i> (Hagerup) Böcher	3.7 to 3.8
<i>Carex montana</i> L.	3.3 to 7.8	<i>Epilobium montanum</i> L.	3.3 to 7.8
<i>Carex nigra</i> (L.) Reichard	3.1 to 6.7	<i>Epipactis atrorubens</i> (Hoffm.) Besser	3.3 to 7.8
<i>Carex ornithopoda</i> subsp. <i>ornithopoda</i>	3.3 to 7.8	<i>Epipactis helleborine</i> (L.) Crantz	3.3 to 7.8
<i>Carex pallescens</i> L.	3.3 to 7.8	<i>Equisetum palustre</i> L.	3.3 to 6.7
<i>Carex pauciflora</i> Lightf.	3.1 to 6.7	<i>Equisetum sylvaticum</i> L.	3.5 to 6.7
<i>Carex pendula</i> Huds.	3.3 to 7.8	<i>Eriophorum vaginatum</i> L.	3.1 to 4.5
<i>Carex pilulifera</i> L.	3.3 to 7.8	<i>Eucalyptus</i> sp.	4.6 to 4.8
<i>Carex remota</i> L.	3.3 to 7.8	<i>Eupatorium cannabinum</i> L.	3.3 to 7.8
<i>Carex rostrata</i> Stokes	3.3 to 6.7	<i>Euphorbia amygdaloides</i> L.	3.3 to 7.8
<i>Cassinia uncata</i> A.Cunn. ex DC.	4.6 to 4.8	<i>Euphorbia dulcis</i> L.	3.3 to 7.8
<i>Cephalanthera longifolia</i> (L.) Fritsch	3.3 to 7.8	<i>Euphrasia collina</i> R.Br.	4.6 to 4.8
<i>Chaerophyllum eriopodum</i> (DC.) K.F.Chung [#]	4.6 to 6.5	<i>Euphrasia rostkoviana</i> Hayne	4.7 to 6.7
<i>Chaerophyllum hirsutum</i> L.	3.5 to 6.7	<i>Fagus sylvatica</i> L.	3.3 to 7.8
<i>Cirsium erisithales</i> (Jacq.) Scop.	3.3 to 7.8	<i>Festuca heterophylla</i> Lam.	3.5 to 6.7
<i>Cirsium palustre</i> (L.) Coss. ex Scop.	3.3 to 7.8	<i>Filipendula ulmaria</i> (L.) Maxim.	3.5 to 6.7
<i>Clematis vitalba</i> L.	3.3 to 7.8	<i>Fragaria vesca</i> L.	3.5 to 6.1
<i>Convallaria majalis</i> L.	3.3 to 7.8	<i>Fraxinus ornus</i> L.	7.2 to 7.4
<i>Cornus suecica</i> L.	3.3 to 5.3	<i>Galium album</i> subsp. <i>album</i>	3.3 to 7.8
<i>Corydalis solida</i> (L.) Clairv.	6.9 to 7.4	<i>Galium lucidum</i> All.	3.3 to 7.8
<i>Craspedia aurantia</i> J.Everett & Joy Thomps.	4.6 to 4.8	<i>Galium palustre</i> L.	4.7 to 6.7
<i>Crepis fraasii</i> Sch.Bip.	5.1 to 6.3	<i>Galium rotundifolium</i> L.	3.3 to 7.8
<i>Crepis paludosa</i> (L.) Moench	3.3 to 6.7	<i>Galium sylvaticum</i> L.	3.3 to 7.8
<i>Cruciata glabra</i> (L.) Ehrend.	3.5 to 6.1	<i>Gentiana asclepiadea</i> L.	3.3 to 7.8
<i>Dactylorhiza maculata</i> (L.) Soó	3.5 to 6.7	<i>Geranium potentilloides</i> L'Hér. ex DC.	4.6 to 4.8
<i>Daphne mezereum</i> L.	3.3 to 7.8	<i>Geum rivale</i> L.	4.7 to 6.7
<i>Deschampsia cespitosa</i> (L.) P.Beauv.	3.3 to 7.8	<i>Grevillea australis</i> R.Br.	4.6 to 4.8
<i>Deschampsia flexuosa</i> (L.) Trin.	3.3 to 5.3	<i>Gymnocarpium dryopteris</i> (L.) Newman	3.3 to 7.8
<i>Digitalis grandiflora</i> Mill.	3.3 to 7.8	<i>Gymnocarpium robertianum</i> (Hoffm.) Newman	3.3 to 7.8
<i>Doronicum orientale</i> Hoffm.	5.1 to 7.4	<i>Hedera helix</i> L.	3.3 to 7.8
<i>Dorycnium pentaphyllum</i> Scop.	7.4 to 8.1	<i>Helichrysum microcephalum</i> A.Cunn. ex DC.	4.6 to 4.8
<i>Dryopteris affinis</i> Fraser-Jenk. [#]	3.3 to 7.8	<i>Helictotrichon convolutum</i> (J.Presl) Henrard	7.2 to 8.3
<i>Dryopteris expansa</i> (C. Presl) Fraser- Jenk. & Jermy	3.1 to 6.1	<i>Heracleum austriacum</i> L. [#]	3.3 to 7.8
<i>Dryopteris filix-mas</i> (L.) Schott	3.3 to 7.8	<i>Hieracium murorum</i> L.	3.5 to 6.1
<i>Echium plantagineum</i> L.	6.1 to 6.5	<i>Hovea montana</i> (Hook.f.) J.H.Ross	4.6 to 4.8

Appendix S2.4

Species	pH range	Species	pH range
<i>Huperzia selago</i> (L.) Bernh. ex Schrank & Mart.	3.3 to 7.8	<i>Olearia phlogopappa</i> (Labill.) DC.	4.6 to 4.8
<i>Hypericum hirsutum</i> L.	3.3 to 7.8	<i>Oreopteris limbosperma</i> Holub	3.3 to 7.8
<i>Hypericum maculatum</i> subsp. <i>immaculatum</i> (Murb.) A.Fröhl.	3.3 to 7.8	<i>Origanum vulgare</i> L.	3.3 to 7.8
<i>Hypochoeris radicata</i> L.	5.2 to 6.5	<i>Ostrya carpinifolia</i> Scop.	7.2 to 7.4
<i>Juncus effusus</i> L.	3.3 to 7.8	<i>Oxalis acetosella</i> L.	3.5 to 6.7
<i>Juncus filiformis</i> L.	3.1 to 4.3	<i>Paris quadrifolia</i> L.	3.3 to 7.8
<i>Juniperus oxycedrus</i> L.	5.1 to 8.3	<i>Parnassia palustris</i> <i>Parnassia palustris</i> L.	3.5 to 6.7
<i>Knautia arvensis</i> [#]	3.3 to 7.8	<i>Persicaria vivipara</i> (L.) Ronse Decr.	4.1 to 5.6
<i>Larix decidua</i> Mill.	3.3 to 7.8	<i>Phegopteris connectilis</i> (Michx.) Watt	3.3 to 7.8
<i>Laserpitium latifolium</i> L. [#]	3.3 to 7.8	<i>Phillyrea latifolia</i> L.	7.7 to 8.3
<i>Lilium chalcedonicum</i> L.	6.9 to 7.4	<i>Picea abies</i> (L.) H.Karst.	3.1 to 7.8
<i>Lilium martagon</i> L.	3.3 to 7.8	<i>Pimelea alpina</i> F. Muell. ex Meisn.	4.6 to 4.8
<i>Linnaea borealis</i> L.	3.3 to 4.5	<i>Pimpinella major</i> (L.) Huds.	3.3 to 7.8
<i>Lonicera hetrusca</i> Host [#]	3.3 to 7.8	<i>Pinguicula vulgaris</i> L.	4.7 to 6.7
<i>Lonicera periclymenum</i> Lour. [#]	7.2 to 7.4	<i>Pinus nigra</i> subsp. <i>pallasiana</i> (Lamb.) Holmboe	4.5 to 8.3
<i>Luzula luzulina</i> (Vill.) Racib.	3.1 to 7.8	<i>Pinus sylvestris</i> L.	3.3 to 5.3
<i>Luzula luzuloides</i> (Lam.) Dandy & Wilmott	3.5 to 6.1	<i>Platanus orientalis</i> L.	7.7 to 8.3
<i>Luzula nodulosa</i> E.Mey.	7.2 to 7.4	<i>Poa alpina</i> L.	3.5 to 6.1
<i>Luzula novae-cambriae</i> Gand.	4.6 to 4.8	<i>Poa fawcettiae</i> Vickery	4.6 to 4.8
<i>Luzula pilosa</i> (L.) Willd.	3.1 to 7.5	<i>Poa helmsii</i> Vickery	4.6 to 4.8
<i>Luzula sylvatica</i> subsp. <i>sylvatica</i>	3.3 to 7.8	<i>Poa hiemata</i> Vickery	4.6 to 4.8
<i>Lycopodium annotinum</i> L.	3.3 to 7.8	<i>Polygala chamaebuxus</i> L.	3.3 to 7.8
<i>Maianthemum bifolium</i> (L.) F.W.Schmidt	3.1 to 6.7	<i>Polygala vulgaris</i> L.	4.7 to 6.7
<i>Melampyrum pratense</i> L.	3.3 to 5.3	<i>Polygonatum multiflorum</i> (L.) All.	3.3 to 7.8
<i>Melica nutans</i> L.	3.3 to 7.8	<i>Polygonatum verticillatum</i> (L.) All.	3.3 to 7.8
<i>Melittis melissophyllum</i> subsp. <i>carpatica</i> (Klokov) P.W.Ball	3.3 to 7.8	<i>Polystichum aculeatum</i> (L.) Schott	3.3 to 7.8
<i>Mentha longifolia</i> (L.) L.	3.3 to 7.8	<i>Poranthera microphylla</i> Brongn.	4.6 to 4.8
<i>Mercurialis perennis</i> L.	3.3 to 7.8	<i>Potentilla erecta</i> (L.) Raeusch.	3.1 to 6.7
<i>Mnium biflorum</i> J.R. Forst. & G. Forst.	4.6 to 4.8	<i>Potentilla micrantha</i> Ram. ex DC.	6.9 to 7.4
<i>Moehringia muscosa</i> L.	3.3 to 7.8	<i>Prasophyllum alpestre</i> D.L.Jones	4.6 to 4.8
<i>Molinia caerulea</i> (L.) Moench	3.3 to 7.8	<i>Pseudotsuga menziesii</i> (Mirb.) Franco	6.4 to 7
<i>Mycelis muralis</i> (L.) Dumort.	3.3 to 7.8	<i>Pteridium aquilinum</i> (L.) Kuhn	3.3 to 7.8
<i>Myosotis densiflora</i> C. Koch	5.1 to 7.4	<i>Pulmonaria officinalis</i> L. [#]	3.3 to 7.8
<i>Nardus stricta</i> L.	3.3 to 6.7	<i>Quercus coccifera</i> L.	7.7 to 8.3
<i>Neillia monogyna</i> var. <i>malvacea</i>	6.4 to 8.2	<i>Ranunculus acris</i> L.	4.7 to 6.7
<i>Neottia nidus-avis</i> (L.) Rich.	3.3 to 7.8	<i>Ranunculus granitica</i> Melville ^{##}	4.6 to 4.8
		<i>Ranunculus serpens</i> subsp. <i>nemorosus</i> (DC.) G.López	3.3 to 7.8

Supporting information

Species	pH range	Species	pH range
<i>Rhododendron hirsutum</i> L. #	3.3 to 7.8	(k) Montane grassland and savanna	
<i>Ribes uva-crispa</i> L.	6.9 to 7.4	<i>Acronema nervosum</i> H.Wolff	6 to 7
<i>Rosa pendulina</i> L. #	3.3 to 7.8	<i>Ajuga integrifolia</i> Buch.-Ham.	6 to 7
<i>Rubus chamaemorus</i> L.	3.3 to 5.3	<i>Allium hypsistum</i> Stearn	6 to 7
<i>Rubus idaeus</i> L.	3.3 to 7.8	<i>Anaphalis triplinervis</i> (Sims) Sims ex C.B.Clarke	6 to 7
<i>Salix aurita</i> L.	3.3 to 5.3	<i>Andropogon munroi</i> C.B.Clarke	6 to 7
<i>Salvia glutinosa</i> L.	3.3 to 7.8	<i>Androsace globifera</i> Duby	6 to 7
<i>Scilla bifolia</i> L.	6.9 to 7.4	<i>Anemone rivularis</i> Buch.-Ham. ex DC.	6 to 7
<i>Scrophularia nodosa</i> L. #	3.3 to 7.8	<i>Arabis pterosperma</i> Edgew.	6 to 7
<i>Sesleria albicans</i> Kit.	3.3 to 7.8	<i>Arisaema flavum</i> (Forssk.) Schott	6 to 7
<i>Silene italica</i> (L.) Pers.	6.9 to 7.4	<i>Artemisia biennis</i> Willd.	6 to 7
<i>Solidago virgaurea</i> L.	3.3 to 7.8	<i>Artemisia carvifolia</i> Buch.-Ham. ex Roxb.	6 to 7
<i>Sorbus aria</i> Crantz	3.3 to 7.8	<i>Artemisia gmelinii</i> Weber	6 to 7
<i>Sorbus aucuparia</i> L.	3.3 to 7.8	<i>Aster himalaicus</i> C.B.Clarke	6 to 7
<i>Stachys alopecuroides</i> (L.) Benth.	3.3 to 7.8	<i>Aster indamellus</i> Griens.	6 to 7
<i>Stellaria patens</i> #	4.6 to 4.8	<i>Astragalus rhizanthus</i> Benth.	6 to 7
<i>Taraxacum officinale</i> Webb	3.3 to 7.5	<i>Axyris hybrida</i> L.	6 to 7
<i>Trichophorum alpinum</i> (L.) Pers.	4.7 to 6.7	<i>Berberis ceratophylla</i> G.Don	6 to 7
<i>Trientalis europaea</i> L.	3.3 to 5.3	<i>Brachypodium sylvaticum</i> (Huds.) P.Beauv.	6 to 7
<i>Trifolium heldreichianum</i> Hausskn.	7.4 to 8.1	<i>Brassica rapa</i> L.	6 to 7
<i>Trifolium pratense</i> L.	3.5 to 6.7	<i>Briza media</i> L.	6 to 7
<i>Trifolium repens</i> L.	3.5 to 6.7	<i>Bromus himalaicus</i> Stapf	6 to 7
<i>Ulmus glabra</i> Huds.	3.3 to 7.8	<i>Bupleurum hamiltonii</i> N.P.Balacr.	6 to 7
<i>Vaccinium myrtilloides</i> L.	3.1 to 7.8	<i>Calamagrostis lahulensis</i> G.Singh	6 to 7
<i>Vaccinium oxycoccos</i> L.	3.1 to 6.7	<i>Caltha palustris</i> L.	6 to 7
<i>Vaccinium uliginosum</i> L.	3.3 to 5.3	<i>Campanula pallida</i> Wall	6 to 7
<i>Vaccinium vitis-idaea</i> L.	3.1 to 6.7	<i>Cannabis sativa</i> L.	6 to 7
<i>Valeriana capitata</i> #	3.3 to 7.8	<i>Capsella bursa-pastoris</i> (L.) Medik.	6 to 7
<i>Valeriana capitata</i> Pall. ex Link #	3.3 to 7.5	<i>Carex orbicularis</i> Boott	6 to 7
<i>Valeriana officinalis</i> #	3.3 to 7.8	<i>Chenopodium album</i> L.	6 to 7
<i>Veratrum album</i> L.	3.3 to 7.8	<i>Chenopodium foliosum</i> Asch.	6 to 7
<i>Veronica chamaedrys</i> L.	3.3 to 7.5	<i>Chesneya cuneata</i> (Benth.) Ali	6 to 7
<i>Veronica officinalis</i> L.	3.3 to 7.8	<i>Cirsium falconeri</i> (Hook.f.) Petr.	6 to 7
<i>Vincetoxicum hirundinaria</i> Medik.	3.3 to 7.8	<i>Clematis graveolens</i> Lindl.	6 to 7
<i>Viola biflora</i> L.	3.5 to 6.7	<i>Convolvulus arvensis</i> L.	6 to 7
<i>Viola riviniana</i> Rehb.	5.1 to 6.3	<i>Cotoneaster microphyllus</i> var. <i>thymifolius</i>	6 to 7
		<i>Crepis elongata</i> Babc.	6 to 7

Appendix S2.4

Species	pH range	Species	pH range
<i>Crucihimalaya himalaica</i> (Edgew.) Al-Shehbaz, O'Kane & R.A.Price	6 to 7	<i>Herminium macrophyllum</i> (D.Don) Dandy	6 to 7
<i>Cuscuta europaea</i> L.	6 to 7	<i>Hippolytia gossypina</i> (C.B.Clarke) C.Shih	6 to 7
<i>Cynoglossum zeylanicum</i> (Lehm.) Brand	6 to 7	<i>Hippophae tibetana</i> Schldl.	6 to 7
<i>Dactylis glomerata</i> L.	6 to 7	<i>Hypericum revolutum</i> Vahl	5.5 to 6
<i>Danthonia cumminsii</i> Hook.f.	6 to 7	<i>Juncus triglumis</i> L.	6 to 7
<i>Delphinium williamsii</i> Munz	6 to 7	<i>Juniperus indica</i> Bertol.	6 to 7
<i>Deschampsia cespitosa</i> (L.) P.Beauv.	6 to 7	<i>Krascheninnikovia ceratoides</i> (L.) Gueldenst.	6 to 7
<i>Dicranostigma lactucoides</i> Hook.f. & Thomson	6 to 7	<i>Leontopodium jacotianum</i> Beauverd	6 to 7
<i>Dipsacus inermis</i> [#]	6 to 7	<i>Lepidium apetalum</i> Willd.	6 to 7
<i>Dysphania ambrosioides</i> (L.) Mosyakin & Clematis	6 to 7	<i>Leymus secalinus</i> (Georgi) Tzvelev	6 to 7
<i>Elephantopus scaber</i> L.	6 to 7	<i>Lilium nepalense</i> D.Don	6 to 7
<i>Elsholtzia eriostachya</i> (Benth.) Benth.	6 to 7	<i>Lobelia doniana</i> Skottsb. [#]	6 to 7
<i>Ephedra gerardiana</i> Wall. ex Stapf	6 to 7	<i>Lonicera alpigena</i> K.S. Hao ex P.S. Hsu & H.J. Wang	6 to 7
<i>Epipactis royleana</i> Lindl.	6 to 7	<i>Lotus corniculatus</i> L.	6 to 7
<i>Equisetum arvense</i> L.	6 to 7	<i>Malaxis muscifera</i> (Lindl.) Kuntze	6 to 7
<i>Eragrostis nigra</i> Nees ex Steud.	6 to 7	<i>Malva neglecta</i> Wallr.	6 to 7
<i>Erica arborea</i> L.	5.5 to 6	<i>Medicago edgeworthii</i> Sirj.	6 to 7
<i>Erigeron uniflorus</i> L.	6 to 7	<i>Medicago falcata</i> L.	6 to 7
<i>Eritrichium minimum</i> (Brand) H.Hara	6 to 7	<i>Medicago lupulina</i> L.	6 to 7
<i>Erodium stephanianum</i> Willd.	6 to 7	<i>Miscanthus nepalensis</i> (Trin.) Hack.	6 to 7
<i>Erysimum benthamii</i> Monnet	6 to 7	<i>Morina polyphylla</i> Wall. ex DC. [#]	6 to 7
<i>Euphrasia platyphylla</i> Pennell	6 to 7	<i>Nepeta ciliaris</i> Benth.	6 to 7
<i>Fagopyrum acutatum</i> (Lehm.) Mansf. ex K.Hammer	6 to 7	<i>Origanum vulgare</i> L.	6 to 7
<i>Fagopyrum esculentum</i> Moench	6 to 7	<i>Oxytropis microphylla</i> (Pall.) DC.	6 to 7
<i>Galium acutum</i> Edgew.	6 to 7	<i>Oxytropis williamsii</i> Vassilcz.	6 to 7
<i>Galium aparine</i> L.	6 to 7	<i>Pedicularis lanceolata</i> Michx. [#]	6 to 7
<i>Gaultheria trichophylla</i> Royle	6 to 7	<i>Pennisetum flaccidum</i> Griseb.	6 to 7
<i>Gentiana crassuloides</i> Bureau & Franch.	6 to 7	<i>Persicaria nepalensis</i> (Meisn.) Miyabe	6 to 7
<i>Gentiana pedicellata</i> (D.Don) Wall.	6 to 7	<i>Phleum alpinum</i> L.	6 to 7
<i>Gentiana robusta</i> King ex Hook.f.	6 to 7	<i>Picris angustifolia</i> subsp. <i>angustifolia</i> DC.	6 to 7
<i>Geranium donianum</i> Sweet	6 to 7	<i>Pinus wallichiana</i> A.B.Jacks.	6 to 7
<i>Gerbera nivea</i> (DC.) Sch.Bip.	6 to 7	<i>Plantago holosteum</i> Scop. [#]	6 to 7
<i>Gnaphalium affine</i> D.Don	6 to 7	<i>Poa annua</i> L.	6 to 7
<i>Halenia elliptica</i> D.Don	6 to 7	<i>Polygonatum verticillatum</i> (L.) All.	6 to 7
<i>Hedysarum campylocarpon</i> H.Ohashi	6 to 7	<i>Polygonum polystachyum</i> var. <i>polystachyum</i> [#]	6 to 7
<i>Heracleum nepalense</i> D. Don	6 to 7	<i>Polygonum rottboellioides</i> Jaub. & Spach	6 to 7

Supporting information

Species	pH range	Species	pH range
<i>Potentilla anserina</i> L.	6 to 7	<i>Actaea spicata</i> L.	4.1 to 6.4
<i>Potentilla cuneata</i> Wall. ex Lehm.	6 to 7	<i>Aegopodium podagraria</i> L.	5.1 to 7.7
<i>Potentilla fruticosa</i> L.	6 to 7	<i>Agrostis capillaris</i> L.	3.7 to 5.3
<i>Potentilla lineata</i> Trevir.	6 to 7	<i>Alnus incana</i> (L.) Moench	4.4 to 7.7
<i>Potentilla sericea</i> L.	6 to 7	<i>Alnus viridis</i> (Chaix) DC.	5.3 to 6.9
<i>Pterocephalus hookeri</i> (C.B. Clarke) Diels	6 to 7	<i>Anaphalis margaritacea</i> L. #	5.3 to 6.9
<i>Rosa sericea</i> Lindl.	6 to 7	<i>Anthoxanthum odoratum</i> L.	3.7 to 5.3
<i>Rubus pungens</i> Cambess.	6 to 7	<i>Arctostaphylos uva-ursi</i> (L.) Spreng.	3.2 to 4.8
<i>Rumex nepalensis</i> Spreng.	6 to 7	<i>Aster</i> sp.	5.3 to 6.9
<i>Saccharum rufipilum</i> Steud.	6 to 7	<i>Athyrium filix-femina</i> (L.) Roth	4.4 to 5.8
<i>Salvia hians</i> Royle ex Benth.	6 to 7	<i>Aucuparia americana</i> (Marshall) Nieuwl.	5.3 to 6.9
<i>Salvia nubicola</i> Wall. ex Sweet	6 to 7	<i>Betula pendula</i> Roth	5.1 to 7.7
<i>Saussurea stracheyana</i> (Kuntze) Lipsch. #	6 to 7	<i>Betula pubescens</i> Ehrh.	3.2 to 6.1
<i>Schefflera abyssinica</i> (Hochst. ex A.Rich.) Harms	5.5 to 6.2	<i>Betula pumila</i> L.	5.3 to 6.9
<i>Selinum wallichianum</i> (DC.) Raizada & H.O. Saxena	6 to 7	<i>Calamagrostis purpurea</i> (Trin.) Trin.	4.4 to 5.8
<i>Sibbaldia cuneata</i> Hornem. ex Kuntze	6 to 7	<i>Calluna vulgaris</i> (L.) Hull	3.2 to 4.8
<i>Silene gonosperma</i> (Rohrb.) Majumdar	6 to 7	<i>Carex digitata</i> L.	4 to 6.1
<i>Stellaria palustris</i> D. Don	6 to 7	<i>Chrysanthemum</i> sp.	5.3 to 6.9
<i>Stellera chamaejasme</i> L.	6 to 7	<i>Cicerbita alpina</i> (L.) Wallr.	4.4 to 5.8
<i>Swertia ciliata</i> (D. Don ex G. Don) B.L. Burt	6 to 7	<i>Clintonia borealis</i> (Sol.) Raf.	5.3 to 6.9
<i>Taraxacum eriopodium</i> (D.Don) DC.	6 to 7	<i>Convallaria majalis</i> L.	5.1 to 7.7
<i>Taraxacum nepalense</i> Soest#	6 to 7	<i>Corylus avellana</i> L.	4 to 6.1
<i>Thalictrum alpinum</i> L.	6 to 7	<i>Crepis paludosa</i> (L.) Moench	4.4 to 5.8
<i>Themeda triandra</i> Forssk.	6 to 7	<i>Cylactis pubescens</i> (Raf.) W.A. Weber	5.3 to 6.9
<i>Thymus linearis</i> Benth.	6 to 7	<i>Deschampsia flexuosa</i> (L.) Trin.	3.2 to 6.1
<i>Trifolium pratense</i> L.	6 to 7	<i>Diphasiastrum complanatum</i> (L.) Holub	3.2 to 4.4
<i>Triticum aestivum</i> L.	6 to 7	<i>Dryopteris expansa</i> (C. Presl) Fraser-Jenk. & Jermy	3.5 to 5.3
<i>Valeriana tripteris</i> Jones	6 to 7	<i>Dryopteris filix-mas</i> (L.) Schott	4 to 6.1
<i>Verbascum thapsus</i> L.	6 to 7	<i>Empetrum nigrum</i> L.	6.3 to 6.9
<i>Viola pilosa</i> Blume	6 to 7	<i>Empetrum nigrum</i> subsp. <i>hermaphroditum</i> (Hagerup) Böcher	3.2 to 4.8
(l) Boreal forest / taiga		<i>Epilobium angustifolium</i> L.	5.3 to 6.9
<i>Abies balsamea</i> (L.) Mill.	5.3 to 6.9	<i>Equisetum</i> sp.	5.8 to 6.9
<i>Acer platanoides</i> L.	4 to 6.1	<i>Filipendula ulmaria</i> (L.) Maxim.	4.4 to 5.8
<i>Achillea millefolium</i> L.	5.3 to 6.9	<i>Fragaria vesca</i> L.	4 to 6.9
<i>Aconitum septentrionale</i> Koelle	4.1 to 6.4	<i>Galium triflorum</i> Michx.	4.1 to 6.4
		<i>Gaultheria hispidula</i> (L.) Muhl. ex Bigelow	5.3 to 6.9
		<i>Geranium sylvaticum</i> L.	5.1 to 7.7

Appendix S2.4

Species	pH range	Species	pH range
<i>Geum rivale</i> L.	4.4 to 5.8	<i>Solidago virgaurea</i> L.	4.1 to 5.4
<i>Goodyera repens</i> (L.) R.Br.	3.2 to 4.4	<i>Sorbus aucuparia</i> L.	3.7 to 7.7
<i>Gymnocarpium dryopteris</i> (L.) Newman	3.5 to 6.4	<i>Spiraea alba</i> var. <i>latifolia</i> [#]	5.3 to 6.9
<i>Hepatica nobilis</i> Mill.	4 to 6.1	<i>Trientalis borealis</i> Raf.	5.3 to 6.9
<i>Hieracium murorum</i> L.	4 to 6.1	<i>Trientalis europaea</i> L.	3.5 to 5.3
<i>Iris versicolor</i> L.	5.3 to 6.9	<i>Trifolium repens</i> L.	5.8 to 6.9
<i>Juniperus communis</i> L.	5.3 to 6.9	<i>Trollius europaeus</i> L.	4.4 to 7.7
<i>Kalmia angustifolia</i> L.	5.3 to 6.9	<i>Vaccinium myrtillus</i> L.	3.2 to 6.1
<i>Larix laricina</i> (Du Roi) K.Koch	5.3 to 6.9	<i>Vaccinium stenophyllum</i> Steud.	5.3 to 6.9
<i>Lathyrus linifolius</i> (Reichard) Bassler	4 to 6.1	<i>Vaccinium vitis-idaea</i> L.	3.2 to 6.9
<i>Leontodon autumnalis</i> L.	5.3 to 6.9	<i>Veronica officinalis</i> L.	4 to 6.1
<i>Linnaea borealis</i> L.	3.2 to 6.9	<i>Viola riviniana</i> Rchb.	4 to 6.1
<i>Luzula pilosa</i> (L.) Willd.	3.5 to 5.1		
<i>Lycopodium annotinum</i> L.	3.5 to 5.1	(m) Tundra and alpine lands	
<i>Maianthemum bifolium</i> (L.) F.W.Schmidt	3.5 to 5.4	<i>Aconitum paradoxum</i> Rchb.	4.5 to 7.9
<i>Maianthemum canadense</i> Desf.	5.3 to 6.9	<i>Aconitum septentrionale</i> Koelle	4.4 to 4.5
<i>Melampyrum lineare</i> Lam. [#]	3.7 to 5.3	<i>Alchemilla alpina</i> L. [#]	4.4 to 4.5
<i>Melampyrum pratense</i> L.	4.9 to 5.7	<i>Anemone richardsonii</i> Hook.	5 to 7.4
<i>Melica mutans</i> L.	4 to 6.1	<i>Antennaria alpina</i> (L.) Gaertn.	4.4 to 4.5
<i>Milium effusum</i> L.	4.4 to 5.8	<i>Antennaria dioica</i> (L.) Gaertn.	4.4 to 4.5
<i>Oreopteris limbosperma</i> Holub	3.7 to 5.3	<i>Arctagrostis arundinacea</i> (Trin.) Beal	5 to 7.4
<i>Orthilia secunda</i> (L.) House	3.5 to 5.1	<i>Arctagrostis latifolia</i> (R.Br.) Griseb.	5 to 7.9
<i>Oxalis acetosella</i> L.	3.7 to 6.4	<i>Arctophila fulva</i> (Trin.) Andersson	7 to 7.4
<i>Phegopteris connectilis</i> (Michx.) Watt	4.4 to 5.8	<i>Arctous alpinus</i> (L.) Nied.	4.6 to 5.2
<i>Picea abies</i> (L.) H.Karst.	3.2 to 7.7	<i>Arenaria humifusa</i> Wahlenb.	6.2 to 7.7
<i>Picea mariana</i> (Mill.) Britton, Sterns & Poggenb.	5.3 to 6.9	<i>Argyrotegium poliochlorum</i> (N.G. Walsh) J.M. Ward & Breitw.	4.4 to 4.5
<i>Pinus sylvestris</i> L.	3.2 to 6.1	<i>Artemisia arctica</i> (Besser) Leonova	4.5 to 7.9
<i>Plantago major</i> L.	6.8 to 6.9	<i>Artemisia tilesii</i> Ledeb.	5 to 7.9
<i>Populus tremula</i> L.	5.1 to 7.7	<i>Astragalus alpinus</i> L.	4.4 to 7.7
<i>Populus tremuloides</i> Michx.	5.3 to 6.9	<i>Astragalus umbellatus</i> Bunge	6 to 7.5
<i>Pyrola chlorantha</i> Sw.	3.2 to 4.4	<i>Bartsia alpina</i> L.	4.4 to 4.5
<i>Pyrola rotundifolia</i> L.	5.1 to 6.1	<i>Beckwithia glacialis</i> (L.) Á.Löve & D.Löve	4.9 to 5.2
<i>Rhododendron groenlandicum</i> (Oeder) Kron & Judd	5.3 to 6.9	<i>Betula nana</i> L.	4.6 to 5.2
<i>Rubus idaeus</i> L.	4.1 to 6.4	<i>Campanula rotundifolia</i> L.	4.4 to 4.5
<i>Rubus saxatilis</i> L.	5.1 to 6.1	<i>Campanula uniflora</i> L.	6.2 to 7.7
<i>Salix myrsinifolia</i> Salisb.	4.4 to 5.8	<i>Cardamine digitata</i> Richardson	5 to 7.9
<i>Salix repens</i> L. [#]	4.4 to 5.8	<i>Cardamine microphylla</i> Adams	5 to 7.9

Supporting information

Species	pH range	Species	pH range
<i>Carex aquatilis</i> Wahlenb.	5.3 to 7	<i>Equisetum variegatum</i> Schleich. ex F. Weber & D. Mohr	5 to 7.4
<i>Carex atrofusca</i> Schkuhr	7 to 7.4	<i>Erigeron humilis</i> Graham	6 to 7.9
<i>Carex bigelowii</i> Torr. ex Schwein.	4.6 to 7.4	<i>Eriophorum angustifolium</i> Honck.	5.3 to 7.3
<i>Carex capillaris</i> L.	6.2 to 7.7	<i>Eriophorum angustifolium</i> subsp. <i>triste</i> (T.C.E.Fr.) Hultén	6.9 to 7
<i>Carex fuliginosa</i> Schkuhr	6 to 7.9	<i>Eriophorum russeolum</i> Fr.	6.9 to 7
<i>Carex glacialis</i> Mack.	6.2 to 7.7	<i>Eriophorum vaginatum</i> L.	4 to 7.3
<i>Carex lachenalii</i> subsp. <i>lachenalii</i>	5 to 7.9	<i>Euphrasia frigida</i> Pugsley	4.4 to 4.5
<i>Carex marina</i> Dewey	6.9 to 7.3	<i>Euphrasia wettsteinii</i> G.L.Gusarova	6.2 to 7.7
<i>Carex membranacea</i> Hook.	7.3 to 7.4	<i>Festuca altaica</i> Trin. ex Ledeb.	4.5 to 7.9
<i>Carex microchaeta</i> subsp. <i>nesophila</i> (Holm) D.F.Murray	4.5 to 6.9	<i>Festuca ovina</i> L.	4.9 to 7.7
<i>Carex nardina</i> (Hornem.) Fr.	6.2 to 7.7	<i>Festuca vivipara</i> (L.) Sm.	4.9 to 7.7
<i>Carex podocarpa</i> R.Br.	4.5 to 7.9	<i>Fragaria vesca</i> L.	4.4 to 4.5
<i>Carex rotundata</i> Wahlenb.	7 to 7.3	<i>Gentiana glauca</i> Pall.	4.5 to 6.4
<i>Carex rupestris</i> All.	4.9 to 7.7	<i>Gentianella propinqua</i> (Richardson) J.M.Gillett	4.5 to 7.9
<i>Carex saxatilis</i> L.	7 to 7.4	<i>Geranium sylvaticum</i> L.	4.4 to 4.5
<i>Carex scirpoidea</i> Michx.	5 to 7.9	<i>Geum rivale</i> L.	4.4 to 4.5
<i>Cassiope tetragona</i> (L.) D.Don	4.5 to 7.9	<i>Hedysarum hedysaroides</i> (L.) Schinz & Thell.	4.5 to 7.9
<i>Cerastium alpinum</i> L.	4.4 to 7.7	<i>Hieracium alpinum</i> L.	4.4 to 4.5
<i>Cerastium cerastoides</i> (L.) Britton	4.4 to 4.5	<i>Hierochloa alpina</i> (Sw.) Roem. & Schult.	4.9 to 5.2
<i>Cerastium fontanum</i> Baumg.	4.4 to 4.5	<i>Huleniella integrifolia</i> (Richardson) Tzvelev	6 to 7.9
<i>Cirsium helenioides</i> (L.) Hill	4.4 to 4.5	<i>Huperzia selago</i> (L.) Bernh. ex Schrank & Mart.	4.9 to 7.7
<i>Crepis paludosa</i> (L.) Moench	4.4 to 4.5	<i>Juncus biglumis</i> L.	7 to 7.7
<i>Diapensia lapponica</i> L.	4.6 to 7.7	<i>Juncus trifidus</i> L.	4.6 to 7.7
<i>Diapensia lapponica</i> subsp. <i>obovata</i> (F.Schmidt) Hultén	4.5 to 6.9	<i>Ledum palustre</i> var. <i>decumbens</i>	4 to 7.3
<i>Disterigma microphyllum</i> (G.Don) Luteyn	4.5 to 7.4	<i>Leontodon autumnalis</i> L.	4.4 to 4.5
<i>Draba alpina</i> L.	6.9 to 7.3	<i>Lloydia serotina</i> (L.) Rchb.	5 to 7.9
<i>Draba chamissonis</i> G.Don	4.5 to 7.9	<i>Lotus corniculatus</i> L.	4.4 to 4.5
<i>Dryas integrifolia</i> f. <i>canescens</i> (Simmons) Fernald	6 to 7.9	<i>Luzula arcuata</i> (Wahlenb.) Sw.	4.6 to 7.7
<i>Dryas integrifolia</i> Vahl	5 to 7.9	<i>Luzula arcuata</i> subsp. <i>unalaschkensis</i> (Buchenau) Hultén	5 to 6.4
<i>Dryas octopetala</i> L.	4.6 to 7.7	<i>Luzula spicata</i> (L.) DC.	6.2 to 7.7
<i>Dupontia fisheri</i> R.Br.	5.3 to 7.4	<i>Maianthemum bifolium</i> (L.) F.W.Schmidt	4.4 to 4.5
<i>Empetrum nigrum</i> subsp. <i>hermaphroditum</i> (Hagerup) Böcher	4.6 to 7.7	<i>Melampyrum lineare</i> Lam. #	4.4 to 4.5
<i>Empetrum nigrum</i> subsp. <i>subholarcticum</i> (V.N.Vassil.) Kuvaev	4.5 to 6.9	<i>Melampyrum pratense</i> L.	4.4 to 4.5
<i>Epilobium anagallidifolium</i> Lam.	4.4 to 4.5	<i>Minuartia arctica</i> (Steven ex Ser.) Graebn.	5.5 to 7.9
<i>Epilobium latifolium</i> L.	5 to 7.4	<i>Minuartia stricta</i> (Sw.) Hiern	6.2 to 7.7
<i>Equisetum boreale</i> Bong.	5 to 7.9		

Appendix S2.4

Species	pH range	Species	pH range
<i>Myosotis decumbens</i> Host	4.4 to 4.5	<i>Rubus chamaemorus</i> L.	4 to 7.3
<i>Omalotheca norvegica</i> (Gunnerus) Sch.Bip. & F.W.Schultz	4.4 to 4.5	<i>Rumex acetosa</i> L.	4.4 to 4.5
<i>Oxyria digyna</i> (L.) Hill	4.5 to 7.9	<i>Rumex aquaticus</i> subsp. <i>arcticus</i> (Trautv.) Hiitonen	5 to 7.9
<i>Oxytropis lapponica</i> (Wahlenb.) Gay	6.2 to 7.7	<i>Sagina procumbens</i> L.	4.4 to 4.5
<i>Oxytropis nigrescens</i> (Pall.) DC.	7 to 7.5	<i>Sagina saginoides</i> (L.) H.Karst.	4.4 to 4.5
<i>Papaver macounii</i> Greene [#]	7.3 to 7.7	<i>Salix chamissonis</i> Andersson	4.5 to 7.4
<i>Parnassia kotzebuei</i> Cham. ex Spreng. [#]	5 to 7.9	<i>Salix polaris</i> Wahlenb.	5 to 7.9
<i>Parnassia palustris</i> <i>Parnassia palustris</i> L.	4.4 to 7.4	<i>Salix reticulata</i> L.	4.5 to 7.9
<i>Parrya nudicaulis</i> (L.) Boiss.	5 to 7.9	<i>Salix reticulata</i> var. <i>reticulata</i>	6.9 to 7.3
<i>Pedicularis capitata</i> Adams	4.5 to 7.9	<i>Salix richardsonii</i> Hook.	6.9 to 7.4
<i>Pedicularis flammea</i> L. [#]	6.2 to 7.7	<i>Salix rotundifolia</i> Trautv.	5.3 to 7.9
<i>Pedicularis hirsuta</i> L. [#]	4.6 to 7.7	<i>Saussurea alpina</i> (L.) DC.	4.4 to 4.5
<i>Pedicularis sylvatica</i> L. [#]	4 to 7.3	<i>Saussurea angustifolia</i> (L.) DC.	4.5 to 7.9
<i>Persicaria vivipara</i> (L.) Ronse Decr.	4.4 to 7.9	<i>Saxifraga aizoides</i> L.	7 to 7.7
<i>Petasites frigidus</i> (L.) Fr.	5 to 7.4	<i>Saxifraga hieraciifolia</i> Waldst. & Kit. ex Willd.	5 to 7.4
<i>Phyllodoce caerulea</i> (L.) Bab.	4.5 to 7.4	<i>Saxifraga hirculus</i> L.	5 to 7.9
<i>Pinguicula vulgaris</i> L.	4.4 to 4.5	<i>Saxifraga nelsoniana</i> D.Don	4.5 to 7.9
<i>Poa arctica</i> R.Br.	4.5 to 7.4	<i>Saxifraga oppositifolia</i> L.	4.6 to 7.9
<i>Poa lanata</i> Scribn. & Merr.	5 to 7.9	<i>Sibbaldia procumbens</i> L.	4.4 to 4.5
<i>Poa paucispicula</i> Scribn. & Merr.	5 to 7.9	<i>Silene acaulis</i> (L.) Clairv.	4.4 to 4.5
<i>Polemonium caeruleum</i> var. <i>acutiflorum</i>	5 to 7.9	<i>Silene himalayensis</i> (L.) Jacq.	4.9 to 7.7
<i>Polygonum ellipticum</i> Willd. ex Spreng.	5 to 6.4	<i>Solidago compacta</i> Turcz.	4.5 to 7.4
<i>Potentilla crantzii</i> (Crantz) Beck ex Fritsch	4.4 to 4.5	<i>Solidago virgaurea</i> L.	4.4 to 4.5
<i>Potentilla erecta</i> (L.) Raeusch.	4.4 to 4.5	<i>Stellaria pungens</i> Bigelow	4.4 to 4.5
<i>Potentilla fruticosa</i> var. <i>fruticosa</i>	4.5 to 7.4	<i>Taraxacum alaskanum</i> Rydb.	5 to 7.9
<i>Potentilla hyparctica</i> Malte	4.5 to 6.9	<i>Thalictrum alpinum</i> L.	4.4 to 7.9
<i>Puccinellia wrightii</i> (Scribn. & Merr.) Tzvelev	6.5 to 7.9	<i>Therorhodium camtschaticum</i> (Pall.) Small	4.5 to 6.9
<i>Pyrola minor</i> L.	4.4 to 4.5	<i>Tofieldia coccinea</i> Richardson	4.5 to 7.9
<i>Pyrola rotundifolia</i> L.	4.4 to 4.5	<i>Tofieldia pusilla</i> (Michx.) Pers.	4.9 to 7.9
<i>Ranunculus acris</i> L.	4.4 to 4.5	<i>Trientalis europaea</i> L.	4.4 to 4.5
<i>Ranunculus nivalis</i> L.	5 to 7.9	<i>Trisetum spicatum</i> (L.) K.Richt.	4.5 to 7.9
<i>Ranunculus platanifolius</i> L.	4.4 to 4.5	<i>Vaccinium minus</i> Vorosch.	4 to 7.3
<i>Ranunculus pygmaeus</i> Wahlenb.	5 to 7.9	<i>Vaccinium uliginosum</i> L.	6.2 to 7.7
<i>Rhinanthus minor</i> L. [#]	4.4 to 4.5	<i>Vaccinium vitis-idaea</i> L.	4.9 to 7.7
<i>Rhodiola atropurpurea</i> (Turcz.) Trautv. & Mey. in Middendorf	4.5 to 7.4	<i>Valeriana saxatilis</i> L. [#]	5 to 7.9
<i>Rhododendron lapponicum</i> (L.) Wahlenb.	6.2 to 7.7	<i>Veronica alpina</i> L.	4.4 to 4.5
		<i>Veronica fruticans</i> Jacq. [#]	4.4 to 4.5

Supporting information

Species	pH range
<i>Viola biflora</i> L.	4.4 to 4.5
<i>Viola epipsiloides</i> Á.Löve & D.Löve	5 to 6.9
<i>Viola palustris</i> L.	4.4 to 4.5
<i>Wilhelmsia physodes</i> (Fisch. ex Ser.) McNeill	5 to 7.9

[#] Taxonomy is unresolved according to *The Plant List* (2010).

Appendix S2.5

Appendix S2.5 Sensitivity analysis of the variability within biomes

We performed a sensitivity analysis by investigating the success in deriving PNOF – soil pH log-logistic functions at three spatial resolution levels. First, we allocated studies into ecoregions. Figure S2.5.1 shows an example of the aggregation procedure of studies within ecoregions and of the same biome.

In order to avoid double counting of plant species – pH ranges, we did not include studies that covered two or more ecoregions. Also, we did not include studies where the described vegetation is outside the boundaries of the corresponding biome (Figure 2.1, main text).

After deriving logistic regressions for all ecoregions, we proceeded with the sensitivity analysis of the PNOF – soil pH functions across ecoregions and across studies within the same biome.

An overview of the data available by ecoregion (Table S2.5.1 of this appendix) and per individual studies (Table S2.3.1 of appendix S2.3) are available in this supporting information. The log-logistic results per ecoregion (Table S2.5.2) show that we were able to successfully derive log-logistic regressions for few ecoregions. Likewise, at an even more detailed spatial resolution (i.e. studies), the success in deriving PNOF – pH functions was even lower (Table S2.5.3).

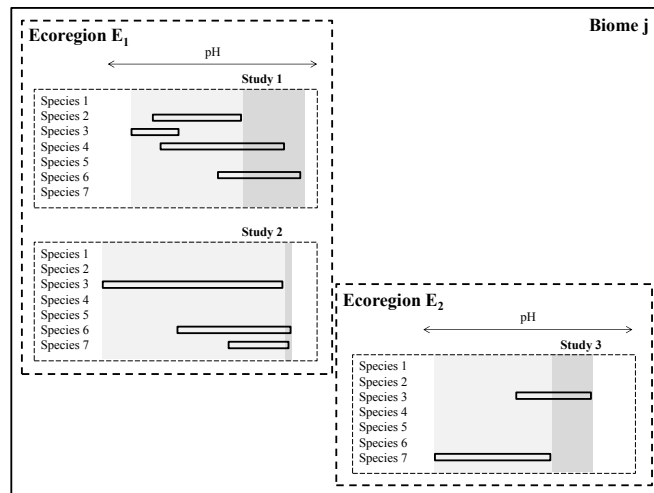


Figure S2.5.1 Example of aggregation procedure in three different spatial resolution levels with seven hypothetical species occurrences. Sites (studies) 1 and 2, belong to ecoregion E_1 and site (study) 3 belongs to Ecoregion E_2 . Both E_1 and E_2 are within biome j . The light and dark grey areas represent the pH values below and above the pH optimum, respectively. Note that, at the spatial resolution level of biome, all species with the exception of species 1, 5 and 6 are present. Additionally, species 7 is confirmed to occur at a broader pH range at the biome level rather than narrower ranges at the ecoregion and site levels. At an ecoregion resolution, species 6 does not occur in E_2 . Likewise, at a site resolution, only a number of four species can occur within a single site.

Supporting information

Table S2.5.1 Total number of studies and species per ecoregion, the total number of species in the optimum pH, the pH range of species occurrence and the (range of) optimum pH ($SR_{opt,j}$) in **(a)** (sub)tropical moist broadleaf forests, **(b)** (sub)tropical grassland, savanna, and shrubland, **(c)** mangrove, **(d)** (sub)tropical dry broadleaf forests, **(e)** flooded grassland and savanna, **(f)** desert and xeric shrubland, **(g)** mediterranean forest, woodland, and shrubland, **(h)** temperate broadleaf mixed forest, **(i)** temperate grassland, savanna, and shrubland, **(j)** temperate coniferous forest, **(k)** montane grassland and shrubland, **(l)** boreal Forest / taiga, and **(m)** tundra and alpine.

Ecoregion	Studies	Species	$SR_{opt,j}$	pH range	(Range of) optimum pH
(a) (Sub)tropical moist broadleaf forest					
Borneo lowland rain forests	2	38	30	3.7 to 4.6	4.0 to 4.1
Eastern Cordillera real montane forests	1	155	155	3.5 to 5.8	3.8 to 4.3
Isthmian-Atlantic mixed forests	1	1	1	4.8 to 6.9	4.8 to 6.9
Jian Nan subtropical evergreen forests	1	39	39	5.4 to 6.7	6.4 to 6.7
Luzon rain forests	1	11	10	4.4 to 7.2	4.9 to 5.0
Mato Grosso seasonal forests	1	69	69	3.4 to 4.3	3.5 to 3.8
Mount Cameroon and Bioko montane forests	1	53	50	4.9 to 5.8	5.3
Peninsular Malaysian rain forests	1	24	24	3.8 to 4.2	3.8 to 4.2
South Taiwan monsoon rain forests	1	50	50	4.1 to 4.7	4.2 to 4.7
Taiwan subtropical evergreen forest	1	65	65	3.0 to 5.6	3.7
Western Ecuador moist forest	1	14	14	5.9 to 6.4	5.9 to 6.4
(b) (Sub)tropical grassland, savanna, and shrubland					
Cerrado	3	131	107	4.5 to 6.1	4.9
(c) Mangrove					
Central African mangroves	1	21	21	3.4 to 7.1	4.1 to 5.8
Sunda Shelf mangroves	1	12	12	4.1 to 7.2	6.0 to 6.5
(d) (Sub)tropical dry broadleaf forest					
Yucatán dry forests	1	71	65	6.9 to 7.6	7.0
(e) Flooded grassland and savanna					
Pantanal	1	7	7	5.9 to 6.6	5.9 to 6.6
(f) Desert and xeric shrubland					
Alashan Plateau semi-desert	1	11	11	7.4 to 7.6	7.4 to 7.6
Baja California desert	1	27	26	6.0 to 7.7	6.9 to 7.0
Great Basin shrub steppe	1	1	1	9.6 to 9.7	9.6 to 9.7

Appendix S2.5

Ecoregion	Studies	Species	SR _{opt,j}	pH range	(Range of optimum pH)
Mojave desert	2	3	3	7.6 to 8.8	8.1 to 8.5
Northwestern thorn scrub forest	1	15	11	5.3 to 9.4	7.0 to 7.1
Sonoran desert	1	12	12	6.6 to 8.7	7.2 to 8.0
Southwestern Arabian foothills savanna	2	36	36	6.2 to 9.7	7.9 to 8.5
Taklimatan desert	1	18	17	6.1 to 10.5	7.4 to 7.8
Tehuacán Valley matorral	1	60	33	5.1 to 7.5	6.3 to 7.4
(g) Mediterranean Forest, Woodland, and Shrubland					
Iberian conifer forest	1	3	3	8.0 to 8.3	8.0 to 8.3
Lowland fynbos and renosterveld	1	14	9	4.9 to 7.9	5.4 to 5.5
Northeastern Spain and Southern France Mediterranean forests	1	6	6	6.4 to 6.7	6.5 to 6.7
(h) Temperate broadleaf mixed forest					
Appalachian mixed mesophytic forests	5	121	119	3.3 to 8.2	4.2
Appalachian-Blue Ridge forests	1	21	13	5.3 to 6.1	5.3 to 5.5
Atlantic mixed forests	8	234	230	2.4 to 8.4	5.2
Baltic mixed forest	4	81	57	3.2 to 8.0	5.0 to 5.9
Cantabrian mixed forests	2	19	19	4.2 to 5.6	4.8 to 4.9
Celtic broadleaf forest	1	3	3	7.1 to 8.1	7.5
Central European mixed forests	4	241	152	3.3 to 9.4	4.2 to 6.2
Central U.S. hardwood forests	1	6	6	6.1 to 6.6	6.3 to 6.4
Eastern Great Lakes lowland forests	1	10	10	4.1 to 5.9	4.1 to 5.9
Eastern Himalayan broadleaf forests	1	1	1	4.0 to 7.5	4.0 to 7.5
English Lowlands beech forests	1	52	52	5.1 to 6.6	5.8 to 5.9
New-England-Acadian forest	1	88	88	4.7 to 5.1	4.7 to 5.1
Northeastern coastal forests	2	15	15	3.3 to 7.1	4.3 to 4.9
Ozark Mountain forests	1	21	21	4.5 to 8.0	6.6 to 7.8
Sarmatic mixed forests	7	177	156	3.9 to 7.2	4.7
Taiheiyō montane deciduous forests	1	1	1	4.9 to 5.7	4.9 to 5.7
Western European broadleaf forests	4	70	61	3.8 to 8.7	5.1
Western Great Lakes forests	3	52	36	3.6 to 7.9	4.6
(i) Temperate grassland, savanna, and shrubland					
Alain-Western Tian Shan steppe	1	64	64	5.0 to 7.0	5.0 to 7.0
Central forest-grasslands transition	1	95	69	4.1 to 8.1	4.5 to 7.6
Mongolian-Manchurian grassland	1	25	25	7.0 to 7.6	7.3 to 7.5

Supporting information

Ecoregion	Studies	Species	SR _{opt,j}	pH range	(Range of optimum pH)
(j) Temperate Coniferous Forest					
Alps conifer and mixed forests	2	151	149	3.1 to 7.8	4.1 to 6.1
South Central Rockies forests	1	6	6	6.4 to 8.2	7.0
(k) Montane grassland and shrubland					
Eastern Himalayan alpine shrub and meadows	1	135	135	6.0 to 7.0	6.0 to 7.0
Ethiopian montane moorlands	1	4	4	5.5 to 6.2	5.5 to 6.0
(l) Boreal Forest / Taiga					
Eastern Canadian forest	1	33	33	5.3 to 6.9	6.8 to 6.9
Scandinavian and Russian taiga	3	62	56	3.2 to 7.7	5.1
(m) Tundra and alpine					
Arctic foothills tundra	1	5	5	4.0 to 7.3	4.0 to 7.3
Scandinavian Montane Birch forest and grasslands	2	90	53	4.4 to 7.7	4.4 to 4.5

Table S2.5.2 The optimum pH and the PNOF regressions coefficients $\alpha^{\#}$ and $\beta^{\#}$ (95% confidence interval in brackets) at the ecoregions of **(a)** (sub)tropical moist broadleaf forests, **(b)** (sub)tropical grassland, savanna, and shrubland, **(c)** mangrove, **(d)** (sub)tropical dry broadleaf forests, **(e)** flooded grassland and savanna, **(f)** desert and xeric shrubland, **(g)** mediterranean forest, woodland, and shrubland, **(h)** temperate broadleaf mixed forest, **(i)** temperate grassland, savanna, and shrubland, **(j)** temperate coniferous forest, **(k)** montane grassland and shrubland, **(l)** boreal Forest / taiga, and **(m)** tundra and alpine.

Ecoregion	α	β	R ² ‡
(a) (Sub)tropical moist broadleaf forest			
Borneo lowland rain forests	3.40 ^{§,‡} (2.61 to 4.18)	0.22 ^{§,‡} (NS)	0.61
Eastern Cordillera real montane forests	3.65 (3.60 to 3.70)	0.08 (0.04 to 0.13)	0.93
Isthmian-Atlantic mixed forests	Model did not fit empirical data		
Jian Nan subtropical evergreen forests	6.15 (5.96 to 6.35)	0.29 (0.09 to 0.48)	0.64
Luzon rain forests	4.58 (4.51 to 4.65)	0.13 (0.06 to 0.21)	0.92
Mato Grosso seasonal forests	3.38 [‡] (3.37 to 3.38)	0.01 [‡] (0.006 to 0.009)	1.00
Mount Cameroon and Bioko montane forests	5.02 [‡] (4.92 to 5.11)	0.09 [‡] (NS)	0.88
Peninsular Malaysian rain forests	Model did not fit empirical data		

Appendix S2.5

Ecoregion	α	β	$R^{2\pm}$
South Taiwan monsoon rain forests	4.07 ^b (4.06 to 4.08)	0.01 ^b (0.008 to 0.01)	1.00
Taiwan subtropical evergreen forest	2.47 ^b (1.72 to 3.22)	0.59 ^b (0.04 to 1.14)	0.59
Western Ecuador moist forest	Model did not fit empirical data		
(b) (Sub)tropical grassland, savanna, and shrubland			
Cerrado	4.55 ^y (4.40 to 4.70)	0.16 ^y (NS)	0.82
(c) Mangrove			
Central African mangroves	3.33 ^f (3.58 to 3.67)	0.24 ^f (0.19 to 0.29)	0.94
Sunda Shelf mangroves	4.20 (4.16 to 4.24)	0.08 (0.04 to 0.12)	0.79
(d) (Sub)tropical dry broadleaf forest			
Yucatán dry forests	Model did not fit empirical data		
(e) Flooded grassland and savanna			
Pantanal	2.97 ^{g,y} (NS)	0.20 ^{g,y} (NS)	
(f) Desert and xeric shrubland			
Alashan Plateau semi-desert	Model did not fit empirical data		
Baja California desert	6.29 (6.20 to 6.38)	0.16 (0.07 to 0.26)	0.87
Great Basin shrub steppe	Model did not fit empirical data		
Mojave desert	Model did not fit empirical data		
Northwestern thorn scrub forest	6.38 (6.28 to 6.47)	0.33 (0.24 to 0.43)	0.91
Sonoran desert	5.63 ^f (4.93 to 6.32)	0.45 ^f (0.19 to 0.71)	0.71
Southwestern Arabian foothills savanna	5.81 ^f (5.54 to 6.08)	0.72 ^f (0.52 to 0.92)	0.83
Taklimatan desert	6.4 (6.30 to 6.50)	0.24 (0.14 to 0.35)	0.83
Tehuacán Valley matorral	Model did not fit empirical data		
(g) Mediterranean Forest, Woodland, and Shrubland			
Iberian conifer forest	Model did not fit empirical data		
Lowland fynbos and renosterveld	5.30 ^y (5.20 to 5.40)	0.07 ^y (NS)	0.78
Northeastern Spain and Southern France Mediterranean forests	6.41 (6.41 to 6.41)	0.006 (0.002 to 0.010)	0.99
(h) Temperate broadleaf mixed forest			
Appalachian mixed mesophytic forests	3.78 (3.76 to 3.80)	0.04 (0.01 to 0.06)	0.98
Appalachian-Blue Ridge forests	Model did not fit empirical data		
Atlantic mixed forests	3.33 (3.22 to 3.44)	0.49 (0.39 to 0.60)	0.91

Supporting information

Ecoregion	α	β	$R^{2\ddagger}$
Baltic mixed forest	3.92 (3.71 to 4.12)	0.78 (0.46 to 1.11)	0.69
Cantabrian mixed forests	2.58 [§] (0.14 to 5.02)	0.64 [§] (NS)	0.45
Celtic broadleaf forest	7.17 [§] (7.00 to 7.34)	0.16 [§] (NS)	0.77
Central European mixed forests	3.43 (2.90 to 3.95)	1.21 (0.64 to 1.78)	0.43
Central U.S. hardwood forests	3.43 [§] (2.90 to 3.95)	0.11 [§] (NS)	0.73
Eastern Great Lakes lowland forests	Model did not fit empirical data		
Eastern Himalayan broadleaf forests	Model did not fit empirical data		
English Lowlands beech forests	4.01 [§] (2.33 to 5.69)	0.72 [§] (NS)	0.43
North Island temperate forests	Model did not fit empirical data		
Northeastern coastal forests	4.12 (4.04 to 4.21)	0.15 (0.08 to 0.23)	0.91
Ozark Mountain forests	5.58 (5.44 to 5.72)	0.64 (0.50 to 0.78)	0.88
Sarmatic mixed forests	4.2 (4.16 to 4.24)	0.15 (0.11 to 0.19)	0.98
Taiheiyō montane deciduous forests	Model did not fit empirical data		
Western European broadleaf forests	4.38 (4.31 to 4.46)	0.20 (0.14 to 0.27)	0.93
Western Great Lakes forests	4.25 (4.11 to 4.39)	0.30 (0.14 to 0.47)	0.76
(i) Temperate grassland, savanna, and shrubland			
Alain-Western Tian Shan steppe	Model did not fit empirical data		
Central forest-grasslands transition	-49.23 [§] (NS)	93.37 [§] (NS)	0.00
Mongolian-Manchurian grassland	7.02 [§] (6.84 to 7.21)	0.15 [§] (NS)	0.72
(j) Temperate Coniferous Forest			
Alps conifer and mixed forests	3.26 (3.24 to 3.27)	0.03 (0.02 to 0.04)	0.95
South Central Rockies forests	6.09 [§] (5.02 to 7.16)	0.65 [§] (NS)	0.33
(k) Montane grassland and shrubland			
Eastern Himalayan alpine shrub and meadows	3.18 [§] (NS)	0.20 [§] (NS)	
Ethiopian montane moorlands	2.38 [§] (NS)	0.21 [§] (NS)	
(l) Boreal Forest / Taiga			
Eastern Canadian forest	3.97 [§] (3.53 to 4.41)	0.74 [§] (0.55 to 0.93)	0.88
Scandinavian and Russian taiga	3.78 (3.73 to 3.85)	0.38 (0.32 to 0.44)	0.96
(m) Tundra and alpine			
Arctic foothills tundra	Model did not fit empirical data		
Scandinavian Montane Birch forest and grasslands	Model did not fit empirical data		

[§] The 95% confidence interval around α and β is shown in parenthesis

[¶] α is not within the range pH values used in the regression (as reported in Table S2.5.1)

Appendix S2.5

Ecoregion	α	β	$R^{2\ddagger}$
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[†] Coefficient not included in the sensitivity analysis because their results are based on one (or both) coefficient non-different than zero (NS)

[‡] $Pseudo - R^2 = 1 - \frac{SS_{Residual}}{SS_{CorrectedTotal}}$, as defined by Schabenberger and Pierce (2001)

Table S2.5.3 The optimum pH and the PNOF regressions coefficients $\alpha^{\#}$ and $\beta^{\#}$ (95% confidence interval in brackets) of studies of **(a)** (sub)tropical moist broadleaf forests, **(b)** (sub)tropical grassland, savanna, and shrubland, **(c)** mangrove, **(d)** (sub)tropical dry broadleaf forests, **(e)** flooded grassland and savanna, **(f)** desert and xeric shrubland, **(g)** mediterranean forest, woodland, and shrubland, **(h)** temperate broadleaf mixed forest, **(i)** temperate grassland, savanna, and shrubland, **(j)** temperate coniferous forest, **(k)** montane grassland and shrubland, **(l)** boreal Forest / taiga, and **(m)** tundra and alpine.

Study	α	β	$R^{2\ddagger}$
(a) (Sub)tropical moist broadleaf mixed forest			
Banack <i>et al.</i> (2002)		Model did not fit empirical data	
Banaticla & Buot (2005)	4.58 (4.51 to 4.65)	0.13 (0.06 to 0.21)	0.92
Chen <i>et al.</i> (1997)	4.07 [†] (4.07 to 4.07)	0.0081 [†] (0.008 to 0.009)	1.00
Haro-Carrión <i>et al.</i> (2009)		Model did not fit empirical data	
Homeier <i>et al.</i> (2010)	3.65 (3.6 to 3.7)	0.08 (0.04 to 0.13)	0.93
Hsieh <i>et al.</i> (1998)	2.48 [†] (1.75 to 3.2)	0.58 [†] (0.05 to 1.11)	0.60
Ivanauskas <i>et al.</i> (2003)	3.38 [†] (3.37 to 3.38)	0.008 [†] (0.007 to 0.010)	1.00
Lesueur <i>et al.</i> (1993)		Model did not fit empirical data	
Paoli <i>et al.</i> (2006)		Model did not fit empirical data	
Penfold & Lamb (2002)		Model did not fit empirical data	
Poulsen (1996)	3.39 ^{†‡} (2.59 to 4.18)	0.22 ^{†‡} (NS)	0.62
Proctor <i>et al.</i> (2007)	5.01 [†] (4.91 to 5.11)	0.09 [†] (NS)	0.88
Siebert (2005)		Model did not fit empirical data	
Teo <i>et al.</i> (2003)		Model did not fit empirical data	
Turner <i>et al.</i> (1995)		Model did not fit empirical data	
Vetaas (1997)		Model did not fit empirical data	
Zhang <i>et al.</i> (2001)	6.15 (5.95 to 6.35)	0.29 (0.09 to 0.49)	0.64
(b) (Sub)tropical grassland, savanna, and shrubland			
Amorim & Batalha (2007)	4.82 [†] (4.75 to 4.9)	0.05 [†] (NS)	0.90
da Silva & Batalha (2008)	4.34 ^{†‡} (1.51 to 7.18)	0.14 ^{†‡} (NS)	0.61
Neto <i>et al.</i> (1999)		Model did not fit empirical data	
(c) Mangrove			

Supporting information

Study	α	β	R^{2E}
Ashton & Macintosh (2002)	4.2 (4.16 to 4.24)	0.08 (0.04 to 0.12)	0.79
Ukpong (1995)	3.63 (3.58 to 3.67)	0.24 (0.19 to 0.29)	0.94
(d) (Sub)tropical dry broadleaf forest			
de Souza <i>et al.</i> (2007)		Model did not fit empirical data	
Dubbin <i>et al.</i> (2006)	6.15 (6.03 to 6.26)	0.49 (0.34 to 0.63)	0.94
White & Hood (2004)		Model did not fit empirical data	
(e) Flooded grassland and savanna			
Haase (1999)		Model did not fit empirical data	
Ssegawa <i>et al.</i> (2004)		Model did not fit empirical data	
(f) Desert and xeric shrubland			
El-Ghani (1998)	6.56 ^b (6.56 to 6.56)	0.04 ^f (0.04 to 0.05)	1.00
Camargo-Ricalde <i>et al.</i> (2002)		Model did not fit empirical data	
El-Demerdash <i>et al.</i> (1994)	5.86 ^g (5.54 to 6.17)	0.79 ^g (0.53 to 1.05)	0.80
El-Demerdash <i>et al.</i> (1995)	5.87 ^h (5.62 to 6.12)	0.68 ^h (0.49 to 0.86)	0.84
Franco-Vizcaino <i>et al.</i> (1993)	6.29 (6.19 to 6.39)	0.16 (0.07 to 0.26)	0.87
Kabir <i>et al.</i> (2010)	6.37 (6.28 to 6.47)	0.34 (0.25 to 0.43)	0.91
Li <i>et al.</i> (2008)		Model did not fit empirical data	
Mahmood <i>et al.</i> (1994)		Model did not fit empirical data	
Parker (1991)	5.6 ⁱ (4.89 to 6.31)	0.45 ⁱ (0.19 to 0.72)	0.71
Pettit & Naiman (2007)		Model did not fit empirical data	
Shaltout <i>et al.</i> (1997)	7.16 (7.14 to 7.19)	0.09 (0.06 to 0.11)	0.99
Titus <i>et al.</i> (2002)	7.86 (7.81 to 7.91)	0.1 (0.05 to 0.15)	0.93
Toft & Elliot-Fisk (2002)		Model did not fit empirical data	
Walker <i>et al.</i> (2001)		Model did not fit empirical data	
Zhang <i>et al.</i> (2005)	6.4 (6.3 to 6.5)	0.23 (0.13 to 0.34)	0.83
(g) Mediterranean Forest, Woodland, and Shrubland			
Navas <i>et al.</i> (2008)	7 (6.84 to 7.16)	0.37 (0.21 to 0.53)	0.77
Richards <i>et al.</i> (1997)	5.3 ^y (5.2 to 5.39)	0.07 ^y (NS)	0.78
Römermann <i>et al.</i> (2005)	6.41 (6.41 to 6.41)	0.006 (0.004 to 0.007)	0.99
Ruecker <i>et al.</i> (1998)		Model did not fit empirical data	
(h) Temperate broadleaf mixed forest			
Abrams & Hayes (2008)		Model did not fit empirical data	

Appendix S2.5

Study	α	β	R ²
Ahokas (1997)	3.72 (3.69 to 3.75)	0.15 (0.12 to 0.18)	0.97
Akbar <i>et al.</i> (2009)	7.17 [§] (7 to 7.34)	0.16 [§] (NS)	0.77
Andersson (1992)		Model did not fit empirical data	
Arii & Lechowicz (2002)		Model did not fit empirical data	
Baeten <i>et al.</i> (2009)	2.5 [§] (2.16 to 2.84)	0.42 [§] (0.25 to 0.59)	0.77
Bellemare <i>et al.</i> (2005)		Model did not fit empirical data	
Bernard & Seischab (1995)		Model did not fit empirical data	
Bigelow & Canham (2002)	3.76 (3.71 to 3.8)	0.21 (0.16 to 0.25)	0.95
Bjørnstad (1991)		Model did not fit empirical data	
Brosfoske <i>et al.</i> (2001)	3.35 [§] (3.14 to 3.56)	0.32 [§] (0.17 to 0.47)	0.85
Brunet <i>et al.</i> (1996)	4.12 (4.08 to 4.16)	0.09 (0.05 to 0.13)	0.96
Brunet <i>et al.</i> (1997a)	4.12 ^{§,§} (-1.83 to 10.07)	0.16 ^{§,§} (NS)	0.46
Brunet <i>et al.</i> (1997b)	4.33 [§] (3.94 to 4.72)	0.3 [§] (0.04 to 0.56)	0.72
Chapman & Bannister (1995)		Model did not fit empirical data	
Cole & Weltzin (2004)		Model did not fit empirical data	
Coudun & Gégout (2007)		Model did not fit empirical data	
Coudun <i>et al.</i> (2006)		Model did not fit empirical data	
Dambrine <i>et al.</i> (2007)		Model did not fit empirical data	
De Graaf <i>et al.</i> (2009)	4.14 (4.07 to 4.2)	0.24 (0.17 to 0.31)	0.94
Dick & Gilliam (2007)		Model did not fit empirical data	
Diekmann & Lawesson (1999)	3.76 [§] (3.63 to 3.89)	0.32 [§] (0.23 to 0.41)	0.81
Dzwonko (2001)	4.19 (4.18 to 4.2)	0.07 (0.06 to 0.08)	1.00
Emerson <i>et al.</i> (2009)		Model did not fit empirical data	
Falkengren-Grerup <i>et al.</i> (1998)		Model did not fit empirical data	
Fennema (1992)	2.93 (2.9 to 2.96)	0.09 (0.06 to 0.12)	0.87
Gilliam & Turrill (1993)		Model did not fit empirical data	
Graae (2000)	4.09 [§] (4.09 to 4.09)	0.007 [§] (0.005 to 0.009)	1.00
Graae <i>et al.</i> (2003)	3.27 [§] (3.27 to 3.27)	0.009 [§] (0.008 to 0.009)	1.00
Härdtle <i>et al.</i> (2005)	2.33 [§] (2.27 to 2.4)	0.08 [§] (0.03 to 0.13)	0.87
Hofmeister <i>et al.</i> (2009)	3.66 (3.54 to 3.77)	0.25 (0.13 to 0.38)	0.84
Hutchinson <i>et al.</i> (1999)	2.69 ^{§,§} (NS)	0.47 ^{§,§} (NS)	0.36
Jacob <i>et al.</i> (2009)	1.37 ^{§,§} (NS)	2.24 ^{§,§} (0.45 to 4.03)	0.32
Kooijman (2010)	4.07 [§] (3.76 to 4.37)	0.68 [§] (0.44 to 0.92)	0.76
Lang <i>et al.</i> (2009)	4.52 [§] (3.37 to 5.68)	0.01 [§] (NS)	0.96
Lukešová & Hoffmann (1996)	4.01 (3.34 to 4.68)	2.31 (0.75 to 3.88)	0.31
Petersen (1994)	4.8 (4.76 to 4.84)	0.07 (0.03 to 0.11)	0.86

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Study	α	β	R^{2E}
Piernik (2005)	6.13 (6.07 to 6.2)	0.09 (0.03 to 0.14)	0.93
Plue <i>et al.</i> (2008)	3.73 (3.42 to 4.03)	1.00 (0.68 to 1.32)	0.70
Plue <i>et al.</i> (2009)		Model did not fit empirical data	
Roberts & Gilliam (1995)		Model did not fit empirical data	
Sage <i>et al.</i> (2005)	4.04 [§] (2.39 to 5.69)	0.72 [§] (NS)	0.43
Skousen <i>et al.</i> (1994)	2.71 [†] (2.43 to 3.00)	0.53 [†] (0.37 to 0.69)	0.86
Tyler (1996)	4.21 (4.16 to 4.26)	0.07 (0.01 to 0.12)	0.95
Van Couwenberghe <i>et al.</i> (2010)		Model did not fit empirical data	
Van Rossum <i>et al.</i> (1999)		Model did not fit empirical data	
Verheyen & Hermy (2001)		Model did not fit empirical data	
Vetaas (2000)		Model did not fit empirical data	
Ware <i>et al.</i> (1992)	5.58 (5.44 to 5.72)	0.66 (0.50 to 0.79)	0.87
West <i>et al.</i> (2009)	6.05 [§] (5.7 to 6.39)	0.11 [§] (NS)	0.73
Xu & Inubushi (2009)		Model did not fit empirical data	
Zas & Alonso (2002)	2.48 [§] (NS)	0.64 [§] (NS)	0.45
(i) Temperate grassland, savanna, and shrubland			
Baasch <i>et al.</i> (2009)	2.98 (2.92 to 3.03)	0.2 (0.14 to 0.25)	0.87
Beumer <i>et al.</i> (2008)		Model did not fit empirical data	
Dollar <i>et al.</i> (1992)	2.86 [§] (NS)	0.91 [§] (NS)	0.10
Heikens & Robertson (1995)		Model did not fit empirical data	
Mårtensson & Olsson (2010)	4.45 [†] (4.2 to 4.71)	0.77 [†] (0.55 to 0.98)	0.77
Olsson <i>et al.</i> (2009)	4.9 [‡] (4.06 to 5.73)	1.30 [‡] (NS)	0.00
Reinhammar <i>et al.</i> (2002)		Model did not fit empirical data	
Rodríguez <i>et al.</i> (1995)	4.9 [§] (4.06 to 5.73)	1.3 [§] (NS)	0.29
Roem & Berendse (2000)	5.04 (4.99 to 5.09)	0.04 (0.0003 to 0.08)	0.88
Sebastiá (2004)		Model did not fit empirical data	
Spiegelberger <i>et al.</i> (2006)		Model did not fit empirical data	
Stevens <i>et al.</i> (2010)		Model did not fit empirical data	
Tyler (2000)	3.82 [†] (3.54 to 4.1)	0.61 [†] (0.45 to 0.76)	0.86
Wagner (2009)		Model did not fit empirical data	
Walker <i>et al.</i> (2004)	-1.06 [§] (NS)	2.45 [§] (NS)	0.21
Zuo <i>et al.</i> (2009)	7.02 [‡] (6.84 to 7.21)	0.15 [‡] (NS)	0.72
(j) Temperate Coniferous Forest			
Dimopoulos <i>et al.</i> (1996)	6.58 (6.29 to 6.86)	0.96 (0.61 to 1.31)	0.65
Goldin (2001)	6.09 [§] (5.02 to 7.16)	0.65 [§] (NS)	0.33

Appendix S2.5

Study	α	β	$R^{2\epsilon}$
Hülber <i>et al.</i> (2008)	2.3 ^b (1.97 to 2.62)	0.23 ^b (0.16 to 0.3)	0.81
Johnston & Johnston (2004)		Model did not fit empirical data	
Kutnar & Martinčič (2003)	3.33 (3.26 to 3.4)	0.22 (0.15 to 0.3)	0.85
Nygaard & Abrahamsen (1991)		Model did not fit empirical data	
Nygaard & Ødegaard (1999)		Model did not fit empirical data	
Totland & Nylehn (1998)		Model did not fit empirical data	
(k) Montane grassland and shrubland			
Baniya <i>et al.</i> (2009)		Model did not fit empirical data	
Yimer <i>et al.</i> (2006)		Model did not fit empirical data	
(l) Boreal Forest / Taiga			
Elgersma & Dhillion (2002)	3.72 (3.64 to 3.8)	0.39 (0.29 to 0.49)	0.92
Giesler <i>et al.</i> (1998)	3.68 [†] (3.55 to 3.81)	0.31 [†] (0.17 to 0.45)	0.79
Karim & Mallik (2008)	3.97 [†] (3.53 to 4.41)	0.74 [†] (0.55 to 0.93)	0.88
Koptsik <i>et al.</i> (2001)	5.02 [‡] (4.8 to 5.25)	0.02 [‡] (NS)	0.95
(m) Tundra and alpine			
Arnesen <i>et al.</i> (2007)	5.34 (5.11 to 5.57)	0.78 (0.53 to 1.03)	0.74
Auerbach <i>et al.</i> (1997)		Model did not fit empirical data	
Austrheim <i>et al.</i> (2005)		Model did not fit empirical data	
Razzhivin (1994)	4.77 (4.67 to 4.86)	0.32 (0.22 to 0.43)	0.87
Walker (2000)		Model did not fit empirical data	
Walker & Everett (1991)	6.87 ^{‡,§} (6.45 to 7.19)	0.19 ^{‡,§} (NS)	0.62

[#] The 95% confidence interval around α and β is shown in parenthesis

[†] α is not within the range pH values used in the regression

[‡] Coefficient not included in the sensitivity analysis because their results are based on one (or both) coefficient non-different than zero (NS)

^ε $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{corrected Total}}$, as defined by Schabenberger & Pierce (2001)

Supporting information

Appendix S3.1 Biome-specific log-logistic coefficients.

Table S3.1.1 Coefficients α and β (95% confidence interval) of the PNOF – pH function used to derive effect factors

Biomes	α	β
Tundra	4.63 (4.61 to 4.65)	0.32 (0.29 to 0.35)
Boreal forest / Taiga	4.37 (4.31 to 4.44)	0.44 (0.38 to 0.50)
Temperate conifer forests	3.41 (3.29 to 3.52)	1.16 (0.93 to 1.39)
Temperate broadleaf and mixed forests	3.95 (3.94 to 3.96)	0.58 (0.56 to 0.59)
Montane grasslands and shrublands	5.91 (5.9 to 5.93)	0.02 (0.01 to 0.02)
Temperate grasslands, savannas and shrublands	4.69 (4.61 to 4.76)	0.88 (0.76 to 1.0)
Mediterranean forests, woodlands and scrub	6.04 (5.48 to 6.61)	1.3 (0.64 to 1.96)
Desert and xeric shrublands	6.79 (6.78 to 6.79)	0.29 (0.29 to 0.3)
(Sub)tropical moist broadleaf forest	4.11 (4.07 to 4.15)	0.70 (0.65 to 0.75)
(Sub)tropical grasslands, savannas and shrublands	4.73 (4.71 to 4.76)	0.07 (0.05 to 0.09)
(Sub)tropical coniferous forests [#]	3.55	0.18
(Sub)tropical dry broadleaf forests [#]	3.55	0.18
Flooded grasslands and savannas	6.8 (6.79 to 6.81)	0.28 (0.27 to 0.29)
Mangroves	3.87 (3.73 to 4.0)	0.16 (0.06 to 0.26)

[#] Biomes whose coefficients were approximated by other biomes based on similar climate conditions

Appendix S3.2 Characterization factors

Table S3.2.1 Global atmospheric fate factors ($\sum FF$), midpoint characterization factors ($\sum FF \cdot SF$), and endpoint characterization factors ($\sum FF \cdot SF \cdot EF$).

	$\sum FF$ (keq·kg ⁻¹)		$\sum FF \cdot SF$ (mol H·m ² ·yr·kg ⁻¹)		$\sum FF \cdot SF \cdot EF$ (m ² ·yr·kg ⁻¹)				
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂			
	4.18×10 ⁻⁹	1.10×10 ⁻⁸	6.08×10 ⁻⁹	9.17×10 ⁻⁴	4.93×10 ⁻³	2.52×10 ⁻³	7.9	28.4	16.4

Table S3.2.2 Continent-specific atmospheric fate factors ($\sum FF$), midpoint characterization factors ($\sum FF \cdot SF$), and endpoint characterization factors ($\sum FF \cdot SF \cdot EF$).

Continent	$\sum FF$ (keq·kg ⁻¹)			$\sum FF \cdot SF$ (mol H·m ² ·yr·kg ⁻¹)			$\sum FF \cdot SF \cdot EF$ (m ² ·yr·kg ⁻¹)		
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂
NorthAmerica	4.18×10 ⁻⁹	1.21×10 ⁻⁸	6.25×10 ⁻⁹	1.50×10 ⁻³	1.57×10 ⁻²	4.32×10 ⁻³	8.02×10 ⁰	66.1	22.7
SouthAmerica	3.20×10 ⁻⁹	1.02×10 ⁻⁸	5.46×10 ⁻⁹	7.22×10 ⁻⁴	5.21×10 ⁻³	3.46×10 ⁻³	6.70×10 ⁰	40.6	16.4
Europe	4.87×10 ⁻⁹	1.32×10 ⁻⁸	7.31×10 ⁻⁹	1.57×10 ⁻³	8.02×10 ⁻³	4.44×10 ⁻³	9.76×10 ⁰	46.9	29.4
Asia	3.93×10 ⁻⁹	1.01×10 ⁻⁸	5.94×10 ⁻⁹	1.45×10 ⁻³	5.37×10 ⁻³	3.59×10 ⁻³	8.61×10 ⁰	25.2	23.0
Australia	3.03×10 ⁻⁹	9.92×10 ⁻⁹	5.38×10 ⁻⁹	6.23×10 ⁻⁴	2.87×10 ⁻³	2.40×10 ⁻³	10.8×10 ¹	36.1	31.5
Oceania	3.32×10 ⁻⁹	1.08×10 ⁻⁸	5.70×10 ⁻⁹	3.01×10 ⁻⁴	8.52×10 ⁻⁴	7.08×10 ⁻⁴	2.96×10 ⁰	10.1	8.76

Table S3.2.1 Country-specific atmospheric fate factors ($\sum FF$), midpoint characterization factors ($\sum FF \cdot SF$), and endpoint characterization factors ($\sum FF \cdot SF \cdot EF$).

Country	$\sum FF$ (keq·kg ⁻¹)			$\sum FF \cdot SF$ (mol H·m ² ·yr·kg ⁻¹)			$\sum FF \cdot SF \cdot EF$ (m ² ·yr·kg ⁻¹)		
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂
Afghanistan	3.73E-09	1.05E-08	5.94E-09	2.21E-03	8.09E-03	5.47E-03	1.26E+01	4.66E+01	4.02E+01
Albania	4.25E-09	1.21E-08	6.59E-09	1.32E-03	6.02E-03	3.22E-03	9.05E+00	3.67E+01	2.42E+01
Algeria	3.75E-09	1.13E-08	6.10E-09	5.80E-04	2.34E-03	1.16E-03	8.47E+00	4.01E+01	3.51E+01
American Samoa	3.74E-09	9.80E-09	5.06E-09	1.81E-05	1.53E-05	2.07E-05	1.26E-01	1.05E-01	1.64E-01
Andorra	4.34E-09	1.26E-08	6.81E-09	1.39E-03	7.85E-03	3.64E-03	1.06E+01	5.72E+01	3.01E+01
Angola	2.90E-09	9.79E-09	5.16E-09	7.34E-04	2.65E-03	2.88E-03	1.09E+01	3.94E+01	5.53E+01
Anguilla	3.22E-09	1.05E-08	5.51E-09	1.63E-04	1.47E-03	4.32E-04	1.32E+00	9.55E+00	3.34E+00
Antarctica	4.22E-09	1.83E-08	9.47E-09	1.51E-04	8.48E-05	6.41E-05	1.15E+00	6.23E-01	5.83E-01
Antigua & Barbuda	2.84E-09	1.05E-08	5.54E-09	1.43E-04	1.48E-03	4.48E-04	1.13E+00	9.50E+00	3.37E+00
Argentina	3.51E-09	1.16E-08	5.78E-09	3.56E-04	1.69E-03	2.50E-03	2.47E+00	1.20E+01	1.16E+01
Armenia	4.28E-09	1.14E-08	6.60E-09	1.79E-03	7.86E-03	4.70E-03	1.03E+01	4.37E+01	3.03E+01
Aruba	3.22E-09	1.00E-08	5.23E-09	2.27E-04	1.56E-03	4.30E-04	2.49E+00	1.68E+01	4.40E+00
Australia	3.32E-09	1.08E-08	5.70E-09	3.51E-04	1.09E-03	7.08E-04	2.55E+00	8.48E+00	8.15E+00
Austria	4.79E-09	1.34E-08	7.29E-09	2.33E-03	1.61E-02	6.41E-03	1.14E+01	6.65E+01	3.11E+01
Azerbaijan	4.32E-09	1.13E-08	6.60E-09	1.66E-03	6.43E-03	3.76E-03	9.52E+00	3.49E+01	2.61E+01
Bahamas	3.20E-09	1.08E-08	5.74E-09	3.84E-04	3.42E-03	1.00E-03	2.07E+00	1.68E+01	5.41E+00
Bahrain	3.48E-09	1.05E-08	5.54E-09	1.67E-03	4.71E-03	2.97E-03	5.99E+00	2.35E+01	1.42E+01
Bangladesh	3.45E-09	1.04E-08	5.51E-09	8.04E-04	1.65E-03	1.48E-03	5.58E+00	1.09E+01	1.07E+01
Barbados	3.12E-09	1.03E-08	5.40E-09	1.68E-04	1.45E-03	4.59E-04	1.50E+00	1.04E+01	3.64E+00
Belarus	5.08E-09	1.36E-08	7.76E-09	1.51E-03	6.00E-03	5.14E-03	1.05E+01	4.97E+01	3.49E+01
Belgium	4.92E-09	1.40E-08	7.67E-09	1.87E-03	1.15E-02	5.06E-03	9.98E+00	6.03E+01	2.63E+01

Country	$\Sigma FF \cdot SF \text{ (keq} \cdot \text{kg}^{-1}\text{)}$				$\Sigma FF \cdot SF \text{ (mol H} \cdot \text{m}^{-2}\text{yr} \cdot \text{kg}^{-1}\text{)}$				$\Sigma FF \cdot SF \cdot EF \text{ (m}^2\text{yr} \cdot \text{kg}^{-1}\text{)}$			
	NO _x	NH ₃	SO ₂		NO _x	NH ₃	SO ₂		NO _x	NH ₃	SO ₂	
Belize	3.26E-09	1.02E-08	5.39E-09		2.55E-04	1.96E-03	8.20E-04		2.26E+00	1.48E+01	6.22E+00	
Benin	3.16E-09	9.89E-09	5.27E-09		3.19E-04	1.41E-03	1.68E-03		3.48E+00	1.29E+01	2.03E+01	
Bhutan	3.55E-09	1.04E-08	5.59E-09		1.21E-03	5.78E-03	3.38E-03		8.17E+00	2.93E+01	2.08E+01	
Bolivia	3.26E-09	9.98E-09	5.38E-09		5.78E-04	3.10E-03	5.25E-03		4.26E+00	2.57E+01	1.80E+01	
Bosnia Herzegovina	4.47E-09	1.28E-08	6.91E-09		1.79E-03	1.06E-02	4.88E-03		1.04E+01	5.69E+01	2.82E+01	
Botswana	3.03E-09	1.02E-08	5.50E-09		8.28E-04	3.10E-03	2.80E-03		6.27E+00	2.51E+01	2.91E+01	
Brazil	3.13E-09	1.00E-08	5.28E-09		7.34E-04	4.21E-03	3.18E-03		0.00E+00	4.21E+01	2.82E+01	
British Indian Ocean Territory	2.43E-09	9.69E-09	5.12E-09		1.00E-04	3.00E-04	1.81E-04		7.24E+00	2.11E+00	1.50E+00	
British Virgin Isl.	3.22E-09	1.05E-08	5.51E-09		1.63E-04	1.47E-03	4.32E-04		6.31E-01	9.55E+00	3.34E+00	
Brunei	2.74E-09	9.68E-09	5.15E-09		3.14E-04	8.12E-04	7.09E-04		1.32E+00	5.46E+00	4.96E+00	
Bulgaria	4.43E-09	1.23E-08	6.71E-09		1.35E-03	4.79E-03	2.75E-03		2.01E+00	3.68E+01	2.73E+01	
Burkina Faso	3.18E-09	1.00E-08	5.34E-09		3.55E-04	1.85E-03	1.80E-03		9.90E+00	1.91E+01	2.59E+01	
Burundi	2.67E-09	9.66E-09	5.13E-09		5.96E-04	3.14E-03	3.36E-03		3.76E+00	3.01E+01	5.08E+01	
Cambodia	3.02E-09	9.88E-09	5.32E-09		4.51E-04	1.13E-03	1.01E-03		7.61E+00	2.20E+01	1.61E+01	
Cameroon	2.80E-09	9.77E-09	5.17E-09		6.13E-04	2.79E-03	2.74E-03		4.72E+00	2.69E+01	2.70E+01	
Canada	4.78E-09	1.33E-08	7.05E-09		2.15E-03	1.61E-02	7.99E-03		7.17E+00	7.84E+01	3.76E+01	
Cape Verde	2.95E-09	1.02E-08	5.31E-09		1.16E-04	1.25E-03	5.54E-04		1.04E+01	9.01E+00	4.17E+00	
Central African Republic	3.06E-09	9.75E-09	5.20E-09		1.31E-03	4.94E-03	4.72E-03		8.31E-01	8.32E+01	7.77E+01	
Chad	3.06E-09	9.94E-09	5.28E-09		7.99E-04	3.41E-03	3.59E-03		2.25E+01	3.15E+01	4.43E+01	
Chile	3.56E-09	1.21E-08	5.74E-09		7.85E-04	6.07E-03	3.57E-03		1.13E+01	2.81E+01	1.14E+01	
China	3.98E-09	1.00E-08	5.81E-09		1.60E-03	5.78E-03	3.91E-03		4.11E+00	3.10E+01	2.30E+01	
Christmas Isl.	2.34E-09	9.69E-09	5.13E-09		1.59E-04	4.34E-04	4.14E-04		9.07E+00	2.86E+00	2.56E+00	
Colombia	3.08E-09	9.69E-09	5.11E-09		4.35E-04	3.24E-03	1.21E-03		4.39E+00	3.69E+01	8.29E+00	

Country	$\Sigma FF \cdot SF \text{ (keq} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \text{ (mol H} \cdot \text{m}^{-2}\text{, yr} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \cdot EF \text{ (m}^2\text{, yr} \cdot \text{kg}^{-1}\text{)}$		
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂
Congo	2.30E-09	9.65E-09	5.11E-09	6.60E-04	4.83E-03	4.10E-03	7.37E+00	4.91E+01	5.96E+01
Congo DRC	2.63E-09	9.69E-09	5.16E-09	6.84E-04	2.77E-03	4.80E-03	9.99E+00	3.64E+01	9.21E+01
Comoros	2.82E-09	9.79E-09	5.14E-09	3.65E-04	1.06E-03	9.82E-04	4.41E+00	1.10E+01	1.43E+01
Cook Isl.	4.00E-09	1.01E-08	5.33E-09	2.36E-05	4.81E-06	8.68E-06	1.69E-01	3.15E-02	5.89E-02
Costa Rica	3.34E-09	9.87E-09	5.15E-09	3.88E-04	3.79E-03	1.86E-03	2.62E+00	2.06E+01	8.77E+00
Cote d'Ivoire	3.07E-09	9.82E-09	5.24E-09	2.89E-04	1.89E-03	1.53E-03	2.65E+00	1.57E+01	1.74E+01
Croatia	4.61E-09	1.30E-08	7.08E-09	1.88E-03	1.04E-02	4.41E-03	1.03E+01	5.31E+01	2.57E+01
Cuba	3.20E-09	1.05E-08	5.58E-09	2.67E-04	2.31E-03	7.91E-04	2.24E+00	1.87E+01	7.18E+00
Cyprus	3.91E-09	1.10E-08	6.08E-09	1.03E-03	2.36E-03	1.43E-03	8.18E+00	2.83E+01	1.94E+01
Czech Republic	4.95E-09	1.37E-08	7.53E-09	2.45E-03	1.69E-02	6.99E-03	1.24E+01	8.61E+01	3.62E+01
Denmark	5.19E-09	1.43E-08	8.07E-09	2.01E-03	1.26E-02	6.16E-03	8.84E+00	4.87E+01	2.41E+01
Djibouti	2.82E-09	9.96E-09	5.24E-09	5.54E-04	1.80E-03	1.27E-03	5.80E+00	1.79E+01	1.41E+01
Dominican Republic	3.21E-09	1.04E-08	5.45E-09	1.82E-04	1.47E-03	3.94E-04	1.55E+00	1.12E+01	3.71E+00
Ecuador	3.32E-09	9.57E-09	5.07E-09	6.17E-04	4.45E-03	2.28E-03	4.26E+00	3.01E+01	1.50E+01
Egypt	3.59E-09	1.03E-08	5.72E-09	1.80E-03	3.78E-03	5.18E-03	9.76E+00	2.78E+01	2.47E+01
El Salvador	3.30E-09	1.00E-08	5.27E-09	2.88E-04	2.15E-03	9.42E-04	3.07E+00	2.42E+01	8.62E+00
Equatorial Guinea	2.31E-09	9.69E-09	5.15E-09	5.50E-04	4.45E-03	2.52E-03	4.79E+00	3.22E+01	2.36E+01
Eritrea	2.94E-09	1.01E-08	5.31E-09	6.54E-04	2.18E-03	1.51E-03	6.68E+00	1.81E+01	1.76E+01
Estonia	5.29E-09	1.35E-08	8.06E-09	1.65E-03	5.70E-03	6.36E-03	9.83E+00	4.02E+01	3.52E+01
Ethiopia	3.05E-09	9.85E-09	5.22E-09	6.18E-04	1.85E-03	1.68E-03	7.94E+00	1.93E+01	2.31E+01
Faroe Isl.	3.34E-09	1.44E-08	8.02E-09	8.13E-04	1.91E-03	2.13E-03	4.74E+00	8.08E+00	9.95E+00
Falkland Isl.	4.02E-09	1.50E-08	7.78E-09	1.90E-04	2.89E-04	2.36E-03	1.45E+00	2.14E+00	1.49E+01
Fiji	3.77E-09	9.90E-09	5.09E-09	2.38E-05	4.32E-05	4.67E-05	1.70E-01	3.26E-01	6.80E-01

Country	$\Sigma FF \cdot SF$ (keq·kg ⁻¹)			$\Sigma FF \cdot SF$ (mol H·m ² ·yr·kg ⁻¹)			$\Sigma FF \cdot SF \cdot EF$ (m ² ·yr·kg ⁻¹)		
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂
Finland	5.30E-09	1.29E-08	7.94E-09	1.58E-03	6.47E-03	9.09E-03	8.14E+00	2.30E+01	3.24E+01
France	4.69E-09	1.35E-08	7.34E-09	1.67E-03	9.13E-03	4.30E-03	9.96E+00	5.57E+01	2.71E+01
French Guiana	3.01E-09	9.82E-09	5.19E-09	3.71E-04	2.51E-03	1.44E-03	3.00E+00	1.91E+01	1.09E+01
French Polynesia	3.88E-09	9.79E-09	5.17E-09	1.53E-05	3.72E-06	6.29E-06	1.10E-01	2.87E-02	3.60E-02
French Southern Antarctic Lands	3.61E-09	1.46E-08	7.59E-09	1.47E-04	6.12E-06	8.51E-05	1.07E+00	5.65E-02	7.50E-01
Gabon	2.25E-09	9.65E-09	5.12E-09	5.28E-04	4.35E-03	2.99E-03	5.24E+00	4.16E+01	3.50E+01
Gaza Strip	3.74E-09	1.06E-08	5.82E-09	1.76E-03	4.59E-03	3.35E-03	7.25E+00	2.15E+01	1.81E+01
Georgia	4.42E-09	1.16E-08	6.78E-09	1.86E-03	1.02E-02	5.14E-03	1.10E+01	5.73E+01	3.34E+01
Germany	4.99E-09	1.40E-08	7.68E-09	2.16E-03	1.25E-02	6.12E-03	1.07E+01	5.73E+01	2.96E+01
Ghana	3.14E-09	9.83E-09	5.25E-09	2.80E-04	1.41E-03	1.56E-03	2.85E+00	1.25E+01	1.87E+01
Greece	4.16E-09	1.18E-08	6.42E-09	1.06E-03	3.78E-03	1.97E-03	8.60E+00	3.28E+01	2.21E+01
Greenland	3.43E-09	1.36E-08	7.66E-09	2.76E-04	1.20E-03	2.95E-03	1.96E+00	1.95E+01	5.13E+01
Grenada	3.31E-09	1.01E-08	5.31E-09	2.39E-04	1.52E-03	5.02E-04	2.35E+00	1.21E+01	4.25E+00
Guadeloupe	2.40E-09	1.04E-08	5.46E-09	1.35E-04	1.47E-03	4.54E-04	1.13E+00	1.01E+01	3.57E+00
Guam	3.03E-09	9.88E-09	5.19E-09	1.14E-04	5.31E-04	2.77E-04	6.53E-01	3.13E+00	1.69E+00
Guatemala	3.24E-09	1.01E-08	5.28E-09	2.93E-04	2.39E-03	1.04E-03	2.71E+00	2.14E+01	6.66E+00
Guinea	3.05E-09	9.91E-09	5.24E-09	3.44E-04	2.70E-03	1.33E-03	0.00E+00	0.00E+00	0.00E+00
Guinea-Bissau	3.06E-09	9.96E-09	5.20E-09	3.10E-04	2.44E-03	9.14E-04	3.13E+00	2.75E+01	1.29E+01
Guyana	3.06E-09	9.79E-09	5.20E-09	6.12E-04	4.81E-03	2.07E-03	2.17E+00	1.49E+01	6.83E+00
Haiti	3.11E-09	1.04E-08	5.47E-09	1.89E-04	1.54E-03	4.61E-04	5.02E+00	3.69E+01	1.56E+01
Honduras	3.27E-09	1.00E-08	5.28E-09	2.58E-04	1.75E-03	8.30E-04	1.61E+00	1.21E+01	4.69E+00
Hungary	4.77E-09	1.32E-08	7.22E-09	1.97E-03	9.90E-03	4.62E-03	2.86E+00	2.15E+01	8.67E+00
Iceland	4.62E-09	1.54E-08	7.81E-09	4.76E-04	4.53E-03	2.77E-03	1.07E+01	5.25E+01	2.66E+01

Country	$\Sigma FF \cdot SF \text{ (keq} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \text{ (mol H} \cdot \text{m}^{-2}\text{, yr} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \cdot EF \text{ (m}^2\text{, yr} \cdot \text{kg}^{-1}\text{)}$		
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂
India	3.49E-09	1.03E-08	5.50E-09	8.87E-04	2.11E-03	1.66E-03	3.04E+00	3.37E+01	2.12E+01
Indonesia	2.97E-09	9.61E-09	5.06E-09	3.41E-04	1.24E-03	1.14E-03	5.48E+00	1.30E+01	1.12E+01
Iran	3.80E-09	1.07E-08	5.99E-09	1.28E-03	4.12E-03	2.71E-03	2.07E+00	7.51E+00	6.22E+00
Iraq	3.86E-09	1.08E-08	6.09E-09	1.33E-03	3.07E-03	2.58E-03	7.31E+00	2.58E+01	1.86E+01
Ireland	4.66E-09	1.45E-08	7.79E-09	8.90E-04	3.23E-03	3.08E-03	7.33E+00	2.04E+01	1.70E+01
Isle of Man	4.81E-09	1.46E-08	7.93E-09	1.10E-03	5.20E-03	3.51E-03	5.04E+00	1.75E+01	1.71E+01
Israel	3.73E-09	1.06E-08	5.82E-09	2.39E-03	6.23E-03	4.74E-03	5.97E+00	2.80E+01	1.97E+01
Italy	4.49E-09	1.29E-08	6.50E-09	1.77E-03	1.20E-02	3.15E-03	7.55E+00	2.32E+01	1.95E+01
Jamaica	3.19E-09	1.03E-08	5.42E-09	2.06E-04	1.67E-03	4.95E-04	9.50E+00	4.79E+01	2.16E+01
Jan Mayen	4.21E-09	1.35E-08	7.79E-09	4.54E-04	5.28E-04	8.01E-04	1.65E+00	1.12E+01	4.64E+00
Japan	3.98E-09	9.86E-09	5.75E-09	7.30E-04	4.08E-03	2.06E-03	2.58E+00	2.54E+00	5.81E+00
Jersey	4.77E-09	1.40E-08	7.59E-09	1.28E-03	5.61E-03	3.24E-03	7.53E+00	3.17E+01	2.01E+01
Jordan	3.74E-09	1.06E-08	5.83E-09	1.60E-03	3.84E-03	4.01E-03	7.28E+00	2.26E+01	1.94E+01
Kazakhstan	4.76E-09	1.10E-08	7.05E-09	1.89E-03	5.88E-03	4.29E-03	1.38E+01	5.15E+01	3.95E+01
Kenya	3.11E-09	9.70E-09	5.13E-09	6.92E-04	2.47E-03	2.32E-03	8.85E+00	2.35E+01	3.00E+01
Kiribati	3.56E-09	9.57E-09	4.96E-09	2.49E-05	8.68E-06	2.89E-05	1.61E-01	6.77E-02	1.80E-01
Kuwait	3.65E-09	1.06E-08	5.75E-09	1.86E-03	5.12E-03	4.35E-03	6.96E+00	2.68E+01	1.37E+01
Kyrgyzstan	4.18E-09	1.02E-08	6.29E-09	3.37E-03	1.61E-02	7.15E-03	1.95E+01	1.07E+02	4.32E+01
Laos	3.24E-09	1.00E-08	5.44E-09	6.19E-04	1.75E-03	1.37E-03	5.19E+00	2.08E+01	1.33E+01
Latvia	5.23E-09	1.37E-08	7.97E-09	1.61E-03	6.00E-03	5.33E-03	1.02E+01	5.17E+01	3.50E+01
Lebanon	3.83E-09	1.08E-08	5.97E-09	1.17E-03	2.73E-03	1.79E-03	7.28E+00	2.30E+01	1.64E+01
Lesotho	3.50E-09	1.09E-08	5.78E-09	6.57E-04	1.39E-03	1.31E-03	3.48E+00	6.60E+00	8.78E+00
Liberia	2.72E-09	9.78E-09	5.20E-09	3.68E-04	5.99E-03	1.83E-03	2.94E+00	4.42E+01	1.64E+01

Country	$\Sigma FF \cdot SF \text{ (keq} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \text{ (mol H} \cdot \text{m}^{-2}\text{, yr} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \cdot EF \text{ (m}^2\text{, yr} \cdot \text{kg}^{-1}\text{)}$		
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂
Libya	3.58E-09	1.07E-08	5.79E-09	6.49E-04	2.30E-03	1.46E-03	7.60E+00	2.34E+01	3.44E+01
Liechtenstein	4.80E-09	1.36E-08	7.36E-09	2.08E-03	1.19E-02	5.49E-03	1.08E+01	5.95E+01	2.93E+01
Lithuania	5.19E-09	1.37E-08	7.90E-09	1.67E-03	6.64E-03	5.32E-03	1.04E+01	5.18E+01	3.48E+01
Luxembourg	4.92E-09	1.39E-08	7.59E-09	2.08E-03	1.42E-02	6.13E-03	1.12E+01	7.80E+01	3.39E+01
Macedonia	4.35E-09	1.22E-08	6.68E-09	1.69E-03	8.27E-03	4.56E-03	1.03E+01	4.15E+01	2.77E+01
Madagascar	3.01E-09	1.00E-08	5.29E-09	5.39E-04	2.22E-03	1.54E-03	4.48E+00	1.65E+01	1.41E+01
Malawi	2.98E-09	9.82E-09	5.21E-09	8.35E-04	3.22E-03	3.39E-03	1.20E+01	4.19E+01	6.26E+01
Malaysia	3.08E-09	9.63E-09	5.13E-09	3.47E-04	8.80E-04	1.04E-03	2.14E+00	5.50E+00	5.89E+00
Mali	3.22E-09	1.01E-08	5.31E-09	4.52E-04	3.46E-03	1.67E-03	4.16E+00	3.51E+01	1.97E+01
Malta	3.81E-09	1.15E-08	6.25E-09	7.88E-04	2.63E-03	1.72E-03	6.28E+00	1.88E+01	1.59E+01
Martinique	2.54E-09	1.03E-08	5.38E-09	1.54E-04	1.48E-03	4.62E-04	1.38E+00	1.09E+01	3.75E+00
Mauritania	3.24E-09	1.02E-08	5.32E-09	8.25E-04	9.13E-03	2.84E-03	4.56E+00	3.87E+01	1.68E+01
Mauritius	3.31E-09	1.00E-08	5.27E-09	2.08E-04	4.80E-04	3.14E-04	1.86E+00	4.14E+00	3.62E+00
Mayotte	2.97E-09	9.79E-09	5.14E-09	3.62E-04	9.62E-04	8.44E-04	4.14E+00	9.54E+00	1.13E+01
Mexico	3.54E-09	1.07E-08	5.51E-09	5.15E-04	4.28E-03	1.86E-03	3.93E+00	3.20E+01	9.74E+00
Moldova	4.72E-09	1.29E-08	7.16E-09	1.28E-03	3.85E-03	2.98E-03	8.60E+00	2.84E+01	2.15E+01
Micronesia	3.02E-09	9.66E-09	5.03E-09	2.53E-05	1.10E-04	1.28E-04	1.53E-01	7.13E-01	8.59E-01
Mongolia	4.31E-09	7.80E-09	5.67E-09	1.68E-03	4.40E-03	4.52E-03	1.17E+01	4.69E+01	4.24E+01
Montserrat	2.40E-09	1.04E-08	5.46E-09	1.35E-04	1.47E-03	4.54E-04	1.13E+00	1.01E+01	3.57E+00
Morocco	3.78E-09	1.13E-08	6.01E-09	4.41E-04	2.01E-03	8.54E-04	7.43E+00	4.20E+01	1.93E+01
Mozambique	3.06E-09	9.98E-09	5.46E-09	6.23E-04	1.85E-03	2.45E-03	6.42E+00	1.71E+01	2.14E+01
Myanmar	3.41E-09	1.02E-08	5.56E-09	7.18E-04	2.15E-03	2.06E-03	4.96E+00	1.45E+01	1.49E+01
Namibia	3.10E-09	1.02E-08	5.40E-09	9.15E-04	4.22E-03	1.41E-03	4.95E+00	1.28E+01	1.55E+01

Country	$\Sigma FF \cdot SF \text{ (keq} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \text{ (mol H} \cdot \text{m}^{-2}\text{yr} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \cdot EF \text{ (m}^2\text{yr} \cdot \text{kg}^{-1}\text{)}$		
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂
Nepal	3.60E-09	1.05E-08	5.56E-09	1.15E-03	3.45E-03	2.16E-03	8.37E+00	2.49E+01	1.84E+01
Netherlands	5.02E-09	1.42E-08	7.82E-09	1.84E-03	1.02E-02	5.00E-03	8.74E+00	3.56E+01	1.98E+01
Netherlands Antilles	3.22E-09	1.00E-08	5.23E-09	2.27E-04	1.56E-03	4.30E-04	2.49E+00	1.68E+01	4.40E+00
New Caledonia	3.70E-09	1.01E-08	5.28E-09	4.28E-05	1.55E-04	2.41E-04	3.02E-01	1.11E+00	2.25E+00
New Zealand	4.02E-09	1.28E-08	5.98E-09	4.77E-04	1.77E-03	2.16E-03	3.22E+00	1.69E+01	1.13E+01
Nicaragua	3.19E-09	9.99E-09	5.20E-09	2.45E-04	1.66E-03	9.11E-04	2.48E+00	1.88E+01	7.34E+00
Niger	3.20E-09	1.02E-08	5.40E-09	5.72E-04	3.25E-03	5.04E-03	6.20E+00	2.47E+01	4.33E+01
Nigeria	3.10E-09	9.87E-09	5.19E-09	4.63E-04	1.82E-03	2.05E-03	5.28E+00	1.74E+01	2.03E+01
Niue	3.92E-09	1.00E-08	5.19E-09	2.21E-05	1.55E-05	1.76E-05	1.58E-01	1.01E-01	1.41E-01
North Korea	4.24E-09	9.71E-09	5.95E-09	1.94E-03	1.23E-02	4.18E-03	8.88E+00	4.70E+01	2.19E+01
Norway	5.24E-09	1.34E-08	7.96E-09	1.83E-03	1.39E-02	5.75E-03	7.47E+00	4.10E+01	2.18E+01
Oman	3.30E-09	1.03E-08	5.44E-09	8.27E-04	2.63E-03	1.70E-03	6.09E+00	1.95E+01	1.56E+01
Palau	2.10E-09	9.72E-09	5.16E-09	1.88E-04	5.68E-04	3.51E-04	1.06E+00	3.35E+00	2.24E+00
Pakistan	3.45E-09	1.05E-08	5.72E-09	2.37E-03	9.12E-03	6.27E-03	8.79E+00	3.08E+01	2.31E+01
Panama	3.16E-09	9.82E-09	5.15E-09	2.81E-04	2.16E-03	1.39E-03	2.30E+00	1.69E+01	7.48E+00
Papua New Guinea	2.62E-09	9.63E-09	5.05E-09	1.07E-04	5.57E-04	5.52E-04	7.52E-01	4.04E+00	4.20E+00
Paraguay	3.16E-09	1.04E-08	5.50E-09	3.81E-04	2.07E-03	2.48E-03	3.01E+00	1.72E+01	1.67E+01
Peru	3.22E-09	9.73E-09	5.21E-09	8.36E-04	6.49E-03	6.92E-03	3.39E+00	2.57E+01	1.51E+01
Philippines	2.98E-09	9.72E-09	5.27E-09	3.51E-04	1.00E-03	8.40E-04	2.16E+00	6.45E+00	5.41E+00
Pitcairn Isl.	4.12E-09	1.04E-08	5.54E-09	3.07E-05	1.50E-05	4.86E-05	2.18E-01	1.00E-01	2.16E-01
Poland	5.04E-09	1.38E-08	7.66E-09	2.27E-03	1.45E-02	6.55E-03	1.09E+01	5.63E+01	2.97E+01
Portugal	4.19E-09	1.23E-08	6.53E-09	8.81E-04	6.75E-03	2.23E-03	6.91E+00	4.45E+01	1.69E+01
Puerto Rico	3.20E-09	1.04E-08	5.48E-09	1.68E-04	1.47E-03	4.08E-04	1.40E+00	1.04E+01	3.79E+00

Country	$\Sigma FF \cdot SF \text{ (keq} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \text{ (mol H} \cdot \text{m}^{-2}\text{yr} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \cdot EF \text{ (m}^2\text{yr} \cdot \text{kg}^{-1}\text{)}$		
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂
Qatar	3.48E-09	1.04E-08	5.54E-09	1.69E-03	5.10E-03	3.14E-03	6.36E+00	2.85E+01	1.57E+01
Reunion	3.28E-09	1.01E-08	5.34E-09	2.44E-04	5.58E-04	6.98E-04	2.14E+00	4.80E+00	9.15E+00
Romania	4.62E-09	1.28E-08	7.05E-09	1.67E-03	1.02E-02	4.62E-03	9.92E+00	4.93E+01	2.72E+01
Russia	5.12E-09	1.12E-08	7.72E-09	1.63E-03	6.40E-03	5.80E-03	1.24E+01	5.29E+01	4.77E+01
Rwanda	2.28E-09	9.66E-09	5.13E-09	5.91E-04	4.50E-03	4.07E-03	6.87E+00	3.69E+01	5.45E+01
Samoa	3.75E-09	9.80E-09	5.06E-09	1.81E-05	1.57E-05	2.12E-05	1.26E-01	1.07E-01	1.68E-01
Sao Tome & Principe	1.90E-09	9.65E-09	5.14E-09	1.59E-04	1.20E-03	1.75E-03	0.00E+00	1.11E+01	1.98E+01
Saudi Arabia	3.40E-09	1.04E-08	5.54E-09	2.10E-03	6.33E-03	6.89E-03	1.38E+00	2.85E+01	2.06E+01
Senegal	3.25E-09	1.01E-08	5.25E-09	4.72E-04	3.26E-03	1.95E-03	8.07E+00	1.52E+01	1.03E+01
Serbia & Montenegro	4.51E-09	1.26E-08	6.90E-09	1.77E-03	8.51E-03	4.68E-03	2.57E+00	4.82E+01	2.85E+01
Seychelles	3.06E-09	9.73E-09	5.11E-09	3.78E-04	8.11E-04	7.54E-04	1.06E+01	7.57E+00	9.57E+00
Sierra Leone	2.79E-09	9.84E-09	5.22E-09	3.93E-04	5.35E-03	1.81E-03	4.40E+00	5.05E+01	1.74E+01
Slovakia	4.88E-09	1.34E-08	7.44E-09	2.22E-03	1.38E-02	6.26E-03	3.59E+00	6.31E+01	2.99E+01
Slovenia	4.65E-09	1.31E-08	7.14E-09	2.16E-03	1.54E-02	5.71E-03	1.12E+01	6.61E+01	2.90E+01
Solomon Isl.	3.11E-09	9.66E-09	5.05E-09	2.33E-05	8.12E-05	1.69E-04	1.09E+01	6.11E-01	1.43E+00
Somalia	3.13E-09	9.79E-09	5.19E-09	6.64E-04	2.81E-03	1.24E-03	1.55E-01	2.32E+01	1.18E+01
South Africa	3.47E-09	1.08E-08	5.72E-09	7.46E-04	2.46E-03	1.60E-03	6.83E+00	1.12E+01	1.15E+01
South Georgia & the South Sandwich Isl.	3.71E-09	1.56E-08	8.37E-09	2.16E-04	8.53E-05	6.14E-05	4.42E+00	6.77E-01	6.04E-01
South Korea	3.95E-09	9.77E-09	5.84E-09	1.12E-03	4.19E-03	2.29E-03	1.76E+00	2.65E+01	1.53E+01
Spain	4.26E-09	1.24E-08	6.71E-09	1.02E-03	5.71E-03	2.76E-03	6.18E+00	5.65E+01	2.35E+01
Sri Lanka	3.10E-09	9.74E-09	5.16E-09	2.69E-04	4.94E-04	3.55E-04	9.27E+00	4.28E+00	2.98E+00
St. Helena	2.44E-09	9.84E-09	5.14E-09	2.02E-04	4.00E-04	2.29E-04	1.85E+00	3.41E+00	2.03E+00
St. Lucia	2.54E-09	1.03E-08	5.38E-09	1.54E-04	1.48E-03	4.62E-04	1.57E+00	1.09E+01	3.75E+00

Country	$\Sigma FF \cdot SF \text{ (keq} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \text{ (mol H} \cdot \text{m}^{-2}\text{yr} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \cdot EF \text{ (m}^2\text{yr} \cdot \text{kg}^{-1}\text{)}$		
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂
St. Kitts & Nevis	3.22E-09	1.05E-08	5.51E-09	1.63E-04	1.47E-03	4.32E-04	1.38E+00	9.55E+00	3.34E+00
Sudan	3.09E-09	9.87E-09	5.23E-09	9.46E-04	3.46E-03	3.49E-03	1.32E+00	4.90E+01	6.02E+01
Suriname	2.97E-09	9.81E-09	5.20E-09	4.52E-04	3.34E-03	1.52E-03	1.53E+01	2.50E+01	1.13E+01
Svalbard	4.53E-09	1.05E-08	7.22E-09	6.53E-04	3.51E-04	3.77E-04	4.59E+00	1.78E+00	2.04E+00
Swaziland	3.44E-09	1.06E-08	5.64E-09	6.12E-04	1.30E-03	1.40E-03	4.62E+00	1.34E+01	1.35E+01
Sweden	5.24E-09	1.37E-08	7.98E-09	2.11E-03	1.98E-02	7.73E-03	9.02E+00	6.29E+01	2.85E+01
Switzerland	4.71E-09	1.34E-08	7.26E-09	2.09E-03	1.39E-02	5.56E-03	1.06E+01	5.73E+01	2.81E+01
Syria	3.99E-09	1.09E-08	6.14E-09	1.12E-03	2.59E-03	1.87E-03	7.25E+00	1.97E+01	1.59E+01
Tajikistan	4.03E-09	1.04E-08	6.20E-09	2.82E-03	8.94E-03	6.13E-03	1.64E+01	5.67E+01	4.08E+01
Tanzania	3.00E-09	9.70E-09	5.14E-09	6.05E-04	2.02E-03	2.61E-03	8.55E+00	2.33E+01	4.38E+01
Thailand	3.07E-09	1.00E-08	5.39E-09	5.21E-04	1.28E-03	1.13E-03	4.64E+00	1.93E+01	1.28E+01
Gambia	3.26E-09	1.01E-08	5.23E-09	3.63E-04	2.31E-03	1.75E-03	2.21E+00	1.45E+01	7.87E+00
East Timor	2.73E-09	9.68E-09	5.10E-09	1.69E-04	4.81E-04	4.50E-04	1.38E+00	5.35E+00	6.11E+00
Togo	3.15E-09	9.84E-09	5.26E-09	2.95E-04	1.31E-03	1.60E-03	3.14E+00	1.18E+01	1.93E+01
Tonga	3.93E-09	1.00E-08	5.17E-09	2.32E-05	3.00E-05	3.01E-05	1.66E-01	1.93E-01	2.52E-01
Trinidad Tobago	3.26E-09	9.98E-09	5.25E-09	3.03E-04	1.53E-03	5.91E-04	3.15E+00	1.36E+01	5.25E+00
Tunisia	3.74E-09	1.14E-08	6.21E-09	7.33E-04	2.30E-03	1.41E-03	7.28E+00	2.58E+01	2.40E+01
Turkey	4.18E-09	1.14E-08	6.40E-09	1.13E-03	3.64E-03	2.20E-03	8.75E+00	3.02E+01	2.12E+01
Turkmenistan	4.05E-09	1.06E-08	6.32E-09	2.14E-03	7.51E-03	4.84E-03	1.10E+01	3.83E+01	3.51E+01
Turks & Caicos Isl.	2.17E-09	1.07E-08	5.65E-09	2.02E-04	1.86E-03	5.59E-04	1.31E+00	1.06E+01	3.92E+00
Uganda	2.95E-09	9.69E-09	5.15E-09	8.31E-04	4.06E-03	3.97E-03	1.24E+01	5.80E+01	6.47E+01
Ukraine	4.89E-09	1.30E-08	7.36E-09	1.23E-03	4.36E-03	2.98E-03	8.71E+00	3.30E+01	2.26E+01
United Arab Emirates	3.37E-09	1.04E-08	5.47E-09	1.29E-03	5.28E-03	2.81E-03	7.25E+00	2.84E+01	2.33E+01

Country	$\Sigma FF \cdot SF \text{ (keq} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \text{ (mol H} \cdot \text{m}^{-2} \cdot \text{yr} \cdot \text{kg}^{-1}\text{)}$			$\Sigma FF \cdot SF \cdot EF \text{ (m}^2 \cdot \text{yr} \cdot \text{kg}^{-1}\text{)}$		
	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂	NO _x	NH ₃	SO ₂
United Kingdom	4.88E-09	1.44E-08	7.86E-09	1.31E-03	6.96E-03	3.93E-03	7.14E+00	3.67E+01	2.19E+01
USA	4.20E-09	1.23E-08	6.45E-09	1.52E-03	1.35E-02	4.82E-03	8.16E+00	7.34E+01	2.52E+01
Uruguay	3.54E-09	1.13E-08	5.98E-09	2.65E-04	1.08E-03	9.96E-04	1.95E+00	7.75E+00	6.64E+00
Uzbekistan	4.16E-09	1.05E-08	6.29E-09	2.48E-03	6.86E-03	6.14E-03	1.45E+01	4.70E+01	4.30E+01
Vanuatu	3.64E-09	9.82E-09	4.96E-09	2.46E-05	7.16E-05	8.27E-05	1.72E-01	5.04E-01	6.99E-01
Venezuela	3.14E-09	9.82E-09	5.22E-09	3.86E-04	2.84E-03	8.10E-04	4.02E+00	2.94E+01	7.95E+00
Vietnam	3.23E-09	1.00E-08	5.45E-09	6.19E-04	1.74E-03	1.64E-03	4.75E+00	1.58E+01	1.30E+01
Virgin Isl.	3.22E-09	1.05E-08	5.51E-09	1.63E-04	1.47E-03	4.32E-04	1.32E+00	9.55E+00	3.34E+00
Wallis & Futuna	3.78E-09	9.78E-09	5.01E-09	1.95E-05	3.03E-05	3.48E-05	1.40E-01	2.07E-01	2.92E-01
West Bank	3.76E-09	1.06E-08	5.84E-09	1.47E-03	3.17E-03	2.93E-03	7.35E+00	2.33E+01	1.89E+01
Western Sahara	3.25E-09	1.08E-08	5.58E-09	3.52E-04	2.02E-03	1.01E-03	4.65E+00	5.56E+01	1.58E+01
Yemen	3.10E-09	1.01E-08	5.29E-09	7.92E-04	3.17E-03	1.85E-03	6.22E+00	2.15E+01	1.59E+01
Zambia	3.02E-09	9.83E-09	5.22E-09	7.51E-04	2.30E-03	5.30E-03	1.17E+01	3.60E+01	1.06E+02
Zimbabwe	3.08E-09	1.01E-08	5.40E-09	6.76E-04	1.66E-03	2.64E-03	5.88E+00	1.27E+01	2.71E+01

Appendix S3.3 Importance of transboundary emissions

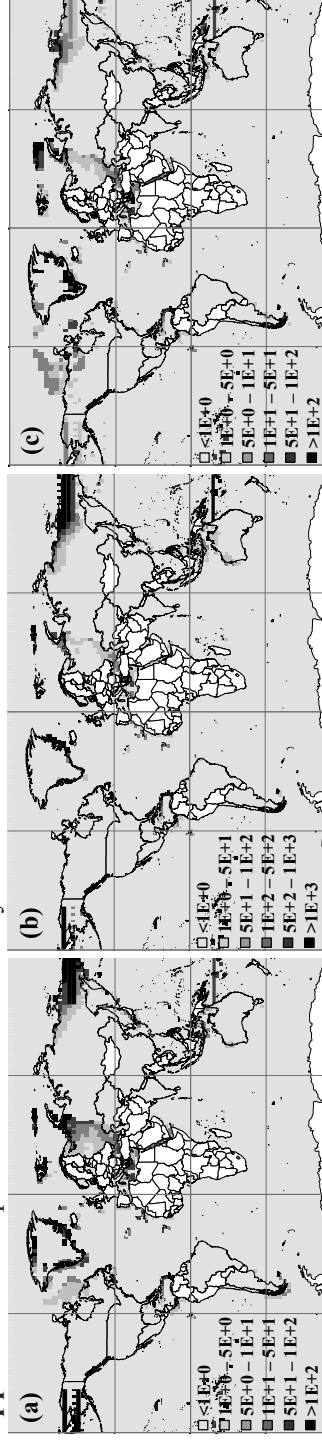


Figure S3.3.1 Percentage of transcontinental potential impacts of (a) NO_x , (b) NH_3 and (c) SO_2 continental emissions

Appendix S4.1

Appendix S4.1 CO₂ partial pressure to marine water pH conversion

When CO₂ partial pressure (pCO₂) for ocean water was reported instead of pH, we employed the following conversion equation (Figure S4.1.1) based on pCO₂ and pH data reported by Feely *et al.* (2009).

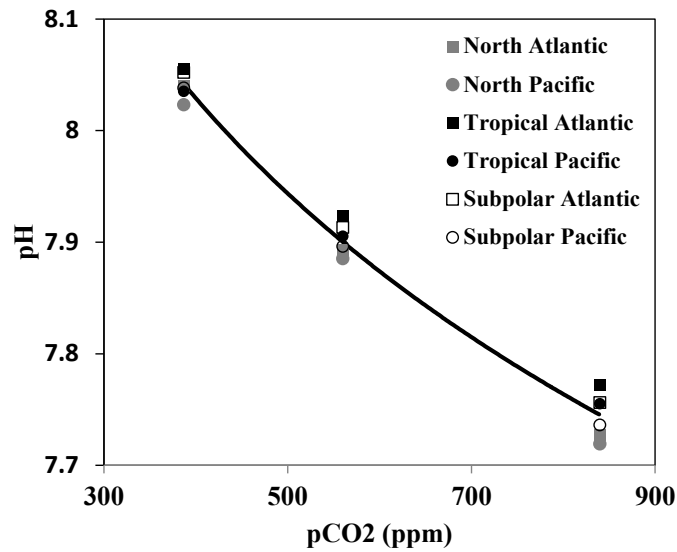


Figure S4.1.1 Correlation between pCO₂ and pH, based on the work of Feely *et al.* (2009) for different world's oceans. The equation for pCO₂ transformation to pH are $-0.38^{(\text{Standard error} = 0.01)} \cdot \ln(\text{pCO}_2) + 10.32^{(\text{Standard error} = 0.07)}$ (p value < 0.001, $R^2 = 0.99$).

Supporting information

Appendix S4.2 Abbreviation of species names

Table S4.2.1 Abbreviation of species names.

Abbreviation	Species name	Abbreviation	Species name
Aca_ery	<i>Acartia erythraea</i>	Por_lob	<i>Porites lobata</i>
Aca_ste	<i>Acartia steueri</i>	Por_lut	<i>Porites lutea</i>
Acr_eur	<i>Acropora eurytoma</i>	Por_onk	<i>Porolithon onkodes</i>
Acr_int	<i>Acropora intermedia</i>	Pse_hut	<i>Pseudechinus huttoni</i>
Amp_fil	<i>Amphiura filiformis</i>	Sac_glo	<i>Saccostrea glomerata</i>
Arb_pun	<i>Arbacia punctulata</i>	Sem_bal	<i>Semibalanus balanoides</i>
Arg_irr	<i>Argopecten irradians</i>	Ste_neu	<i>Sterechinus neumayeri</i>
Cal_lep	<i>Calcidiscus leptoporus</i>	Str_ala	<i>Strombus alatus</i>
Cal_sap	<i>Callinectes sapidus</i>	Sty_pis	<i>Stylophora pistillata</i>
Cra_gig	<i>Crassostrea gigas</i>	Tri_gra	<i>Tripneustes gratilla</i>
Cra_vir	<i>Crassostrea virginica</i>	Uro_cin	<i>Urosalpinx cinerea</i>
Cre_for	<i>Crepidula fornicata</i>		
Ech_mat	<i>Echinometra mathaei</i>		
Emi_hux	<i>Emiliana huxleyi</i>		
Euc_tri	<i>Eucidaris tribuloides</i>		
Eve_chl	<i>Evechinus chloroticus</i>		
Fav_fra	<i>Favia fragum</i>		
Gam_loc	<i>Gammarus locusta</i>		
Gep_oce	<i>Gephyrocapsa oceanica</i>		
Hal_inc	<i>Halimeda incrassata</i>		
Hel_ery	<i>Heliocidaris erythrogramma</i>		
Hem_pul	<i>Hemicentrotus pulcherrimus</i>		
Hom_ame	<i>Homarus americanus</i>		
Lit_lit	<i>Littorina littorea</i>		
Lop_per	<i>Lophelia pertusa</i>		
Mer_mer	<i>Mercenaria mercenaria</i>		
Mya_are	<i>Mya arenaria</i>		
Myt_edi	<i>Mytilus edulis</i>		
Ocu_arb	<i>Oculina arbuscula</i>		
Oph_fra	<i>Ophiothrix fragilis</i>		
Osi_tur	<i>Osilinus turbinata</i>		
Pen_ple	<i>Penaeus plebejus</i>		
Por_ast	<i>Porites astreoides</i>		
Por_com	<i>Porites compressa</i>		

Appendix S4.3

Appendix S4.3 Selection of experimental data: literature review

Beneficial and uncertain effects of pH decrease on growth and reproduction and on growth, reproduction, and mortality are shown in Tables S4.3.1 and S4.3.2, respectively. List of studies comprising our literature review are shown in Table S4.3.3.

Table S4.3.1 Logistic regression coefficients, i.e. EC_{50} and slope β (95% confidence interval) for benefiting effects of pH decreases on species **(a)** growth and **(b)** reproduction.

Species ^{#,¶}	EC_{50}	β	R^2 / p value
(a) Growth			
Pen_ple ^A	7.73 (7.73 to 7.73)	0.12 (0.11 to 0.13)	1.00 / <0.001
Emi_hux ^H	8.07 (8.06 to 8.07)	0.0008 (0.0007 to 0.0009)	1.00 / <0.001
(b) Reproduction			
Hem_pul ^E	7.24 (6.99 to 7.49)	0.64 (0.36 to 2.78)	0.9 / <0.001
Ech_mat ^E	7.69 (7.68 to 7.71)	0.09 (0.05 to 0.32)	1.00 / <0.001

[#] Legend of abbreviations of species names can be found in Table S4.2.1.
^AArthropoda, ^HHaptophyta, ^EEchinodermata

Table S4.3.2 Species for which logistic regression did not yield significant results (p value > 0.05) or that yielded slope β coefficient non-significantly different than zero. For these experiments, effects of pH decreases on species **(a)** growth, **(b)** reproduction, and **(c)** mortality are considered uncertain.

Species [#]
(a) Growth Arc_eur ^C , Arc_int ^C , Amp_fil ^E , Arb_pun ^E , Arg_irr ^M , Cal_lep ^H , Cal_sap ^A , Cra_vir ^M , Cre_for ^M , Emi_hux ^H , Euc_tri ^E , Fav_fra ^C , Gam_loc ^A , Gep_oce ^H , Hal_inc ^C , Hom_ame ^A , Lit_lit ^M , Lop_per ^C , Mer_mer ^M , Mya_are ^M , Myt_edi ^M , Oph_fra ^E , Por_ast ^C , Por_com ^C , Por_lob ^C , Por_lut ^C , Por_onk ^R , Sac_glo ^M , Sem_bal ^A , Str_ala ^M , Sty_pis ^C , Uro_cin ^M
(b) Reproduction Aca_ery ^A , Amp_fil ^E , Ech_mat ^E , Emi_hux ^H , Hel_ery ^E , Hem_pul ^E , Oph_fra ^E , Osi_tur ^M , Sac_glo ^M
(c) Mortality Aca_ery ^A , Aca_ste ^A , Arg_irr ^M , Eve_chl ^E , Gam_loc ^A , Mer_mer ^M , Myt_edi ^M , Pse_hut ^E , Sem_bal ^A , Ste_neu ^E

[#] Legend of abbreviations of species names can be found in Table S4.2.1.
^AArthropoda, ^HHaptophyta, ^MMollusca, ^EEchinodermata, ^CCnidaria

Supporting information

Table S4.3.3 List of studies used in the study, the number of species and of experiments, and the experimental pH range for the specific phylum and response category.

Study	Phylum	Response	Species	pH range
Albright <i>et al.</i> (2008)	C	G	1	7.80 – 7.99
Anthony <i>et al.</i> (2008)	C	G	2	7.65 – 8.20
Anthony <i>et al.</i> (2008)	R	G	1	7.65 – 8.20
Berge <i>et al.</i> (2006)	M	G	1	6.70 – 8.10
Berge <i>et al.</i> (2006)	M	S	1	6.70 – 8.10
Byrne <i>et al.</i> (2009)	E	R	1	7.67 – 8.20
Byrne <i>et al.</i> (2010)	E	R	1	7.60 – 8.17
Clark <i>et al.</i> (2009)	E	S	4	6.00 – 8.15
Cohen <i>et al.</i> (2009)	C	G	1	7.62 – 8.25
Dupont <i>et al.</i> (2008)	E	G	1	7.70 – 8.10
Dupont <i>et al.</i> (2008)	E	S	1	7.70 – 8.10
Dupont <i>et al.</i> (2008)	E	R	1	7.70 – 8.10
Findlay <i>et al.</i> (2010)	A	G	1	7.30 – 8.10
Findlay <i>et al.</i> (2010)	A	S	1	7.30 – 8.10
Gattuso <i>et al.</i> (1998)	C	G	2	7.34 – 8.30
Gazeau <i>et al.</i> (2007)	M	G	2	7.46 – 8.13
Hall-Spencer <i>et al.</i> (2008)	M	R	1	6.57 – 8.15
Hauton <i>et al.</i> (2009)	A	G	1	7.60 – 8.10
Hauton <i>et al.</i> (2009)	A	S	1	7.60 – 8.10
Kurihara & Shirayama (2004)	E	G	1	7.02 – 7.98
Kurihara & Shirayama (2004)	E	R	2	6.78 – 8.11
Kurihara <i>et al.</i> (2004a)	A	S	2	6.82 – 8.15
Kurihara <i>et al.</i> (2004a)	A	R	2	6.82 – 8.15
Kurihara <i>et al.</i> (2004b)	A	S	1	6.93 – 8.15
Kurihara <i>et al.</i> (2004b)	A	R	1	6.93 – 8.15
Kurihara <i>et al.</i> (2004b)	E	G	2	6.78 – 8.11
Kurihara <i>et al.</i> (2004b)	E	R	2	6.78 – 8.11
Shirayama & Kurihara (2004)	E	G	1	7.02 – 8.11
Shirayama & Kurihara (2004)	E	R	2	6.78 – 8.11
Kurihara (2008) [#]	E	R	2	6.78 – 8.11
Langer <i>et al.</i> (2006)	H	G	1	7.86 – 8.74
Langer <i>et al.</i> (2006)	H	S	1	7.86 – 8.74
Maier <i>et al.</i> (2009)	C	G	1	7.76 – 8.10
Marubini <i>et al.</i> (2001)	C	G	1	7.82 – 8.31
Marubini <i>et al.</i> (2001)	C	G	1	7.58 – 8.19

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Ohde & Hossain (2004)	C	G	1	7.65 – 8.46
Parker <i>et al.</i> (2009)	M	G	1	7.69 – 8.07
Parker <i>et al.</i> (2009)	M	R	1	7.69 – 8.07
Riebesell <i>et al.</i> (2000)	H	G	1	7.81 – 8.43
Riebesell <i>et al.</i> (2000)	A	G	3	7.31 – 8.03
Riebesell <i>et al.</i> (2000)	Ch	G	1	7.49 – 8.19
Riebesell <i>et al.</i> (2000)	C	G	1	7.48 – 8.11
Riebesell <i>et al.</i> (2000)	E	G	2	7.36 – 8.04
Riebesell <i>et al.</i> (2000)	M	G	9	7.42 – 8.15
Riebesell <i>et al.</i> (2000)	R	G	1	7.49 – 8.19
Schneider & Erez (2006)	C	G	1	7.87 – 8.50
Talmage & Gobler (2009)	M	G	3	7.48 – 8.08
Talmage & Gobler (2009)	M	S	3	7.48 – 8.08
Wood <i>et al.</i> (2008)	E	G	1	6.80 – 8.00
Wood <i>et al.</i> (2008)	E	R	1	6.80 – 8.00
Shipe & Brzezinski (2001)	H	G	1	7.92 – 8.56

Supporting information

Appendix S5.1 Keyword combination used in the Web of Science (Box 1) and list of peer-reviewed articles used in this study (Table S5.1.1)

The keyword combination (Box 1) resulted in approximately 6800 articles in June 2011. Later, we selected the articles that fulfilled our selection criteria, which consisted of:

- (a) The organisms had to be reported at the species taxonomic level. Occasional infra specific records were also included (total of eighteen organisms reported at the variety or subspecies taxonomic level).
- (b) Nutrients had to be reported as total P. Records of concentration which did not specified a value were not included, e.g. trophic state or below or above a given concentration.
- (c) Studies focusing on other inland waters were excluded, i.e. brackish or inland saline, fish ponds, wastewater treatment plants, or (constructed) wetlands.
- (d) The location of the study and the type of freshwater (stream or lake) had to be reported. We also included paleolimnology studies of diatoms if it was possible to relate the occurrence of species with TP concentrations.
- (e) Reservoirs and ponds were considered as lakes while rivers and springs were considered as streams.
- (f) If multiple sampling dates or locations were reported within a study, we only included records where there was a connection in the location and sampling time between species occurrence and total P concentrations.

BOX 1

```
1#: TS = ((freshwater* OR river* OR lake* OR stream* OR fresh-water* OR wetland* OR basin* OR floodplain* OR watershed* OR lagoon* OR creek*) AND (mesocosm* OR macrocosm* OR field* OR survey* OR landscape* OR site* OR habitat* OR ecosystem* OR gradient* OR region*) AND (phosph* OR orthoph* OR ortho-P* OR nitrogen OR ammonium OR ammonia OR nitrate* OR eutroph* OR oligotroph* OR mesotroph* OR hypertroph* OR (trophi AND (level* OR stat*))) OR autoanalyzer OR (core SAME1 sampl*) OR (dip SAME1 net)))
#2: TS = (((EPT OR Ephemeroptera OR mayfly* OR Plecoptera OR stonefly* OR Trichoptera OR caddisfl* OR fish* OR insect* OR microfauna* OR fauna OR Animal* OR Annelid* OR Arthropod* OR Chordat* OR Cnidar* OR Mollusc* OR Nemat* OR Platyhelminth* OR Porifer* OR Rotifer*) SAME1 (divers* OR species OR taxa OR taxon OR population* OR communit* OR abundance OR occur* OR compos* OR count* OR biodivers* OR biomass OR frequen* OR densit* OR assembl*)) AND #1)
#3: TS = (((macro-invertebrate* OR benthic OR (macro AND invertebrate*) OR macroinvertebrate* OR invertebrate* OR zooplankt* OR fauna OR autotroph* OR plankton* OR phyt* OR plant* OR chlorophyl* OR macrophyte OR (primar* SAME1 product*) OR algae* OR flora OR diatom* OR photosynthe*) SAME1 (divers* OR species OR taxa OR taxon OR population* OR communit* OR abundance OR occur* OR compos* OR count* OR biodivers* OR biomass OR frequen* OR densit* OR assembl*)) AND #1)
#4: TS = (((Plant* OR Bryoph* OR Chloroph* OR Cyanidioph* OR Glaucoph* OR Magnolioph* OR Pteridoph* OR Rhodoph*) SAME1 (divers* OR species OR taxa OR taxon OR population* OR communit* OR abundance OR occur* OR compos* OR count* OR biodivers* OR biomass OR frequen* OR densit* OR assembl*)) AND #1)
```

Final harvest: #2 OR #3 OR #4

¹ SAME: Boolean keyword that selects two or more words within the same sentence

Appendix S5.1

Table S5.1.1 Freshwater type, trophic group, and minimum and maximum total phosphorus (TP) concentration range within each study.

Study	Freshwater type	Trophic group	Range (mg P·L ⁻¹)
Armstrong <i>et al.</i> (2003)	Lake	Autotroph	0.013 to 0.06
Ask <i>et al.</i> (2009)	Lake	Heterotroph	0.006 to 0.023
Bagella <i>et al.</i> (2010)	Lake	Auto/heterotroph	0.052 to 0.181
Beklioglu & Tan (2008)	Lake	Heterotroph	0.085 to 0.615
Bennion <i>et al.</i> (2000)	Lake	Autotroph	0.025 to 0.028
Bennion <i>et al.</i> (1995)	Lake	Autotroph	0.009 to 0.034
Bere & Tundisi (2011)	Stream	Autotroph	0 to 5.088
Bere & Tundisi (2010)	Stream	Auto/heterotroph	0.01 to 2.97
Bertolo <i>et al.</i> (2005)	Lake	Heterotroph	0.004 to 0.016
Bouvy <i>et al.</i> (2003)	Lake	Autotroph	0.005 to 0.18
Caballero <i>et al.</i> (2006)	Lake	Autotroph	0.652 to 7.1
Cabecinha <i>et al.</i> (2009a)	Lake	Autotroph	0.043 to 16.576
Cabecinha <i>et al.</i> (2009b)	Lake	Autotroph	0.018 to 8.236
Cai <i>et al.</i> (2011)	Lake	Heterotroph	0.06 to 0.17
Cantonati & Spitale (2009)	Stream	Autotroph	0.002 to 0.021
Capers <i>et al.</i> (2009)	Lake	Autotroph	0.027 to 0.045
Caputo <i>et al.</i> (2008)	Lake	Autotroph	0.006 to 3.187
Carol <i>et al.</i> (2006)	Lake	Heterotroph	0.012 to 0.375
Casas <i>et al.</i> (2011)	Lake/stream	Heterotroph	0.01 to 0.041
Casco <i>et al.</i> (2009)	Lake	Auto/heterotroph	0.011 to 0.115
Castro <i>et al.</i> (2007)	Lake	Heterotroph	0.08 to 0.3
Catalano <i>et al.</i> (2010)	Lake	Heterotroph	0.04 to 0.141
Čerba <i>et al.</i> (2010)	Lake	Heterotroph	0.01 to 1.16
Chellappa <i>et al.</i> (2008)	Lake	Autotroph	0.64 to 0.85
Chen <i>et al.</i> (2008)	Lake	Autotroph	0.005 to 0.098
Cheng <i>et al.</i> (2010)	Lake	Heterotroph	0.005 to 0.268
Coops <i>et al.</i> (2008)	Lake	Auto/heterotroph	0.04 to 0.21
Cottenie <i>et al.</i> (2001)	Lake	Heterotroph	0.221 to 0.506
Cowell <i>et al.</i> (2004)	Stream	Heterotroph	0.389 to 1.225
Cronin <i>et al.</i> (2006)	Lake	Heterotroph	0.003 to 0.008
Da Silva <i>et al.</i> (2005)	Lake	Autotroph	0.003 to 0.014
Dasí <i>et al.</i> (1998)	Lake	Autotroph	0.025 to 15.386
De Backer <i>et al.</i> (2010)	Lake	Auto/heterotroph	0.041 to 0.578
De Paggi & Devercelli (2011)	Stream	Heterotroph	0.072 to 4.329
Del Pozo <i>et al.</i> (2010)	Lake	Autotroph	0.051 to 5.913

Supporting information

Study	Freshwater type	Trophic group	Range (mg P·L ⁻¹)
DeNicola <i>et al.</i> (2004)	Lake	Autotroph	0.005 to 0.079
Devlin & Finkelstein (2011)	Lake	Autotroph	0.002 to 0.013
Dong <i>et al.</i> (2008)	Lake	Autotroph	0.051 to 0.258
Douda (2010)	Stream	Heterotroph	0.07 to 0.45
Dunn <i>et al.</i> (2008)	Stream	Auto/heterotroph	0.052 to 0.199
Edlund <i>et al.</i> (2009)	Lake	Autotroph	0.04 to 0.063
Ekdahl <i>et al.</i> (2007)	Lake	Autotroph	0.002 to 0.027
Epnors <i>et al.</i> (2010)	Lake	Heterotroph	0.019 to 0.248
Erős <i>et al.</i> (2009)	Lake	Heterotroph	0.011 to 0.064
Fabris <i>et al.</i> (2009)	Stream	Autotroph	0.002 to 0.004
Feuchtmayr <i>et al.</i> (2009)	Lake	Autotroph	0.352 to 0.352
Free <i>et al.</i> (2009)	Lake	Autotroph	0.002 to 0.06
Friberg <i>et al.</i> (2009)	Stream	Heterotroph	0.01 to 0.044
Frost <i>et al.</i> (2003)	Lake	Heterotroph	0.004 to 0.176
Füreder <i>et al.</i> (2006)	Lake	Heterotroph	2.87 to 3.74
Gacia <i>et al.</i> (1994)	Lake	Autotroph	0.002 to 0.29
Gélinas & Pinel-Alloul (2008)	Lake	Heterotroph	0.004 to 0.023
Gregory-Eaves <i>et al.</i> (2003)	Lake	Autotroph	0.006 to 0.012
Güecker <i>et al.</i> (2011)	Stream	Heterotroph	0.104 to 0.666
Ha <i>et al.</i> (2002)	Stream	Autotroph	0.059 to 0.803
Ha <i>et al.</i> (1998)	Stream	Autotroph	0.062 to 0.441
Haberman <i>et al.</i> (2010)	Lake	Auto/heterotroph	0.021 to 0.22
Hadley <i>et al.</i> (2010)	Lake	Autotroph	0.027 to 0.027
Hausmann & Pienitz (2007)	Lake	Autotroph	0.001 to 0.01
Hausmann & Pienitz (2009)	Lake	Autotroph	0.005 to 0.029
Havens <i>et al.</i> (1996)	Lake	Auto/heterotroph	0.03 to 0.22
Hazewinkel <i>et al.</i> (2008)	Lake	Autotroph	5.22 to 41.97
Hessen & Leu (2006)	Lake	Autotroph	0.004 to 0.076
Hill <i>et al.</i> (2010)	Stream	Heterotroph	0.02 to 0.4
Hilt <i>et al.</i> (2010)	Lake	Autotroph	0.01 to 0.05
Holz <i>et al.</i> (1997)	Lake	Autotroph	0.1 to 0.38
Hough & Thompson (1996)	Lake	Autotroph	0.015 to 0.026
Hsieh <i>et al.</i> (2010)	Lake	Autotroph	0.006 to 0.011
Iglesias <i>et al.</i> (2011)	Lake	Heterotroph	0.024 to 2.4
Izaguirre <i>et al.</i> (1993)	Lake	Autotroph	0.027 to 0.404
Jansson <i>et al.</i> (2010)	Lake	Heterotroph	0.004 to 0.01
Jeppesen <i>et al.</i> (1998)	Lake	Heterotroph	0.4 to 1

Appendix S5.1

Study	Freshwater type	Trophic group	Range (mg P·L ⁻¹)
Jocqué <i>et al.</i> (2007)	Lake	Heterotroph	0.385 to 4.124
Joniak <i>et al.</i> (2007)	Lake	Autotroph	0.017 to 0.265
Jyväsjärvi <i>et al.</i> (2009)	Lake	Heterotroph	0.002 to 0.03
Karst-Riddoch <i>et al.</i> (2009)	Lake	Autotroph	0.003 to 0.074
Kirilova <i>et al.</i> (2008)	Lake	Autotroph	0.02 to 0.14
(2010)	Lake	Auto/heterotroph	0.03 to 0.3
Kirkwood <i>et al.</i> (2007)	Stream	Autotroph	0 to 0.664
Korosi <i>et al.</i> (2008)	Lake	Heterotroph	0.005 to 0.018
Köster & Pienitz (2006)	Lake	Autotroph	0.002 to 0.03
Kuczyńska-Kippen (2009)	Lake	Auto/heterotroph	0.08 to 0.76
Kuczyńska-Kippen & Joniak (2010a)	Lake	Heterotroph	0 to 0.76
Kuczyńska-Kippen & Joniak (2010b)	Lake	Auto/heterotroph	0.028 to 1.743
Lauridsen <i>et al.</i> (2008)	Lake	Heterotroph	0.093 to 0.101
Leitão & Légize (2000)	Lake	Autotroph	0.04 to 0.212
Leland & Porter (2000)	Stream	Autotroph	0.043 to 1.534
Lenat & Crawford (1994)	Stream	Heterotroph	0.09 to 0.27
Lewin (2006)	Stream	Autotroph	0.46 to 0.6
Lewin & Smoliński (2006)	Lake	Autotroph	0.01 to 0.98
Liu & Wang (2007)	Lake	Heterotroph	0.176 to 0.344
Liu <i>et al.</i> (2009a)	Lake	Heterotroph	0.017 to 0.017
Liu <i>et al.</i> (2009b)	Lake	Autotroph	0.156 to 0.156
Lucca <i>et al.</i> (2010)	Lake	Heterotroph	0.005 to 0.012
Lund <i>et al.</i> (2010)	Lake	Heterotroph	0.037 to 0.28
Mäemets <i>et al.</i> (2010)	Lake	Autotroph	0.027 to 0.098
Magbanua <i>et al.</i> (2010)	Stream	Heterotroph	0.045 to 1.163
Mäkelä <i>et al.</i> (2004)	Lake	Autotroph	0.011 to 0.051
May (1995)	Lake	Heterotroph	0.002 to 0.277
May & O'Hare (2005)	Lake	Heterotroph	0.005 to 0.017
McGarrigle & Champ (1999)	Lake	Heterotroph	0.008 to 0.044
McIntire <i>et al.</i> (2007)	Lake	Autotroph	0.023 to 0.029
Meerhoff <i>et al.</i> (2003)	Lake	Heterotroph	0.159 to 0.242
Mehner <i>et al.</i> (2007)	Lake	Heterotroph	0.007 to 0.608
Mehner <i>et al.</i> (2005)	Lake	Heterotroph	0.013 to 0.268
Mieczan (2010)	Lake	Heterotroph	0.027 to 0.36
Miserendino (2009)	Stream	Heterotroph	0.01 to 0.09
Miserendino (2006)	Stream	Heterotroph	0.007 to 0.126
Miserendino & Archangelsky (2006)	Stream	Heterotroph	0.007 to 0.126

Supporting information

Study	Freshwater type	Trophic group	Range (mg P·L ⁻¹)
Miserendino & Brand (2007)	Stream	Heterotroph	0.007 to 0.126
Moser <i>et al.</i> (2000)	Lake	Autotroph	0.005 to 0.03
Moss <i>et al.</i> (2005)	Lake	Auto/heterotroph	0.038 to 0.397
Naselli-Flores & Barone (1998)	Lake	Autotroph	0.025 to 0.11
Nedbalová <i>et al.</i> (2006)	Lake	Auto/heterotroph	0.002 to 0.011
Newall & Walsh (2005)	Stream	Autotroph	0.02 to 0.33
Nixdorf & Deneke (1997)	Lake	Autotroph	0.05 to 0.124
Nixdorf <i>et al.</i> (2003)	Lake	Autotroph	0.057 to 0.057
Nyström <i>et al.</i> (2006)	Lake	Heterotroph	0.006 to 0.056
Olin <i>et al.</i> (2010)	Lake	Heterotroph	0.007 to 0.055
Olin <i>et al.</i> (2002)	Lake	Heterotroph	0.012 to 0.13
Olrik (1998)	Lake	Autotroph	0.115 to 0.407
Özkan <i>et al.</i> (2010)	Lake	Auto/heterotroph	0.027 to 0.06
Pacheco <i>et al.</i> (2010)	Lake	Autotroph	0.022 to 0.147
Perbiche-Neves <i>et al.</i> (2011)	Stream	Autotroph	0 to 0.09
Pereira <i>et al.</i> (2002)	Lake	Heterotroph	0 to 1.2
Peretyatko <i>et al.</i> (2009)	Lake	Autotroph	0.051 to 0.599
Persson <i>et al.</i> (2004)	Lake	Heterotroph	0.002 to 0.01
Pla <i>et al.</i> (2005)	Lake	Autotroph	0.007 to 0.025
Ponader <i>et al.</i> (2007)	Stream	Autotroph	0.021 to 2.625
Post <i>et al.</i> (2008)	Lake	Heterotroph	0.008 to 0.047
Prchalová <i>et al.</i> (2008)	Lake	Heterotroph	0.018 to 0.032
Quinlan & Smol (2010)	Lake	Heterotroph	0.003 to 0.029
Rajagopal <i>et al.</i> (2010)	Lake	Autotroph	8 to 35
Reid (2005)	Lake	Autotroph	0.002 to 0.101
Romo <i>et al.</i> (2007)	Lake	Autotroph	0.017 to 0.022
Rosso <i>et al.</i> (2010)	Lake	Heterotroph	0.89 to 1.14
Rydin <i>et al.</i> (2008)	Lake	Heterotroph	0.002 to 0.007
Sager & Lachavanne (2009)	Lake	Autotroph	0.003 to 0.076
Sass <i>et al.</i> (2010)	Lake	Autotroph	0 to 0.094
Sayer <i>et al.</i> (2010)	Lake	Heterotroph	0.097 to 0.536
Schagerl <i>et al.</i> (2010)	Lake	Autotroph	0.006 to 0.298
Schlegel <i>et al.</i> (1998)	Lake	Autotroph	0.061 to 0.243
Schultz <i>et al.</i> (2006)	Lake	Heterotroph	0.07 to 0.95
Serieyssol <i>et al.</i> (2009)	Lake	Autotroph	0.013 to 0.017
Shao <i>et al.</i> (2001)	Lake	Heterotroph	0.214 to 0.794
Shinneman <i>et al.</i> (2009a)	Lake	Autotroph	0.011 to 0.145

Appendix S5.1

Study	Freshwater type	Trophic group	Range (mg P·L ⁻¹)
Shinneman <i>et al.</i> (2009b)	Lake	Autotroph	0.009 to 1.18
Skov <i>et al.</i> (2010)	Lake	Heterotroph	0.001 to 0.001
Smiley <i>et al.</i> (2009)	Stream	Heterotroph	0.042 to 2.894
Smith <i>et al.</i> (2007)	Stream	Heterotroph	0.012 to 0.556
Song <i>et al.</i> (2010)	Lake	Autotroph	0.086 to 0.377
Sosnovsky & Quirós (2009)	Lake	Heterotroph	0.923 to 4.07
Srivastava <i>et al.</i> (1995)	Lake	Autotroph	0.003 to 5.95
St. Jacques <i>et al.</i> (2005)	Lake	Auto/heterotroph	0.002 to 0.028
Steinman <i>et al.</i> (2011)	Lake	Autotroph	0.01 to 0.01
Stephen <i>et al.</i> (2004)	Lake	Auto/heterotroph	0.1 to 1.045
Stowa (2010)	Lake/stream	Heterotroph	0.01 to 17
Suutari <i>et al.</i> (2009)	Lake	Autotroph	0.023 to 0.277
Tarkowska-Kukuryk (2011)	Lake	Auto/heterotroph	0.049 to 0.37
Tate & Heiny (1995)	Stream	Heterotroph	0.019 to 4.722
Tátrai <i>et al.</i> (2008)	Lake	Heterotroph	0.035 to 0.067
Thiébaud (2006)	Stream	Autotroph	0.013 to 0.886
Tolotti <i>et al.</i> (2006)	Lake	Auto/heterotroph	0.003 to 0.01
Tonn <i>et al.</i> (2004)	Lake	Heterotroph	0.01 to 0.244
Tracy <i>et al.</i> (2003)	Lake	Autotroph	0.017 to 0.02
Train & Rodrigues (1998)	Stream	Autotroph	0.017 to 0.062
Trevisan <i>et al.</i> (2010)	Lake	Autotroph	0.006 to 0.03
Trigal <i>et al.</i> (2009)	Lake	Auto/heterotroph	0.063 to 2.088
Unrein <i>et al.</i> (2010)	Lake	Autotroph	0.235 to 1.6
Vakkilainen <i>et al.</i> (2004)	Lake	Heterotroph	0.047 to 1.511
Van Geest <i>et al.</i> (2007)	Lake	Heterotroph	0.002 to 0.062
Vázquez <i>et al.</i> (2011)	Stream	Autotroph	0.012 to 0.213
Vermonden <i>et al.</i> (2009)	Stream	Heterotroph	0.016 to 0.151
Vidaković & Bogut (2004)	Lake	Heterotroph	0.11 to 1.02
Villena & Romo (2007)	Lake	Autotroph	0.017 to 0.017
Vinocur & Pizarro (2000)	Lake	Auto/heterotroph	0.002 to 3.155
Vis <i>et al.</i> (2008)	Stream	Autotroph	0.025 to 0.048
Wærvågen & Nilssen (2010)	Lake	Heterotroph	0.008 to 0.008
Wang <i>et al.</i> (2007)	Lake	Heterotroph	0.002 to 0.024
Wen <i>et al.</i> (2011)	Lake	Heterotroph	0.015 to 0.105
Wu & Kow (2010)	Lake	Autotroph	0.005 to 0.08
Wunsam <i>et al.</i> (1995)	Lake	Autotroph	0.002 to 0.266
Xu <i>et al.</i> (2005)	Lake	Autotroph	0.054 to 0.565

Supporting information

Study	Freshwater type	Trophic group	Range (mg P·L⁻¹)
Yang <i>et al.</i> (2006)	Lake	Autotroph	0.04 to 0.175
Ye <i>et al.</i> (2007)	Lake	Autotroph	0.014 to 0.188
Zambrano <i>et al.</i> (2006)	Lake	Heterotroph	0.031 to 0.49

Appendix S5.2

Appendix S5.2.2 Taxonomic classification tools, number of species and list of species within each trophic group.

We used the three taxonomic classification sources (ITIS, AlgaeBase, and PlantList, accessed in January, 2012) not only to classify the species into a species group but also to identify possible taxonomic synonyms (Table S5.2.1). Also, we revisited the studies reporting species which were not found in their respective taxonomic classification source to ensure that their names were not misprinted during the data gathering. However, if the species name was correct in their study and absent in the taxonomic classification source, we kept the species name in the dataset based on the rationale that the peer-reviewed source is more likely to contain a record than a taxonomic database. Also, we included occasional organisms that were reported in a variety or subspecies taxonomic level (total of eighteen) and considered these as another species-level record. The number of species in each species group can be found in Table 2.2. The fraction of species which were found exclusively below, above, and both below and above their respective C_{opt} is shown in Table 5.2.3. Finally, general scatter plots of species richness – TP concentration across regions are shown in Figure S5.2.1.

Table S5.2.1 Taxonomic classification method of (a) autotrophic and (b) heterotrophic species groups based on different taxonomic classification sources (ITIS: Integrated Taxonomic Classification System)

Species group	Classification method	Taxonomic classification source
(a) Autotrophs		
Cyanobacteria	Within the "Bacteria" kingdom, the phylum is "Cyanobacteria"	AlgaeBase
Macrophyte	Within the "Plantae" kingdom, the subkingdom is "Embryophyta"	PlantList
Silicon-based algae	Within the "Chromista" kingdom, the class is "Bacillariophyceae" or, within the "Plantae" kingdom, the family is "Desmidiaceae" [#]	AlgaeBase
Non-silicon-based algae	Within the "Bacteria" kingdom, the phylum is "Cyanobacteria" or, within the "Chromista" kingdom, the class is not "Bacillariophyceae" or, within the "Plantae" kingdom, the family is not "Desmidiaceae"	AlgaeBase
(b) Heterotroph		
Fish	Within the "Chordata" phylum, the class is "Chondrichthyes" or the superclass is "Osteichthyes"	Integrated Taxonomic Information System
Invertebrate	Within the "Animalia" kingdom, the phylum is not "Chordata"	Integrated Taxonomic Information System

[#] Although not all desmids may be silicon-based, we included them as part of this group for simplification

Appendix S5.2

Table S5.2.2 Total phosphorus $^{10}\log$ TP concentration range (log, mg P·L⁻¹) at which species **(a)** Cyanobacteria, **(b)** Fish, **(c)** Invertebrates, **(d)** Macrophytes, **(e)** Non-silicon-based algae, **(f)** Silicon-based algae in lakes and **(g)** Cyanobacteria, **(h)** Fish, **(i)** Invertebrates, **(j)** Macrophytes, **(k)** Non-silicon-based algae, **(l)** Silicon-based algae in streams.

Species	$^{10}\log$ TP	Species	$^{10}\log$ TP
(a) Cyanobacteria in lakes		<i>Anabaenopsis circularis</i>	-0.1 to 0.9
Cold		<i>Aphanizomenon flosaquae</i>	-1.3 to 0
<i>Aphanocapsa delicatissima</i>	-2.2 to -0.4	<i>Aphanocapsa delicatissima</i>	-2 to -1.5
<i>Aphanocapsa elachista</i>	-1.7 to -0.4	<i>Aphanocapsa elachista</i>	-2.2 to 0.9
<i>Chamaesiphon subglobosus</i>	-2.2 to 0.5	<i>Aphanocapsa holsatica</i>	-1.7 to -1
<i>Chondrocystis dermochroa</i>	-0.5 to -0.4	<i>Aphanothece nidulans</i>	-2.2 to -1.6
<i>Chroococcus minutus</i>	-2.2 to -0.4	<i>Chroococcus dispersus</i>	-2.2 to -2
<i>Clastidium setigerum</i>	-2 to -1.8	<i>Cylindrospermopsis raciborskii</i>	-1.7 to -0.8
<i>Geitlerinema amphibium</i>	-2 to -1.2	<i>Cylindrospermum muscicola</i>	-1.8 to -1.7
<i>Geitlerinema deflexum</i>	-1.6 to -0.4	<i>Dolichospermum flosaquae</i>	-2 to -1.2
<i>Gloeocapsa kuetzingiana</i>	-2.7 to 0.5	<i>Heteroleibleinia pusilla</i>	-2 to -1.1
<i>Gloeocapsa ralfsiana</i>	-2.2 to -0.4	<i>Limnococcus limneticus</i>	-2 to -1.6
<i>Gloeocapsopsis magma</i>	-2.2 to -1.2	<i>Limnothrix planctonica</i>	-0.7 to 0
<i>Leptolyngbya angustissima</i>	-2.2 to -0.9	<i>Limnothrix redekei</i>	-1.3 to -0.9
<i>Leptolyngbya antarctica</i>	-2.2 to 0.5	<i>Merismopedia tenuissima</i>	-2 to 0.5
<i>Leptolyngbya fragilis</i>	-2.7 to 0.5	<i>Microcystis aeruginosa</i>	-2 to 0.5
<i>Lyngbya lagerheimii</i>	-1.6 to -0.4	<i>Microcystis flosaquae</i>	-1.2 to 0
<i>Merismopedia tenuissima</i>	-1.8 to 0.5	<i>Microcystis pulvereae</i>	-1.4 to 1.1
<i>Microcystis flosaquae</i>	-2 to -1.8	<i>Microcystis wesenbergii</i>	-1.4 to -1
<i>Nodularia harveyana</i>	-1.8 to -1.4	<i>Oscillatoria angusta</i>	-2 to -1.1
<i>Nostoc commune</i>	-2.7 to -1	<i>Planktolyngbya limnetica</i>	-1.7 to -1
<i>Oscillatoria tenuis</i>	-2.2 to -0.9	<i>Planktolyngbya undulata</i>	-2 to -1.1
<i>Phormidium ambiguum</i>	-2.7 to -0.9	<i>Planktothrix agardhii</i>	-1.4 to 0.5
<i>Phormidium attenuatum</i>	-1.8 to -0.9	<i>Pseudanabaena galeata</i>	-1.8 to -1.7
<i>Phormidium autumnale</i>	-2.7 to 0.5	<i>Pseudanabaena limnetica</i>	-1.6 to 0.9
<i>Phormidium chlorinum</i>	-2.2 to 0.5	<i>Spirulina laxissima</i>	-1.7 to -1
<i>Phormidium corium</i>	-2.7 to -0.2	<i>Woronichinia naegeliana</i>	-2 to -0.7
<i>Phormidium simplicissimum</i>	-1.8 to -0.9	(Sub)tropical	
<i>Pseudanabaena frigida</i>	-2.7 to 0.5	<i>Aphanizomenon flosaquae</i>	1.1 to 1.2
<i>Trichormus variabilis</i>	-2.2 to -0.9	<i>Aphanocapsa delicatissima</i>	-1.4 to 1.2
Temperate		<i>Aphanocapsa holsatica</i>	-2.3 to -1.3
<i>Anabaena solitaria</i>	-1.4 to -1	<i>Aphanocapsa incerta</i>	-1.5 to -0.7

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Aphanocapsa minutissima</i>	-2.3 to -1.1	<i>Anguilla anguilla</i>	-2 to -1.3
<i>Chroococcus aphanocapsoides</i>	-2.3 to -1.3	<i>Blicca bjoerkna</i>	-1.9 to -0.9
<i>Chroococcus dispersus</i>	-0.2 to -0.1	<i>Coregonus lavaretus</i>	-2.1 to -1.7
<i>Chroococcus giganteus</i>	-0.2 to -0.1	<i>Esox lucius</i>	-2.7 to -0.9
<i>Chroococcus varius</i>	-0.2 to -0.1	<i>Gymnocephalus cernuus</i>	-2.2 to -0.9
<i>Coelosphaerium dubium</i>	0.9 to 1.4	<i>Lota lota</i>	-2.7 to -1.3
<i>Cyanodictyon imperfectum</i>	-2.3 to -1.3	<i>Osmerus eperlanus</i>	-1.9 to -1
<i>Cylindrospermopsis raciborskii</i>	-2.3 to -0.1	<i>Perca fluviatilis</i>	-2.7 to -0.9
<i>Dolichospermum affine</i>	-2.5 to -1	<i>Rutilus rutilus</i>	-2.2 to -0.9
<i>Dolichospermum crassum</i>	-2.5 to -1.9	<i>Salmo trutta</i>	-2.7 to -2
<i>Dolichospermum planctonicum</i>	-2.5 to -1.9	<i>Salvelinus alpinus</i>	-2.7 to -1.6
<i>Gloeocapsa alpicola</i>	-0.2 to -0.1	<i>Tinca tinca</i>	-1.9 to -1.5
<i>Gloeocapsa decorticans</i>	-0.2 to -0.1		
<i>Gloeotrichia natans</i>	1 to 1.5	Temperate	
<i>Lynghya aestuarii</i>	1 to 1.2	<i>Abbottina rivularis</i>	-2.3 to -0.6
<i>Lynghya major</i>	-0.2 to -0.1	<i>Abramis brama</i>	-2.2 to -0.2
<i>Merismopedia glauca</i>	0.9 to 1.5	<i>Acheilognathus chankaensis</i>	-2.3 to -0.6
<i>Merismopedia tenuissima</i>	-1.5 to -0.7	<i>Acheilognathus macropterus</i>	-2.3 to -0.6
<i>Microcystis aeruginosa</i>	-2.3 to 1.5	<i>Alburnus alburnus</i>	-2.2 to -0.2
<i>Microcystis flosaquae</i>	-2.3 to -1.1	<i>Alosa pseudoharengus</i>	-2.1 to -1.3
<i>Microcystis ichthyoblabe</i>	-2.3 to -1.1	<i>Anguilla anguilla</i>	-1.9 to 0
<i>Microcystis robusta</i>	-2.3 to -1.1	<i>Aphanius iberus</i>	-2 to -1.4
<i>Microcystis wesenbergii</i>	1 to 1.5	<i>Aspius aspius</i>	-2.2 to -0.2
<i>Nostoc caeruleum</i>	0.9 to 1.5	<i>Australoheros facetus</i>	-1.6 to -0.4
<i>Oscillatoria angusta</i>	0.9 to 1.5	<i>Barbus graellsii</i>	-1.9 to -1.1
<i>Planktolynghya contorta</i>	-1.3 to -0.7	<i>Blicca bjoerkna</i>	-2.2 to -0.2
<i>Planktolynghya limnetica</i>	-1.5 to -0.8	<i>Carassius auratus</i>	-1.3 to -1.2
<i>Pseudanabaena catenata</i>	-2.3 to -0.1	<i>Carassius carassius</i>	-2.3 to -0.2
<i>Pseudanabaena limnetica</i>	-0.2 to -0.1	<i>Carassius gibelio</i>	-1.7 to -0.7
<i>Raphidiopsis mediterranea</i>	-2.3 to -0.7	<i>Catostomus catostomus</i>	-2 to -0.6
<i>Spirulina laxa</i>	1 to 1.2	<i>Catostomus commersonii</i>	-2 to -0.6
<i>Trichodesmium lacustre</i>	-0.2 to -0.1	<i>Characidium rachovii</i>	-1.6 to -0.7
		<i>Charax stenopterus</i>	-1.6 to -0.4
(b) Fish in lakes		<i>Cheirodon interruptus</i>	0.1 to 0.6
Cold		<i>Chondrostoma arcasii</i>	-1.2 to 0.3
<i>Abramis brama</i>	-2.2 to -0.9	<i>Chondrostoma miegii</i>	-1.3 to -0.4
<i>Alburnus alburnus</i>	-2.1 to -1.4	<i>Cirrhinus molitorella</i>	-1.4 to -0.8

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Cnesterodon decemmaculatus</i>	-1.6 to 0.4	<i>Margariscus margarita</i>	-1.2 to -0.7
<i>Cobitis taenia</i>	-2.2 to -0.2	<i>Mastacembelus sinensis</i>	-1.2 to -0.6
<i>Coregonus albula</i>	-2.2 to -0.2	<i>Megalobrama amblycephala</i>	-1.4 to -0.8
<i>Coregonus artedi</i>	-2.7 to -1.4	<i>Micropterus dolomieu</i>	-2.7 to -1.6
<i>Coregonus clupeaformis</i>	-2.7 to -1.4	<i>Micropterus salmoides</i>	-1.9 to -0.4
<i>Corydoras paleatus</i>	-1.6 to 0.1	<i>Misgurnus anguillicaudatus</i>	-2.3 to -0.6
<i>Cottus cognatus</i>	-2 to -1.4	<i>Misgurnus fossilis</i>	-2.2 to -0.2
<i>Cottus poecilopus</i>	-2.2 to -0.2	<i>Neosalanx taihuensis</i>	-1.6 to -0.6
<i>Culter alburnus</i>	-2 to -0.6	<i>Odontesthes bonariensis</i>	-1.9 to 0.5
<i>Culter dabryi</i>	-2 to -0.6	<i>Odontobutis obscura</i>	-2.3 to -0.8
<i>Culter mongolicus</i>	-2.3 to -0.8	<i>Oligosarcus jenynsii</i>	-1.6 to 0.6
<i>Culterichthys erythropterus</i>	-2.3 to -0.6	<i>Oncorhynchus mykiss</i>	-2.2 to -0.2
<i>Cyphocharax voga</i>	-1.5 to 0.5	<i>Osmerus eperlanus</i>	-2.2 to -0.2
<i>Cyprinus carpio</i>	-2.2 to -0.2	<i>Paracanthobrama guichenoti</i>	-1.4 to -0.6
<i>Diapoma terofali</i>	-1.1 to -0.4	<i>Pelteobagrus fulvidraco</i>	-2.3 to -0.8
<i>Distoechodon hupeinensis</i>	-2.3 to -0.6	<i>Perca flavescens</i>	-2.7 to -1.6
<i>Elopichthys bambusa</i>	-1.4 to -0.8	<i>Perca fluviatilis</i>	-2.2 to 0
<i>Esox lucius</i>	-2.2 to -0.2	<i>Percopsis omiscomaycus</i>	-2 to -1.4
<i>Gasterosteus aculeatus</i>	-2.2 to -0.2	<i>Phalloceros caudimaculatus</i>	-1.6 to -0.7
<i>Gobio gobio</i>	-2.2 to -0.2	<i>Phoxinus phoxinus</i>	-2.2 to -0.2
<i>Gymnocephalus cernuus</i>	-2.2 to -0.2	<i>Pimelodella australis</i>	-1.6 to -1.3
<i>Hemibarbus maculatus</i>	-1.2 to -0.6	<i>Pimelodella laticeps</i>	-0.1 to 0.1
<i>Hemiculter bleekeri</i>	-2.3 to -0.6	<i>Prosopium cylindraceum</i>	-2.7 to -1.6
<i>Hemiculter leucisculus</i>	-2.3 to -0.6	<i>Pseudobrama simoni</i>	-1.4 to -0.8
<i>Hoplias malabaricus</i>	-1.9 to 0.5	<i>Pseudorasbora parva</i>	-2.3 to -0.6
<i>Hypophthalmichthys molitrix</i>	-2.2 to -0.2	<i>Pungitius pungitius</i>	-2.2 to -0.2
<i>Hypophthalmichthys nobilis</i>	-2.2 to -0.2	<i>Rhamdia quelen</i>	-1.6 to -0.4
<i>Hyporhamphus intermedius</i>	-2.3 to -0.6	<i>Rhinogobius giurinus</i>	-2.3 to -0.6
<i>Hypostomus commersoni</i>	-1.6 to -0.4	<i>Rhodeus amarus</i>	-2.2 to -0.2
<i>Hypseleotris swinhonis</i>	-2.3 to -0.8	<i>Rhodeus fangi</i>	-2.3 to -0.9
<i>Jenynsia multidentata</i>	-1.6 to 0.1	<i>Rhodeus ocellatus</i>	-2.3 to -0.6
<i>Lepomis gibbosus</i>	-1.9 to -0.3	<i>Rhodeus sericeus</i>	-0.6 to -0.3
<i>Leucaspis delineatus</i>	-2.2 to -0.2	<i>Rutilus rutilus</i>	-2.2 to 0
<i>Leuciscus cephalus</i>	-1.7 to -1.5	<i>Salaria fluviatilis</i>	-1.3 to -0.9
<i>Leuciscus leuciscus</i>	-2.2 to -0.2	<i>Salmo salar</i>	-2.1 to -1.6
<i>Lota lota</i>	-2.7 to -0.2	<i>Salmo trutta</i>	-2.2 to -0.2
<i>Macropodus opercularis</i>	-1.6 to -0.9	<i>Salvelinus alpinus</i>	-2.1 to -1.4

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Salvelinus namaycush</i>	-2.7 to -1.4	<i>Heterotanytarsus apicalis</i>	-2.7 to -1.5
<i>Sarcocheilichthys nigripinnis</i>	-2.3 to -0.6	<i>Heterotrissocladius marcidus</i>	-2.7 to -1.5
<i>Scardinius erythrophthalmus</i>	-2.2 to 0	<i>Heterotrissocladius subpilosus</i>	-2.7 to -1.5
<i>Silurus glanis</i>	-2.2 to -0.2	<i>Holopedium gibberum</i>	-2.7 to -2
<i>Siniperca chuatsi</i>	-2 to -0.6	<i>Lamprodrilus isoporus</i>	-2.7 to -1.5
<i>Squalidus argentatus</i>	-2.3 to -0.6	<i>Monodiamesa bathyphila</i>	-2.7 to -1.5
<i>Squalidus nitens</i>	-2.3 to -0.6	<i>Monoporeia affinis</i>	-2.7 to -1.5
<i>Squalius cephalus</i>	-1.4 to -1.2	<i>Mysis relicta</i>	-2.7 to -1.5
<i>Synbranchus marmoratus</i>	-1.6 to 0.4	<i>Pagastiella orophila</i>	-2.7 to -1.5
<i>Thymallus arcticus</i>	-2 to -0.6	<i>Pallasea quadrispinosa</i>	-2.7 to -1.5
<i>Tinca tinca</i>	-2.2 to 0.3	<i>Polypedilum pullum</i>	-2.7 to -1.5
<i>Xenocypris davidi</i>	-2 to -0.6	<i>Polyphemus pediculus</i>	-2.1 to 0.2
(Sub)tropical		<i>Potamothenix hammoniensis</i>	-2.7 to -1.5
<i>Ameiurus catus</i>	-1.4 to -0.9	<i>Protanypus morio</i>	-2.7 to -1.5
<i>Dorosoma cepedianum</i>	-1.4 to -0.9	<i>Schizothrix fragilis</i>	-1.8 to 0.5
<i>Ictalurus punctatus</i>	-1.4 to -0.9	<i>Sergentia coracina</i>	-2.7 to -1.5
<i>Pomoxis nigromaculatus</i>	-1.4 to -0.9	<i>Specaria josinae</i>	-2.7 to -1.5
(c) Invertebrates in lakes		<i>Spirosperma ferox</i>	-2.7 to -1.5
Cold		<i>Stempellinella minor</i>	-2.7 to -1.5
<i>Ablabesmyia monilis</i>	-2.7 to -1.5	<i>Stictochironomus rosenschoeldi</i>	-2.7 to -1.5
<i>Apsectrotanypus trifascipennis</i>	-2.7 to -1.5	<i>Stylogdrilus heringianus</i>	-2.7 to -1.5
<i>Arctonais lomondi</i>	-2.7 to -1.5	<i>Uncinaiis uncinata</i>	-2.7 to -1.5
<i>Bythotrephes longimanus</i>	-2.4 to -2.1	<i>Vejdovskyella comata</i>	-2.7 to -1.5
<i>Chironomus anthracinus</i>	-2.7 to -1.5	<i>Zalutschia zalutschicola</i>	-2.7 to -1.5
<i>Chironomus plumosus</i>	-2.7 to -1.5	Temperate	
<i>Chironomus salinarius</i>	-2.7 to -1.5	<i>Ablabesmyia longistyla</i>	-1.3 to -0.4
<i>Cladopelma viridula</i>	-2.7 to -1.5	<i>Ablabesmyia monilis</i>	-1.3 to -0.1
<i>Cladotanytarsus mancus</i>	-2.7 to -1.5	<i>Ablabesmyia phatta</i>	-1.4 to -1.1
<i>Cryptochironomus defectus</i>	-2.7 to -1.5	<i>Acanthocyclops bicuspidatus</i>	-1 to -0.5
<i>Daphnia longispina</i>	-1.1 to -0.6	<i>Acanthocyclops languidus</i>	-1 to -0.5
<i>Daphnia pulicaria</i>	-2.7 to -1.7	<i>Acanthocyclops robustus</i>	-3 to 0.1
<i>Daphnia tenebrosa</i>	-2.5 to -1.2	<i>Acanthocyclops vernalis</i>	-2.5 to -1.3
<i>Demicryptochironomus vulneratus</i>	-2.7 to -1.5	<i>Acantholeberis curvirostris</i>	-2.3 to -1.7
<i>Diaphanosoma brachyurum</i>	-2.1 to -0.6	<i>Acricotopus lucens</i>	-1.7 to 0
<i>Eurycerus lamellatus</i>	-2.4 to -2.2	<i>Acroloxus lacustris</i>	-1.3 to -0.3
		<i>Acroperus harpae</i>	-2.7 to -0.9

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Aeschna cyanea</i>	-2.7 to -2	<i>Anatopynia plumipes</i>	-1.3 to -0.7
<i>Aeschna juncea</i>	-2.5 to -2.2	<i>Anisus vortex</i>	-2 to -0.3
<i>Agabus bipustulatus</i>	-1.3 to 0.6	<i>Anuraeopsis coelata</i>	-0.7 to -0.1
<i>Agabus congener</i>	0.5 to 0.6	<i>Anuraeopsis fissa</i>	-3 to 0.1
<i>Agabus solieri</i>	0.5 to 0.6	<i>Aplexa hypnorum</i>	-1.3 to -0.4
<i>Agabus sturmii</i>	-1.3 to -0.4	<i>Apsectrotanytus trifascipennis</i>	0.5 to 0.6
<i>Agraylea multipunctata</i>	-1.3 to -1.2	<i>Aquarius paludulum</i>	-1.4 to -1.3
<i>Agraylea sexmaculata</i>	-1.3 to -0.8	<i>Arctocoris carinata</i>	0.5 to 0.6
<i>Agrypnia pagetana</i>	-1.3 to -0.3	<i>Arctodiaptomus alpinus</i>	-2.4 to -2
<i>Agrypnia varia</i>	-2.7 to -1.3	<i>Arctodiaptomus bacillifer</i>	-1.1 to -0.2
<i>Allogamus antennatus</i>	0.5 to 0.6	<i>Argyroneta aquatica</i>	-2 to 0
<i>Allogamus auricollis</i>	0.5 to 0.6	<i>Arrenurus batillifer</i>	-1.3 to -0.6
<i>Allogamus uncatus</i>	0.5 to 0.6	<i>Arrenurus bicuspidator</i>	-1.3 to -0.8
<i>Alona affinis</i>	-2.5 to -0.5	<i>Arrenurus buccinator</i>	-1 to 0
<i>Alona azorica</i>	-1.3 to -1	<i>Arrenurus crassicaudatus</i>	-1.7 to 0.1
<i>Alona circumfimbriata</i>	-2.3 to -1.7	<i>Arrenurus cuspidator</i>	-1.3 to 0
<i>Alona costata</i>	-3 to 0.1	<i>Arrenurus globator</i>	-2 to 0
<i>Alona guttata</i>	-2.3 to -0.9	<i>Arrenurus inexploratus</i>	-1.3 to 0
<i>Alona intermedia</i>	-2.3 to -1.7	<i>Arrenurus integrator</i>	-1.3 to 0.1
<i>Alona karelica</i>	-3 to -0.1	<i>Arrenurus latus</i>	-1.3 to 0.1
<i>Alona nuragica</i>	-1.3 to -0.7	<i>Arrenurus securiformis</i>	-1.3 to -0.9
<i>Alona protzi</i>	-0.4 to 0.1	<i>Arrenurus sinuator</i>	-1.3 to -0.8
<i>Alona quadrangularis</i>	-2.3 to -0.5	<i>Arrenurus tricuspator</i>	-1 to -0.8
<i>Alona rectangula</i>	-3 to 0.1	<i>Ascomorpha ecaudis</i>	-3 to 0.1
<i>Alona rustica</i>	-2.3 to -1.7	<i>Ascomorpha ovalis</i>	-1.8 to -0.1
<i>Alona tenuicaudis</i>	-1 to 0.1	<i>Ascomorpha saltans</i>	-1.1 to -0.1
<i>Alona weltneri</i>	0 to 0.1	<i>Asellus aquaticus</i>	-1.3 to 0.1
<i>Alonella excisa</i>	-2.3 to -1	<i>Asplanchna brightwellii</i>	-1.8 to -0.1
<i>Alonella exigua</i>	-2.3 to 0.1	<i>Asplanchna girodi</i>	-1.8 to -1
<i>Alonella nana</i>	-3 to -0.1	<i>Asplanchna priodonta</i>	-2.3 to -0.1
<i>Alonella rostrata</i>	-1.5 to -0.9	<i>Athripsodes aterrimus</i>	-1.3 to 0
<i>Alonopsis americana</i>	-2.3 to -1.7	<i>Attheyella trispinosa</i>	-1.3 to -1
<i>Ameletus inopinatus</i>	-2.7 to -2	<i>Bathynomphalus contortus</i>	-2 to -0.2
<i>Amphinemura triangularis</i>	-2.7 to -2.2	<i>Bithynia leachi</i>	-1.3 to -0.3
<i>Anabolia nervosa</i>	-2 to -1.3	<i>Bithynia tentaculata</i>	-1.3 to -0.2
<i>Anacaena globulus</i>	-1.3 to -0.2	<i>Bosmina berlinensis</i>	-1.7 to -0.7
<i>Anacaena limbata</i>	-1.3 to -0.6	<i>Bosmina coregoni</i>	-2.7 to -0.7

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Bosmina longirostris</i>	-3 to 0.1	<i>Chaoborus crystallinus</i>	-1.3 to 0.1
<i>Bosminopsis deitersi</i>	-2.7 to -1.6	<i>Chaoborus flavicans</i>	-2.5 to 0
<i>Brachionus angularis</i>	-1.8 to 0.1	<i>Chaoborus trivittatus</i>	-2.5 to -1.5
<i>Brachionus bidentata</i>	-0.7 to 0.1	<i>Chironomus plumosus</i>	-1.3 to 0.6
<i>Brachionus calyciflorus</i>	-3 to -0.1	<i>Chironomus salinarius</i>	-1.3 to -0.2
<i>Brachionus caudatus</i>	-1.8 to -1.1	<i>Chironomus thummi</i>	0.5 to 0.6
<i>Brachionus diversicornis</i>	-1.8 to -0.1	<i>Chydorus bicornutus</i>	-2.3 to -1.7
<i>Brachionus falcatus</i>	-1.8 to 0.1	<i>Chydorus brevilabris</i>	-2.3 to -1.7
<i>Brachionus forficula</i>	-1.8 to -0.1	<i>Chydorus gibbus</i>	-3 to -0.1
<i>Brachionus patulus</i>	-1 to -0.1	<i>Chydorus linguilabris</i>	-2.3 to -1.7
<i>Brachionus plicatilis</i>	-0.6 to -0.1	<i>Chydorus sphaericus</i>	-3 to 0.1
<i>Brachionus urceolaris</i>	-2.7 to -0.1	<i>Cladotanytarsus mancus</i>	-0.7 to 0.6
<i>Brachytron pratense</i>	-1.3 to -0.7	<i>Clinotanytus nervosus</i>	-1.5 to -0.3
<i>Bradleycypris obliqua</i>	-1.3 to -1	<i>Cloeon dipterum</i>	-2 to 0.5
<i>Branchiodrilus hortensis</i>	-0.6 to -0.5	<i>Cloeon simile</i>	-1.3 to -0.8
<i>Branchiura sowerbyi</i>	-0.8 to -0.5	<i>Codonella cratera</i>	-2.5 to -0.4
<i>Brevitobilus stefanskii</i>	-1 to 0	<i>Colurella adriatica</i>	-2.7 to -0.6
<i>Caenis horaria</i>	-1.5 to 0.1	<i>Colurella tessellata</i>	-2.7 to -0.6
<i>Caenis luctuosa</i>	-2 to -0.7	<i>Colymbetes fuscus</i>	-1.3 to -0.4
<i>Caenis robusta</i>	-1.7 to 0.1	<i>Conochilus dossuarius</i>	-0.6 to -0.1
<i>Callicorixa praeusta</i>	-1.5 to -0.1	<i>Conochilus hippocrepis</i>	-2.3 to -1.8
<i>Camptocercus rectirostris</i>	-2.7 to -0.5	<i>Conochilus unicornis</i>	-0.7 to -0.1
<i>Candona neglecta</i>	-1.3 to -1	<i>Copelatus haemorrhoidalis</i>	-1.3 to -0.4
<i>Canthocamptus staphylinus</i>	-1.3 to -0.7	<i>Cordulia aenea</i>	-2 to -0.8
<i>Cataclysta lemnata</i>	-1.3 to 0.1	<i>Corixa affinis</i>	-1.3 to -0.1
<i>Cephalodella exigua</i>	-1.8 to -1.1	<i>Corixa panzeri</i>	-1.3 to -0.1
<i>Cephalodella gibboides</i>	-1 to -0.5	<i>Corixa punctata</i>	-1.4 to 0.1
<i>Cephalodella gigantea</i>	-1 to -0.5	<i>Corophium curvispinum</i>	-1.3 to 0
<i>Cephalodella mus</i>	-1 to -0.5	<i>Corophium volutator</i>	-1.3 to 0.4
<i>Ceriodaphnia cornuta</i>	-2.7 to -1.6	<i>Corynoneura arctica</i>	0.5 to 0.6
<i>Ceriodaphnia megops</i>	-3 to -0.1	<i>Corynoneura lacustris</i>	-1.3 to 0.6
<i>Ceriodaphnia pulchella</i>	-1.1 to 0.1	<i>Corynoneura lobata</i>	0.5 to 0.6
<i>Ceriodaphnia quadrangula</i>	-2.7 to -0.7	<i>Corynoneura scutellata</i>	-1.3 to 0.6
<i>Chaetocladus dentiforceps</i>	0.5 to 0.6	<i>Cricotopus cylindraceus</i>	-1.3 to -0.4
<i>Chaetogaster diaphanus</i>	-1.3 to -0.1	<i>Cricotopus laricomalis</i>	0.5 to 0.6
<i>Chaetogaster diastrophus</i>	-0.6 to -0.5	<i>Cricotopus myriophylli</i>	-2.5 to -2.1
<i>Chaetogaster limnaei</i>	-0.6 to -0.5	<i>Cricotopus ornatus</i>	-1.3 to -0.1

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Cricotopus sylvestris</i>	-2 to 0.1	<i>Dugesia tigrina</i>	-1.3 to -0.7
<i>Cricotopus trifasciatus</i>	-0.6 to -0.5	<i>Dunhevedia crassa</i>	-3 to -0.1
<i>Cyclops abyssorum</i>	-2.5 to -2	<i>Dytiscus circumflexus</i>	-1.3 to -0.1
<i>Cyclops vicinus</i>	-2.7 to -1.6	<i>Dytiscus marginalis</i>	-1.3 to -0.8
<i>Cymatia bonsdorffii</i>	-1.3 to -0.1	<i>Ecnomus tenellus</i>	-1.3 to -0.3
<i>Cymatia coleoptrata</i>	-1.3 to -0.3	<i>Einfeldia dissidens</i>	-1.3 to -0.9
<i>Cypridopsis hartwigi</i>	-1.3 to -0.8	<i>Enallagma cyathigerum</i>	-2.2 to -0.6
<i>Cyrrnus flavidus</i>	-1.3 to -0.2	<i>Endochironomus albipennis</i>	-2 to 0.1
<i>Daphnia ambigua</i>	-2.4 to -0.4	<i>Endochironomus dispar</i>	-2 to 0.6
<i>Daphnia carinata</i>	-2.7 to -1.6	<i>Endochironomus impar</i>	-1.3 to -0.4
<i>Daphnia catawba</i>	-2.4 to -2.1	<i>Endochironomus tendens</i>	-2 to 0.1
<i>Daphnia cucullata</i>	-1.7 to -0.7	<i>Enochrus testaceus</i>	-1.3 to 0.1
<i>Daphnia dubia</i>	-2.1 to -1.9	<i>Eodiaptomus sinensis</i>	-2.7 to -1.6
<i>Daphnia galeata</i>	-1.7 to -0.3	<i>Erpobdella octoculata</i>	-1.3 to 0.1
<i>Daphnia hyalina</i>	-2.7 to 0	<i>Erpobdella testacea</i>	-1.3 to 0.6
<i>Daphnia longiremis</i>	-2.4 to -1.9	<i>Erythromma najas</i>	-1.4 to -0.6
<i>Daphnia longispina</i>	-2.4 to 0	<i>Estatheroporus gauthieri</i>	-1.3 to -0.7
<i>Daphnia mendotae</i>	-2.4 to -1.6	<i>Ethmolaimus pratensis</i>	-1 to 0
<i>Daphnia pulex</i>	-2.7 to -0.2	<i>Eubosmina longispina</i>	-2.3 to -1.7
<i>Daphnia pulicaria</i>	-2.4 to -1.9	<i>Euchlanis dilatata</i>	-2.7 to -0.6
<i>Demicryptochironomus vulneratus</i>	-1.4 to -1.3	<i>Euchlanis triquetra</i>	-3 to -0.1
<i>Dendrocoelum lacteum</i>	-1.3 to -0.3	<i>Eucyclops euacanthus</i>	-2.7 to -1.6
<i>Dero digitata</i>	-1 to -0.8	<i>Eucyclops serrulatus</i>	-2.7 to -0.8
<i>Diacyclops bicuspidatus</i>	-1.3 to -0.7	<i>Eucypris virens</i>	-1.3 to -0.7
<i>Diacyclops bisetosus</i>	-1 to -0.7	<i>Eudiaptomus gracilis</i>	-0.6 to 0
<i>Diacyclops thomasi</i>	-2.1 to -1.3	<i>Eumonyhystera filiformis</i>	-1 to 0
<i>Diaphanosoma brachyurum</i>	-2.7 to 0.1	<i>Eurycercus lamellatus</i>	-1.5 to -0.5
<i>Dicrotendipes lobiger</i>	-1.3 to -0.4	<i>Eylais infundibulifera</i>	-1.3 to -0.7
<i>Dicrotendipes nervosus</i>	-2 to 0.1	<i>Filinia cornuta</i>	-0.7 to -0.1
<i>Dicrotendipes notatus</i>	-1.3 to -0.7	<i>Filinia longiseta</i>	-2.7 to -0.1
<i>Diplogaster rivalis</i>	-1 to 0	<i>Filinia minuta</i>	-1.8 to -0.1
<i>Disparalona acutirostris</i>	-2.3 to -1.7	<i>Filinia opoliensis</i>	-1 to 0.1
<i>Disparalona rostrata</i>	-2.7 to -1.6	<i>Filinia terminalis</i>	-3 to 0.1
<i>Dorylaimus stagnalis</i>	-1 to 0	<i>Gammarus duebeni</i>	-1.3 to 0
<i>Dreissena polymorpha</i>	-1.4 to -0.5	<i>Gammarus lacustris</i>	-2 to -0.9
<i>Dryops luridus</i>	-1.3 to 0.1	<i>Gammarus pulex</i>	-1.3 to -0.3
<i>Dugesia lugubris</i>	-1.3 to 0	<i>Gammarus tigrinus</i>	-1.4 to 0

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Gammarus zaddachi</i>	-1.3 to 0.4	<i>Hesperocorixa sahlbergi</i>	-1.3 to -0.6
<i>Gerris argentatus</i>	-1.4 to -1.3	<i>Hexarthra intermedia</i>	-0.6 to -0.1
<i>Gerris lacustris</i>	-1.3 to 0	<i>Hexarthra mira</i>	-3 to 0.1
<i>Gerris odontogaster</i>	-1.5 to -0.8	<i>Hippeutis complanatus</i>	-2 to -0.4
<i>Gerris thoracicus</i>	-1.3 to -0.8	<i>Holocentropus picicornis</i>	-1.3 to -0.6
<i>Glossiphonia complanata</i>	-2 to 0.1	<i>Holocentropus stagnalis</i>	-1.1 to -0.6
<i>Glossiphonia heteroclita</i>	-1.3 to -0.2	<i>Holopedium gibberum</i>	-2.4 to -1.7
<i>Glyptotendipes barbipes</i>	-1.3 to 0	<i>Hyalella azteca</i>	-2.4 to -0.8
<i>Glyptotendipes pallens</i>	-2 to 0.1	<i>Hydrachna cruenta</i>	-1.3 to -0.7
<i>Glyptotendipes paripes</i>	-1.4 to -1	<i>Hydrachna globosa</i>	-1.3 to -0.7
<i>Glyptotendipes testaceus</i>	-0.6 to -0.5	<i>Hydrachna skorikowi</i>	-1.3 to -0.1
<i>Graphoderus cinereus</i>	-1.3 to -0.4	<i>Hydrobia ventrosa</i>	-1.3 to 0.4
<i>Graptodytes pictus</i>	-1.4 to 0.1	<i>Hydrobius fuscipes</i>	-1.3 to 0
<i>Graptoleberis testudinaria</i>	-2.7 to -0.5	<i>Hydrodroma despiciens</i>	-1.7 to -0.1
<i>Gyraulus albus</i>	-1.3 to -0.3	<i>Hydroglyphus geminus</i>	-1.3 to -0.3
<i>Gyraulus crista</i>	-2 to -0.1	<i>Hydroporus foveolatus</i>	0.5 to 0.6
<i>Gyrinus paykulli</i>	-1.3 to -0.2	<i>Hydroporus palustris</i>	-1.4 to 0.6
<i>Haliplus apicalis</i>	-1.3 to 0	<i>Hydroporus striola</i>	-1.3 to -0.4
<i>Haliplus confinis</i>	-1.3 to -0.4	<i>Hydroporus umbrosus</i>	-2 to -1.3
<i>Haliplus flavicollis</i>	-1.3 to 0.1	<i>Hydrovatus cuspidatus</i>	-2 to 0.1
<i>Haliplus fluviatilis</i>	-0.8 to -0.4	<i>Hydryphantes dispar</i>	-2 to -0.4
<i>Haliplus heydeni</i>	-1.3 to -0.2	<i>Hygrobates longipalpis</i>	-1.4 to -1.2
<i>Haliplus immaculatus</i>	-1.3 to 0.1	<i>Hygrobia hermanni</i>	-1.3 to 0
<i>Haliplus lineatocollis</i>	-0.8 to 0.5	<i>Hygrotus confluens</i>	-1.3 to -0.9
<i>Haliplus ruficollis</i>	-1.4 to 0.1	<i>Hygrotus decoratus</i>	-1.3 to -0.4
<i>Halocladus varians</i>	-1.3 to 0.4	<i>Hygrotus impressopunctatus</i>	-1.3 to -0.3
<i>Helobdella nuda</i>	-0.6 to -0.5	<i>Hygrotus inaequalis</i>	-1.3 to 0.1
<i>Helobdella stagnalis</i>	-2 to 0.1	<i>Hygrotus nigrolineatus</i>	-1.3 to 0.1
<i>Helochares lividus</i>	-1.3 to -0.4	<i>Hygrotus versicolor</i>	-2 to -0.4
<i>Helochares obscurus</i>	-2 to 0.1	<i>Hyphydrus ovatus</i>	-1.3 to -0.5
<i>Helophorus aequalis</i>	-1.3 to -0.4	<i>Idotea chelipes</i>	-1.3 to 0.4
<i>Helophorus brevipalpis</i>	-1.3 to 0.5	<i>Ilybius fenestratus</i>	-1 to -0.8
<i>Helophorus glacialis</i>	0.5 to 0.6	<i>Ilybius subaeneus</i>	-1.3 to -0.8
<i>Hemiclepsis marginata</i>	-1.3 to -0.6	<i>Ilyocryptus agilis</i>	-2.7 to -1.6
<i>Hesperocorixa castanea</i>	-1.3 to -0.4	<i>Ilyocryptus sordidus</i>	-3 to -0.1
<i>Hesperocorixa linnaei</i>	-2 to -0.3	<i>Ilyocypris decipiens</i>	-1.3 to -1
<i>Hesperocorixa moesta</i>	-1.3 to -0.8	<i>Ischnura elegans</i>	-2 to -0.1

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Jaera ischiosetosa</i>	-1.3 to 0	<i>Leydigia acanthocercoides</i>	-1.1 to -0.5
<i>Kellicottia longispina</i>	-2.3 to -1.8	<i>Leydigia leydigi</i>	-2.7 to -0.5
<i>Keratella cochlearis</i>	-3 to 0.1	<i>Libellula depressa</i>	-0.8 to 0.1
<i>Keratella delicata</i>	-0.6 to -0.1	<i>Libellula quadrimaculata</i>	-1.3 to -0.4
<i>Keratella hiemalis</i>	-2.5 to -2	<i>Liliferotrocha subtilis</i>	-0.7 to -0.1
<i>Keratella quadrata</i>	-3 to 0.1	<i>Limnephilus affinis</i>	-1.4 to -0.7
<i>Keratella serrulata</i>	-2.7 to -0.6	<i>Limnephilus coenosus</i>	0.5 to 0.6
<i>Keratella tropica</i>	-2 to -0.6	<i>Limnephilus flavicornis</i>	-1.4 to -1.1
<i>Keratella valga</i>	-2 to 0.1	<i>Limnephilus griseus</i>	-2.5 to -2.2
<i>Kurzia latissima</i>	-2.3 to -1.7	<i>Limnephilus lunatus</i>	-1.3 to -0.6
<i>Laccobius bipunctatus</i>	-1.2 to -0.4	<i>Limnephilus marmoratus</i>	-1.4 to -1.3
<i>Laccobius colon</i>	-1.3 to -0.8	<i>Limnephilus rhombicus</i>	-2.7 to -0.6
<i>Laccobius minutus</i>	-2 to 0.1	<i>Limnephilus stigma</i>	-2.5 to -2
<i>Laccophilus minutus</i>	-1.7 to -0.1	<i>Limnephilus vittatus</i>	-1.5 to -1.4
<i>Latona parviremis</i>	-2.3 to -1.7	<i>Limnesia maculata</i>	-1.4 to -0.7
<i>Latona setifera</i>	-2.3 to -1.7	<i>Limnesia polonica</i>	-1 to -0.8
<i>Lecane aculeata</i>	-1.8 to -0.5	<i>Limnesia undulata</i>	-1.3 to -0.3
<i>Lecane bifurca</i>	-1 to -0.5	<i>Limnesia undulatoides</i>	-1.7 to -1.3
<i>Lecane clara</i>	-2.7 to -0.6	<i>Limnodrilus claparedeanus</i>	-1.2 to -1
<i>Lecane inermis</i>	-1.8 to -0.5	<i>Limnodrilus hoffmeisteri</i>	-1.3 to -0.4
<i>Lecane ligona</i>	-2.7 to -0.6	<i>Lumbriculus variegatus</i>	-2 to 0.1
<i>Lecane lunaris</i>	-2.7 to -0.1	<i>Lymnaea stagnalis</i>	-1.3 to 0
<i>Lecane mira</i>	-2.3 to -2	<i>Macrothrix rosea</i>	-1.3 to -1
<i>Lecane mylacris</i>	-2.7 to -0.6	<i>Megacyclops gigas</i>	-1.3 to -0.7
<i>Lecane pyriformis</i>	-1 to -0.5	<i>Melampophylax mucoreus</i>	0.5 to 0.6
<i>Lecane quadridentata</i>	-3 to -0.1	<i>Mesocyclops edax</i>	-2.1 to -1.3
<i>Lecane signifera</i>	-2.7 to -0.6	<i>Mesocyclops nothius</i>	-2.7 to -1.6
<i>Lecane stichaea</i>	-2.7 to -0.6	<i>Metacyclops mendocinus</i>	-0.8 to -0.6
<i>Lepadella elliptica</i>	-1 to -0.5	<i>Microchironomus tener</i>	-1.3 to -0.7
<i>Leptodora kindtii</i>	-2.7 to -0.9	<i>Microcodon clavus</i>	-2.7 to -2.2
<i>Leptophlebia vespertina</i>	-2.7 to -1.1	<i>Microcyclops rubellus</i>	-1.3 to -1
<i>Lestes sponsa</i>	-2.2 to -0.6	<i>Mideopsis orbicularis</i>	-1.4 to -0.7
<i>Leuctra aurita</i>	-2.7 to -2	<i>Mixodiaptomus lilljeborgi</i>	-1.3 to -0.7
<i>Leuctra digitata</i>	-2.7 to -2	<i>Moina micrura</i>	-2.7 to -0.5
<i>Leuctra fusca</i>	-2.7 to -2	<i>Molanna angustata</i>	-1.4 to -1
<i>Leuctra handlirschi</i>	-2.5 to -2.2	<i>Monhystera fasciculata</i>	-1 to 0
<i>Leuctra nigra</i>	-2.5 to -2.2	<i>Mononchus aquaticus</i>	-1 to 0

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Monopelopia tenuicalcar</i>	-1.2 to -0.8	<i>Palaemonetes varians</i>	-1.3 to 0.4
<i>Monospilus dispar</i>	-2.3 to -1.7	<i>Parachironomus arcuatus</i>	-1.4 to 0
<i>Monostyla bulla</i>	-1.8 to -1	<i>Parachironomus varus</i>	-2 to 0.1
<i>Mystacides azurea</i>	-2.7 to -2.2	<i>Paracladius alpicola</i>	0.5 to 0.6
<i>Mystacides longicornis</i>	-1.7 to -0.3	<i>Paracladopelma camptolabis</i>	0.5 to 0.6
<i>Mystacides niger</i>	-1 to 0	<i>Parakiefferiella coronata</i>	0.5 to 0.6
<i>Myxas glutinosa</i>	-1 to -0.8	<i>Parakiefferiella triquetra</i>	0.5 to 0.6
<i>Nemotelus notatus</i>	-1.3 to 0	<i>Paralimnocythere psammophila</i>	-1.3 to -0.7
<i>Nemoura cinerea</i>	-2.7 to 0.6	<i>Paralona pigra</i>	-2.3 to -1.7
<i>Nemurella picteti</i>	-2.7 to 0.6	<i>Paramerina cingulata</i>	-1.3 to -1
<i>Neodiptomus schmackeri</i>	-2.7 to -1.6	<i>Paratanytarsus austriacus</i>	-1.3 to 0.6
<i>Neodiptomus yangtsekiangensis</i>	-2.7 to -1.6	<i>Paratanytarsus laccophilus</i>	0.5 to 0.6
<i>Neomysis integer</i>	-1.3 to 0	<i>Paratrichocladius nivalis</i>	0.5 to 0.6
<i>Nepa cinerea</i>	-1.3 to -0.3	<i>Paratrichocladius skirwithensis</i>	0.5 to 0.6
<i>Nereis diversicolor</i>	-1.3 to 0.4	<i>Parorthocladius nudipennis</i>	0.5 to 0.6
<i>Neumania deltoides</i>	-1.4 to -0.8	<i>Peltodytes caesus</i>	-1.3 to -0.4
<i>Neumania vernalis</i>	-1.4 to -0.8	<i>Phryganea bipunctata</i>	-2.7 to -0.3
<i>Neurodiptomus alatus</i>	-2.7 to -1.6	<i>Phryganea striata</i>	-2.2 to -2
<i>Noterus clavicornis</i>	-2 to 0.1	<i>Physa acuta</i>	-1.3 to -0.3
<i>Noterus crassicornis</i>	-1.3 to -0.4	<i>Physa fontinalis</i>	-1.3 to 0.1
<i>Notholca squamula</i>	-2.5 to -0.1	<i>Piona alpicola</i>	-1.3 to 0
<i>Notodiptomus incompositus</i>	-0.8 to -0.6	<i>Piona carnea</i>	-1.3 to -0.1
<i>Notommata glyphura</i>	-3 to -0.1	<i>Piona clavicornis</i>	-1.3 to -0.8
<i>Notonecta obliqua</i>	-1.3 to -0.8	<i>Piona coccinea</i>	-1.3 to -0.7
<i>Notonecta viridis</i>	-1.3 to -0.1	<i>Piona conglobata</i>	-2 to 0
<i>Ochthebius marinus</i>	-2 to -1.5	<i>Piona variabilis</i>	-2 to 0
<i>Ochthebius minimus</i>	-1.3 to -0.9	<i>Pionopsis lutescens</i>	-2 to 0
<i>Odontocerum albicorne</i>	-2.2 to 0.6	<i>Piscicola geometra</i>	-1.3 to 0.1
<i>Odontomyia argentata</i>	-1.3 to -0.8	<i>Pisidium henslowanum</i>	-1.4 to -1
<i>Oecetis furva</i>	-1.7 to -0.5	<i>Pisidium nitidum</i>	-1 to -0.8
<i>Oecetis lacustris</i>	-1.3 to -0.4	<i>Pisidium oasertanum</i>	0.5 to 0.6
<i>Oecetis ochracea</i>	-2 to -0.1	<i>Pisidium personatum</i>	-1.3 to -0.6
<i>Oligotricha striata</i>	-2.5 to 0.6	<i>Planorbarius corneus</i>	-2 to -1.2
<i>Ophidonais serpentina</i>	-1.3 to 0.1	<i>Planorbis planorbis</i>	-1.5 to 0.1
<i>Ophryoxis brevicaudis</i>	-2.3 to -1.7	<i>Plectrocnemia conspersa</i>	-2.5 to 0.6
<i>Oxyurella tenuicaudis</i>	-1.1 to -0.5	<i>Pleuroxus aduncus</i>	-1.5 to -0.9
<i>Palaemon longirostris</i>	-1.3 to -0.7	<i>Pleuroxus denticulatus</i>	-2.3 to -1.7

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Pleuroxus laevis</i>	-2.3 to -1.7	<i>Pseudodiamesa branickii</i>	0.5 to 0.6
<i>Pleuroxus striatus</i>	-2.3 to -1.7	<i>Pseudodiamesa nivosa</i>	0.5 to 0.6
<i>Polyarthra dolichoptera</i>	-2.7 to -0.1	<i>Pseudosmittia forcipatus</i>	-1.3 to -0.8
<i>Polyarthra major</i>	-2.7 to -0.6	<i>Pyrrhosoma nymphula</i>	-2.7 to -0.6
<i>Polyarthra remata</i>	-2.7 to -0.6	<i>Radix ovata</i>	-1.5 to 0.1
<i>Polyarthra vulgaris</i>	-3 to 0.1	<i>Radix peregra</i>	-1.7 to 0.6
<i>Polycelis nigra</i>	-1.4 to -0.6	<i>Radix swinhoei</i>	-0.6 to -0.5
<i>Polycelis tenuis</i>	-2 to -0.1	<i>Ranatra linearis</i>	-1.7 to -0.2
<i>Polycentropus flavomaculatus</i>	-2.5 to 0.6	<i>Rhantus exsoletus</i>	-2 to -0.6
<i>Polypedilum bicrenatum</i>	-1.3 to -0.1	<i>Rhantus frontalis</i>	-1.4 to -0.1
<i>Polypedilum convictum</i>	-2 to -0.8	<i>Rheocricotopus effusus</i>	0.5 to 0.6
<i>Polypedilum nubeculosum</i>	-1.4 to 0	<i>Rhinoglena frontalis</i>	-1.8 to -0.1
<i>Polypedilum pedestre</i>	-2 to -0.8	<i>Rhyacophila italica</i>	0.5 to 0.6
<i>Polypedilum sordens</i>	-2 to 0.1	<i>Rhynchnotalona falcata</i>	-2.3 to -1.7
<i>Polyphemus pediculus</i>	-2.3 to -0.6	<i>Rhynchotalona falcata</i>	-2.7 to -1.6
<i>Pompholyx complanata</i>	-0.6 to -0.1	<i>Scapholeberis mucronata</i>	-2.7 to -0.6
<i>Pompholyx sulcata</i>	-1.8 to -0.1	<i>Scapholeberis rammneri</i>	-1.3 to -1
<i>Potamopyrgus antipodarum</i>	-1.3 to 0	<i>Schmackeria forbesi</i>	-2.7 to -1.6
<i>Potamothenis moldaviensis</i>	-1.3 to -0.4	<i>Segmentina nitida</i>	-1.3 to -0.7
<i>Proales parasita</i>	-0.7 to -0.1	<i>Sialis lutaria</i>	-2.7 to 0
<i>Proalides digitus</i>	-0.7 to -0.1	<i>Sida crystallina</i>	-2.7 to -0.9
<i>Proalides tentaculata</i>	-0.7 to -0.1	<i>Sigara distincta</i>	-1.3 to -0.6
<i>Proasellus meridianus</i>	-1.3 to -0.1	<i>Sigara falleni</i>	-1.4 to 0.1
<i>Procladius chloreus</i>	-0.8 to -0.6	<i>Sigara lateralis</i>	-1.7 to 0.1
<i>Procladius choreus</i>	-1.3 to -0.1	<i>Sigara scotti</i>	-1.5 to -0.9
<i>Prodiamesa olivacea</i>	0.5 to 0.6	<i>Sigara semistriata</i>	-1.4 to -1.1
<i>Propsilocerus akamusi</i>	-0.8 to -0.6	<i>Sigara stagnalis</i>	-1.3 to 0.4
<i>Protanypus caudatus</i>	0.5 to 0.6	<i>Sigara striata</i>	-1.7 to 0.1
<i>Protonemura auberti</i>	-2.5 to -2	<i>Simocephalus serrulatus</i>	-2.7 to -1.6
<i>Protonemura hrabei</i>	-2.7 to -2	<i>Simocephalus vetuloides</i>	-2.7 to -1.6
<i>Psammoryctides barbatus</i>	-1.4 to -1.3	<i>Simocephalus vetulus</i>	-2.7 to -0.5
<i>Psectrocladius barbimanus</i>	-1.3 to -0.8	<i>Sinantharina socialis</i>	-0.6 to -0.1
<i>Psectrocladius limbatellus</i>	0.5 to 0.6	<i>Sinocalanus doerri</i>	-2.7 to -1.6
<i>Psectrocladius platypus</i>	-1.4 to 0.1	<i>Siphonurus lacustris</i>	-2.7 to 0.6
<i>Psectrocladius sordidellus</i>	-2 to 0.6	<i>Sphaerium corneum</i>	-1.3 to -0.5
<i>Psectrotanypus varius</i>	-1.3 to 0.5	<i>Sphaerium lacustre</i>	-0.8 to -0.6
<i>Pseudochydorus globosus</i>	-3 to -0.1	<i>Sphaeroma rugicauda</i>	-1.3 to 0.4

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Spirosperma ferox</i>	-1.4 to -1.3	<i>Trichocerca vargai</i>	-1.8 to -1.1
<i>Stagnicola palustris</i>	-1.3 to 0.1	<i>Trichocerca vernalis</i>	-1 to -0.5
<i>Stephanoceros fimbriatus</i>	-2.7 to -0.6	<i>Trichotria tetractis</i>	-2.7 to -0.6
<i>Stictotarsus griseostriatus</i>	0.5 to 0.6	<i>Tropocyclops extensus</i>	-2.1 to -1.3
<i>Stilociadius montanus</i>	0.5 to 0.6	<i>Tropocyclops meridionalis</i>	-0.8 to -0.6
<i>Streblospio shrubsolii</i>	-1.3 to -1.1	<i>Tropodiatomus oryzanus</i>	-2.7 to -1.6
<i>Stylaria fossularis</i>	-0.6 to -0.5	<i>Tvetenia calvescens</i>	0.5 to 0.6
<i>Stylaria lacustris</i>	-1.7 to 0.1	<i>Valvata cristata</i>	-1.3 to 0
<i>Sympetrum striolatum</i>	-1.3 to -0.6	<i>Valvata piscinalis</i>	-1.4 to 0
<i>Synchaeta oblonga</i>	-1.8 to -0.1		
<i>Synchaeta pectinata</i>	-2.2 to -0.1	Xeric	
<i>Synchaeta stylata</i>	-2 to -0.1	<i>Branchinecta packardi</i>	-0.4 to 0.6
<i>Synchaeta tremula</i>	-2.5 to -1.1	<i>Eretes sticticus</i>	-0.2 to 0.6
<i>Tanytus chinensis</i>	-0.8 to -0.6	<i>Eulimnadia texana</i>	-0.4 to 0.6
<i>Tanytus kraatzi</i>	-1.3 to -0.6	<i>Potamocypriis compressa</i>	-0.2 to 0.6
<i>Tanytus punctipennis</i>	-0.8 to -0.6	<i>Triops longicaudatus</i>	-0.4 to 0.6
<i>Tanytarsus pallidicornis</i>	0.5 to 0.6		
<i>Theodoxus fluviatilis</i>	-1.3 to -0.3	(Sub)tropical	
<i>Thermocyclops hyalinus</i>	-2.7 to -1.6	<i>Caladomyia ortonii</i>	-2.3 to -1.9
<i>Thermocyclops taihokuensis</i>	-2.7 to -1.6	<i>Diatomus dorsalis</i>	-1.5 to -0.7
<i>Theromyzon tessulatum</i>	-1.7 to 0	<i>Eubosmina tubicen</i>	-1.5 to -0.9
<i>Tiphys ornatus</i>	-2 to -1.3	<i>Limnodrilus hoffmeisteri</i>	-2.3 to -2.1
<i>Tobrilus gracilis</i>	-1 to 0	<i>Tropocyclops prasinus</i>	-1.5 to -0.7
<i>Tobrilus wesenbergi</i>	-1 to 0		
<i>Triaenodes bicolor</i>	-2 to 0	(d) Macrophytes in lakes	
<i>Tribelos intextus</i>	-1.4 to -1	Cold	
<i>Trichocerca capucina</i>	-0.6 to -0.4	<i>Eleocharis palustris</i>	-2 to -1.3
<i>Trichocerca cylindrica</i>	-1.8 to -0.1	<i>Equisetum fluviatile</i>	-2 to -1.3
<i>Trichocerca divon-nuttalli</i>	-0.7 to -0.1	<i>Lobelia dortmanna</i>	-2 to -1.3
<i>Trichocerca elongata</i>	-3 to 0.1	<i>Myriophyllum alterniflorum</i>	-2 to -1.3
<i>Trichocerca gracilis</i>	-1.8 to -0.1	<i>Nuphar lutea</i>	-2 to -1.3
<i>Trichocerca longiseta</i>	-2.7 to -0.6	<i>Nymphaea candida</i>	-2 to -1.3
<i>Trichocerca myersi</i>	-2.3 to -1.8	<i>Phragmites australis</i>	-2 to -1.3
<i>Trichocerca pusilla</i>	-1.8 to -0.1	<i>Potamogeton natans</i>	-2 to -1.3
<i>Trichocerca rousseleti</i>	-1.8 to -1	<i>Potamogeton perfoliatus</i>	-2 to -1.3
<i>Trichocerca similis</i>	-1 to -0.1	<i>Ranunculus peltatus</i>	-2 to -1.3
<i>Trichocerca stylata</i>	-2.3 to -0.1	<i>Schoenoplectus lacustris</i>	-2 to -1.3

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Sparganium angustifolium</i>	-2 to -1.3	<i>Caltha palustris</i>	-1.6 to -1
<i>Sparganium emersum</i>	-2 to -1.3	<i>Calystegia sepium</i>	-1.6 to -1
<i>Sparganium erectum</i>	-2 to -1.3	<i>Carex acuta</i>	-1.6 to -1
<i>Stratiotes aloides</i>	-1.6 to -0.6	<i>Carex divisa</i>	-1.3 to -0.7
<i>Typha angustifolia</i>	-2 to -1.3	<i>Carex lasiocarpa</i>	-1.6 to -0.5
<i>Typha latifolia</i>	-2 to -1.3	<i>Carex lurida</i>	-2.5 to -0.5
		<i>Carex pseudocyperus</i>	-0.3 to 0.8
Temperate		<i>Carex riparia</i>	-1.4 to -1.1
<i>Achillea salicifolia</i>	-1.6 to -1	<i>Carex vulpina</i>	-1.6 to -1
<i>Acorus calamus</i>	-1.6 to -0.1	<i>Ceratophyllum demersum</i>	-3 to 0.2
<i>Agrostis pourretii</i>	-1.3 to -0.7	<i>Ceratophyllum muricatum subsp. Australe</i>	-1.6 to -0.5
<i>Agrostis stolonifera</i>	-1.6 to -1	<i>Ceratophyllum submersum</i>	-1.5 to -1.3
<i>Alisma gramineum</i>	-1.6 to -1	<i>Chamaedaphne calyculata</i>	-2.5 to -0.5
<i>Alisma plantago-aquatica</i>	-1.6 to 0	<i>Cicuta virosa</i>	-1.6 to -1
<i>Alopecurus aequalis</i>	-1.6 to -1	<i>Cladium mariscus</i>	-1.6 to -1
<i>Alopecurus bulbosus</i>	-1.3 to -0.7	<i>Comarum palustre</i>	-1.6 to -1
<i>Andromeda glaucophylla</i>	-2.5 to -1.7	<i>Crassula vaillantii</i>	-1.3 to -0.7
<i>Antinoria agrostidea</i>	-1.2 to 0.3	<i>Cyperus fuscus</i>	-1.6 to -1
<i>Antinoria insularis</i>	-1.3 to -0.7	<i>Damasonium alisma</i>	-1.3 to -0.8
<i>Apium crassipes</i>	-1.3 to -1	<i>Dulichium arundinaceum</i>	-2.5 to -0.5
<i>Bellis annua</i>	-1.3 to -0.7	<i>Eichhornia crassipes</i>	-1.6 to -1.3
<i>Berula erecta</i>	-2.5 to -1.4	<i>Elatine americana</i>	-1.6 to -1.3
<i>Bidens beckii</i>	-1.6 to -1.3	<i>Elatine hydropiper</i>	-1.6 to -1
<i>Bidens cernua</i>	-1.6 to 0.8	<i>Elatine minima</i>	-1.6 to -1.3
<i>Bidens radiata</i>	-1.6 to -1	<i>Elatine triandra</i>	-1.6 to -1.3
<i>Bidens tripartita</i>	-1.6 to -1	<i>Eleocharis acicularis</i>	-2.5 to -1
<i>Brasenia schreberi</i>	-2.5 to -1.3	<i>Eleocharis palustris</i>	-1.6 to 0
<i>Butomus umbellatus</i>	-1.6 to -1	<i>Eleocharis parvula</i>	-1.6 to -1.3
<i>Cabomba caroliniana</i>	-1.6 to -1.3	<i>Eleocharis robbinsii</i>	-1.6 to -0.5
<i>Calamagrostis canescens</i>	-1.6 to -1	<i>Eleocharis uniglumis</i>	-1.6 to -1
<i>Calamagrostis purpurea</i>	-1.6 to -1	<i>Elodea canadensis</i>	-2 to 0.8
<i>Calamaria setacea</i>	-2.7 to -1.6	<i>Elodea nuttallii</i>	-1.9 to -0.5
<i>Callitriche brutia</i>	-1.5 to -1.3	<i>Epilobium hirsutum</i>	-1.6 to -1
<i>Callitriche hamulata</i>	-1.6 to -0.8	<i>Epilobium palustre</i>	-1.6 to -1
<i>Callitriche heterophylla</i>	-1.6 to -1.3	<i>Epipactis palustris</i>	-1.6 to -1
<i>Callitriche palustris</i>	-2.7 to -0.5	<i>Equisetum fluviatile</i>	-1.6 to 0.8
<i>Callitriche stagnalis</i>	-1.3 to -0.7	<i>Equisetum palustre</i>	-1.6 to -1

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Eriocaulon aquaticum</i>	-2.5 to -1.3	<i>Juncus militaris</i>	-2.5 to -1.7
<i>Eriocaulon sexangulare</i>	-2.5 to 0.8	<i>Juncus pelocarpus</i>	-2.5 to -1.3
<i>Euphrasia officinalis</i>	-1.6 to -1	<i>Juncus pygmaeus</i>	-1.3 to -0.7
<i>Fontinalis antipyretica</i>	-1.6 to -1.3	<i>Juncus subnodulosus</i>	-1.3 to -1
<i>Fontinalis novae-angliae</i>	-2.5 to -0.5	<i>Kalmia polifolia</i>	-2.5 to -1.7
<i>Galium aparine</i>	-1.6 to -1	<i>Lathyrus japonicus subsp. Maritimus</i>	-1.6 to -1
<i>Galium palustre</i>	-1.6 to -1	<i>Lathyrus palustris</i>	-1.6 to -1
<i>Glossostigma cleistanthum</i>	-1.6 to -1.3	<i>Lemna gibba</i>	-1.6 to -1
<i>Glyceria fluitans</i>	-1.6 to 0.3	<i>Lemna minor</i>	-2 to 0.8
<i>Glyceria maxima</i>	-2 to 0	<i>Lemna trisulca</i>	-3 to 0
<i>Glyceria spicata</i>	-1.3 to -0.7	<i>Leymus arenarius</i>	-1.6 to -1
<i>Gratiola aurea</i>	-1.6 to -1.3	<i>Littorella uniflora</i>	-2.7 to -1.2
<i>Groenlandia densa</i>	-2 to -1.7	<i>Lobelia dortmanna</i>	-2.7 to -1.2
<i>Heteranthera dubia</i>	-1.6 to -1.3	<i>Lotus pedunculatus</i>	-1.3 to -1
<i>Hydrilla verticillata</i>	-1.9 to -0.7	<i>Ludwigia palustris</i>	-1.6 to -0.5
<i>Hydrocharis dubia</i>	-1.6 to -1.4	<i>Lycopus europaeus</i>	-1.6 to -1
<i>Hydrocharis morsus-ranae</i>	-1.6 to -1	<i>Lysimachia terrestris</i>	-1.6 to -0.5
<i>Hypericum mutilum subsp. Boreale</i>	-2.5 to -1.7	<i>Lysimachia thyrsoflora</i>	-1.6 to -1
<i>Illecebrum verticillatum</i>	-1.3 to -1	<i>Lysimachia vulgaris</i>	-1.6 to -1
<i>Inula britannica</i>	-1.6 to -1	<i>Lythrum salicaria</i>	-1.6 to -1
<i>Iris pseudacorus</i>	-1.7 to 0	<i>Marsilea polycarpa</i>	-1.6 to -1.3
<i>Isoetes eatonii</i>	-1.6 to -1.3	<i>Mentha aquatica</i>	-1.6 to -1
<i>Isoetes echinospora</i>	-1.6 to -1.3	<i>Mentha arvensis</i>	-1.6 to -1
<i>Isoetes engelmannii</i>	-1.6 to -1.3	<i>Mentha pulegium</i>	-1.3 to -1
<i>Isoetes lacustris</i>	-2.7 to -1.2	<i>Mentha verticillata</i>	-1.6 to -1
<i>Isoetes riparia</i>	-1.6 to -1.3	<i>Menyanthes trifoliata</i>	-1.6 to -1
<i>Isoetes tiguliana</i>	-1.3 to -0.7	<i>Middendorfia borysthenica</i>	-1.3 to -0.7
<i>Isoetes tuckermanii</i>	-2.5 to -1.3	<i>Myosotis scorpioides</i>	-1.6 to -1
<i>Isoetes tuckermanii subsp. Acadiensis</i>	-1.6 to -1.3	<i>Myosotis sicula</i>	-1.3 to -0.7
<i>Isoetes velata</i>	-1.3 to -0.8	<i>Myosoton aquaticu</i>	-1.6 to -1
<i>Jacobaea paludosa</i>	-1.6 to -1	<i>Myrica gale</i>	-2.5 to -0.5
<i>Juncus articulatus</i>	-1.6 to -1	<i>Myriophyllum alterniflorum</i>	-2.3 to 0.3
<i>Juncus bufonius</i>	-1.6 to -1	<i>Myriophyllum heterophyllum</i>	-1.6 to -1.3
<i>Juncus bulbosus</i>	-2.2 to -2	<i>Myriophyllum humile</i>	-1.6 to -1.3
<i>Juncus canadensis</i>	-2.5 to -1.7	<i>Myriophyllum quitense</i>	-1.9 to -0.9
<i>Juncus effusus</i>	-1.6 to 0.8	<i>Myriophyllum sibiricum</i>	-3 to -1
<i>Juncus marginatus</i>	-2.5 to -1.7	<i>Myriophyllum spicatum</i>	-3 to 0.2

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Myriophyllum tenellum</i>	-1.6 to -1.3	<i>Potamogeton gramineus</i>	-3 to 0.8
<i>Myriophyllum verticillatum</i>	-1.8 to -0.1	<i>Potamogeton illinoensis Morong</i>	-3 to -1
<i>Najas flexilis</i>	-3 to -1	<i>Potamogeton natans</i>	-1.8 to 0.8
<i>Najas gracillima</i>	-1.6 to -1.3	<i>Potamogeton nodosus</i>	-1.8 to -1.1
<i>Najas guadalupensis</i>	-1.6 to -1.3	<i>Potamogeton oakesianus</i>	-2.5 to -0.5
<i>Najas marina</i>	-3 to -0.7	<i>Potamogeton obtusifolius</i>	-1.6 to -1
<i>Najas minor</i>	-1.6 to -1.3	<i>Potamogeton perfoliatus</i>	-2.5 to -1
<i>Nuphar lutea</i>	-2 to -0.1	<i>Potamogeton praelongus</i>	-2.5 to -1
<i>Nuphar lutea subsp. Variegata</i>	-1.8 to -1.3	<i>Potamogeton pulcher</i>	-1.6 to -1.3
<i>Nuphar pumila</i>	-1.6 to -1	<i>Potamogeton pusillus</i>	-2.5 to 0.8
<i>Nuphar variegatum</i>	-2.5 to 0.8	<i>Potamogeton richardsonii</i>	-1.9 to -1.2
<i>Nymphaea alba</i>	-1.6 to -0.4	<i>Potamogeton robbinsii</i>	-1.6 to -1.3
<i>Nymphaea odorata</i>	-2.5 to 0.8	<i>Potamogeton rutilus</i>	-1.6 to -1
<i>Nymphoides cordata</i>	-2.5 to -1.3	<i>Potamogeton spirillus</i>	-1.6 to -1.3
<i>Nymphoides peltatum</i>	-1.8 to -0.9	<i>Potamogeton trichoides</i>	-1.6 to 0.8
<i>Odontites litoralis</i>	-1.6 to -1	<i>Potamogeton vaseyi</i>	-1.6 to -1.3
<i>Oenanthe aquatica</i>	-1.6 to -1	<i>Proserpinaca palustris</i>	-1.6 to -1.3
<i>Pedicularis palustris</i>	-1.6 to -1	<i>Pulicaria vulgaris</i>	-1.3 to -0.7
<i>Persicaria hydropiper</i>	-1.6 to -1	<i>Ranunculus aquatilis</i>	-2.7 to -1
<i>Persicaria lappathifolia</i>	-1.6 to -1	<i>Ranunculus aquatilis var. diffusus</i>	-1.6 to -1.3
<i>Petasites spurius</i>	-1.6 to -1	<i>Ranunculus circinatus</i>	-1.6 to -1
<i>Phalaris arundinacea</i>	-1.6 to -1	<i>Ranunculus lingua</i>	-1.6 to -1
<i>Phragmites australis</i>	-1.8 to 0.2	<i>Ranunculus repens</i>	-1.6 to -1
<i>Polypogon maritimus</i>	-1.3 to -0.8	<i>Ranunculus reptans</i>	-1.6 to -1
<i>Pontederia cordata</i>	-2.5 to 0.8	<i>Ranunculus revellieri</i>	-1.3 to -0.7
<i>Potamogeton acutifolius</i>	-1.6 to -0.4	<i>Ranunculus sardous</i>	-1.3 to -0.7
<i>Potamogeton alpinus</i>	-2.5 to -1.3	<i>Ranunculus sceleratus</i>	-1.6 to -1
<i>Potamogeton amplifolius</i>	-1.6 to -1.3	<i>Ranunculus trichophyllus</i>	-2.5 to -1
<i>Potamogeton berchtoldii</i>	-2.5 to -0.5	<i>Ricciella fluitans</i>	-1.1 to -1
<i>Potamogeton bicupulatus</i>	-1.6 to -1.3	<i>Rorippa amphibia</i>	-1.6 to -1
<i>Potamogeton compressus</i>	-1.9 to -1	<i>Rorippa palustris</i>	-1.6 to -1
<i>Potamogeton confervoides</i>	-2.5 to -1.3	<i>Rumex hydrolapathum</i>	-2 to -0.1
<i>Potamogeton crispus</i>	-2 to -0.1	<i>Rumex maritimus</i>	-1.6 to -1
<i>Potamogeton diversifolius</i>	-1.6 to -1.3	<i>Sagina nodosa</i>	-1.6 to -1
<i>Potamogeton epihydrus</i>	-2.5 to -0.5	<i>Sagittaria latifolia</i>	-0.3 to 0.8
<i>Potamogeton foliosus</i>	-1.8 to 0.8	<i>Sagittaria sagittifolia</i>	-1.6 to -1
<i>Potamogeton friesii</i>	-1.6 to -1	<i>Schoenoplectus californicus</i>	-1.9 to -0.9

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Schoenoplectus lacustris</i>	-1.6 to -0.4	<i>Utricularia subulata</i>	-1.6 to -1.3
<i>Schoenoplectus subterminalis</i>	-1.8 to -0.5	<i>Utricularia vulgaris</i>	-2.5 to -0.5
<i>Scirpus cyperinus</i>	-1.6 to -0.5	<i>Vallisneria americana</i>	-3 to -1
<i>Scirpus microcarpus</i>	-0.3 to 0.8	<i>Vallisneria spiralis</i>	-1.9 to -0.7
<i>Scirpus radicans</i>	-1.6 to -1	<i>Warnstorfia exannulata</i>	-2.7 to -1.9
<i>Scolochloa festucacea</i>	-1.6 to -1	<i>Zannichellia palustris</i>	-1.6 to 0.2
<i>Scutellaria galericulata</i>	-1.6 to -1		
<i>Sium latifolium</i>	-1.6 to -1	(e) Non-silicon-based algae in lakes	
<i>Sium suave</i>	-2.5 to 0.8	Cold	
<i>Solanum dulcamara</i>	-1.6 to -1	<i>Ankyra judayi</i>	-2 to -0.2
<i>Sparganium americanum</i>	-2.5 to -0.5	<i>Chlamydomonas nivalis</i>	-1.6 to 0.5
<i>Sparganium angustifolium</i>	-2.7 to -0.5	<i>Dinobryon divergens</i>	-0.9 to -0.4
<i>Sparganium emersum</i>	-1.6 to -1	<i>Dinobryon sociale</i>	-0.9 to -0.4
<i>Sparganium erectum</i>	-1.6 to -1	<i>Monoraphidium contortum</i>	-1.5 to 0.5
<i>Sparganium eurycarpum</i>	-0.3 to 0.8	<i>Ochromonas ovalis</i>	-1.6 to -0.4
<i>Sparganium fluctuans</i>	-2.5 to -0.5	<i>Oocystis submarina</i>	-2.3 to -1.1
<i>Sphagnum denticulatum</i>	-2.7 to -1.9	<i>Pediastrum integrum</i>	-2.3 to -1.1
<i>Spirodela polyrrhiza</i>	-1.6 to -0.5	<i>Pleurococcus antarcticus</i>	-1.6 to -0.7
<i>Stachys palustris</i>	-1.6 to -1	<i>Prasiococcus calcarius</i>	-2 to 0.5
<i>Stellaria palustris</i>	-1.6 to -1	<i>Prasiola crispa</i>	-1.7 to 0.5
<i>Stratiotes aloides</i>	-1.6 to -0.4	<i>Pseudoschroederia robusta</i>	-2.2 to -1.4
<i>Stuckenia filiformis</i>	-1.8 to -1	<i>Scenedesmus ellipticus</i>	-2 to -1.1
<i>Stuckenia pectinata</i>	-3 to -0.3	<i>Stichococcus bacillaris</i>	-1.5 to 0.5
<i>Subularia aquatica</i>	-2.7 to -1.6	<i>Tetraspora gelatinosa</i>	-1.8 to -1.5
<i>Symphytum officinale</i>	-1.6 to -1	<i>Tribonema utriculosum</i>	-1.6 to -0.4
<i>Thelypteris palustris</i>	-1.6 to -1	<i>Ulothrix moniliformis</i>	-2.7 to -0.2
<i>Trapa natans</i>	-1.6 to -0.7		
<i>Trapa natans var. bispinosa</i>	-1.6 to -0.9	Temperate	
<i>Trifolium michelianum</i>	-1.3 to -0.7	<i>Actinastrum gracillimum</i>	-0.7 to 0
<i>Typha angustifolia</i>	-1.6 to -0.7	<i>Actinastrum hantzschii</i>	-0.7 to 0.2
<i>Typha latifolia</i>	-2.5 to 0.8	<i>Acutodesmus acuminatus</i>	-0.7 to 1.2
<i>Utricularia geminiscapa</i>	-1.6 to -1.3	<i>Ankistrodesmus falcatus</i>	-2.3 to 1.1
<i>Utricularia gibba</i>	-1.6 to -1.3	<i>Ankistrodesmus gracilis</i>	-1 to 0
<i>Utricularia intermedia</i>	-1.6 to -0.5	<i>Ankistrodesmus spiralis</i>	-1.6 to -1.5
<i>Utricularia minor</i>	-2.5 to -0.5	<i>Bitrichia ollula</i>	-2.7 to -2
<i>Utricularia purpurea</i>	-2.5 to -0.5	<i>Botryococcus braunii</i>	-1.6 to -1
<i>Utricularia radiata</i>	-1.6 to -1.3	<i>Carteria pseudoglobosa</i>	-1.3 to -0.2

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Chara contraria</i>	-2 to -1.7	<i>Kephyrion globosum</i>	-1 to -0.4
<i>Chara globularis</i>	-1.6 to -0.5	<i>Komma caudata</i>	-1.6 to -0.7
<i>Chara vulgaris</i>	-1.8 to -1.7	<i>Lagerheimia genevensis</i>	-1.6 to -1
<i>Chlamydomonas microsphaera</i>	-1.3 to -0.2	<i>Mallomonas akrokomos</i>	-2.4 to -2
<i>Chlamydomonas reinhardtii</i>	-1.3 to -0.2	<i>Mallomonas caudata</i>	-1.8 to -0.7
<i>Chlorella vulgaris</i>	-1.8 to -1.6	<i>Mallomonas pseudocoronata</i>	-1.8 to -1.6
<i>Chlorococcum infusioenum</i>	-1.8 to -1.6	<i>Micractinium pusillum</i>	-1.6 to -0.1
<i>Chlorogonium elongatum</i>	-1.3 to -0.2	<i>Monactinus simplex</i>	-1.4 to 1.2
<i>Chloromonas angustissima</i>	-2.7 to -2	<i>Monoraphidium dybowskii</i>	-2.5 to -2.2
<i>Chromulina minor</i>	-1.6 to -1.5	<i>Monoraphidium komarkovae</i>	-0.7 to 0
<i>Chromulina nebulosa</i>	-2.3 to -2	<i>Monoraphidium minutum</i>	-1.4 to -1
<i>Chromulina parvula</i>	-1.6 to -1.5	<i>Monosiga ovata</i>	-1.3 to -0.2
<i>Chrysochromulina parva</i>	-2.5 to -2	<i>Mougeotia parvula</i>	-1.6 to -1.5
<i>Chrysooccus rufescens</i>	-2.3 to -2	<i>Mucidosphaerium pulchellum</i>	-1.8 to 1.1
<i>Coelastrum astroideum</i>	-1.4 to 1.2	<i>Mychonastes minusculus</i>	-2.3 to -2
<i>Coelastrum microporum</i>	-1.8 to 1.2	<i>Nitella flexilis</i>	-1.8 to -1.6
<i>Cosmocladium constrictum</i>	-2.2 to -2	<i>Nitella mucronata</i>	-1.5 to -1.3
<i>Crucigenia tetrapedia</i>	-1.7 to 1.2	<i>Nitelopsis obtusa</i>	-1.6 to -0.7
<i>Crucigeniella apiculata</i>	-1 to 1.2	<i>Ochromonas elegans</i>	-1.6 to -1.5
<i>Crucigeniella rectangularis</i>	-1.6 to -1	<i>Ochromonas minuscula</i>	-1.6 to -1.5
<i>Cryptomonas curvata</i>	-2.2 to 0.9	<i>Ochromonas ovalis</i>	-1.6 to -1.5
<i>Cryptomonas erosa</i>	-2.7 to 1.2	<i>Ochromonas verrucosa</i>	-1.6 to -1.5
<i>Cryptomonas gracilis</i>	-2.5 to -2	<i>Oocystidium ovale</i>	-2.3 to -2
<i>Cryptomonas marssonii</i>	-2.7 to 1.2	<i>Oocystis lacustris</i>	-2.3 to 0.5
<i>Cryptomonas ovata</i>	-2 to -0.2	<i>Oocystis parva</i>	-2.3 to -1
<i>Dactylococcopsis fascicularis</i>	-1.6 to -1.5	<i>Oocystis pusilla</i>	-1.6 to -1.5
<i>Desmodesmus intermedius</i>	-0.5 to 0.9	<i>Ophiocytium capitatum</i>	-1.6 to -1.5
<i>Desmodesmus opoliensis</i>	-0.7 to 0	<i>Ophiocytium cochleare</i>	-1.6 to -1.5
<i>Dinobryon bavaricum</i>	-1.7 to 1.2	<i>Ophiocytium parvulum</i>	-1.6 to -1.5
<i>Dinobryon cylindricum</i>	-2.5 to -2	<i>Pandorina morum</i>	-1.3 to 0
<i>Dinobryon sertularia</i>	-1.6 to -0.2	<i>Pediastrum biwae</i>	-2.2 to -2
<i>Dinobryon stipitatum</i>	-1.8 to -1.6	<i>Pediastrum duplex</i>	-1.8 to 1.2
<i>Elakatothrix gelatinosa</i>	-2.3 to -0.2	<i>Pedinomonas minor</i>	-1.6 to 1.2
<i>Eudorina elegans</i>	-2.2 to -0.2	<i>Phacotus lenticularis</i>	-1.2 to 1.2
<i>Gonium pectorale</i>	-1.3 to -0.6	<i>Plagioselmis lacustris</i>	-0.8 to 0.5
<i>Hariotina reticulata</i>	-1.6 to 1.2	<i>Plagioselmis nannoplanctica</i>	-2.2 to -1.2
<i>Katablepharis ovalis</i>	-2.3 to -2	<i>Planctonema lauterbornii</i>	-1.6 to 0.2

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Planktosphaeria gelatinosa</i>	-1.6 to -1	<i>Campylomonas marssonii</i>	-2.3 to -1
<i>Pseudokephyron entzii</i>	-2.3 to -2	<i>Chara longifolia</i>	0.9 to 1.5
<i>Pseudopediastrum boryanum</i>	-1.8 to 1.2	<i>Chlorella vulgaris</i>	1 to 1.5
<i>Pteromonas angulosa</i>	-0.4 to 0.2	<i>Cladophora glomerata</i>	1 to 1.5
<i>Rhodomonas lacustris</i>	-1.6 to -0.7	<i>Coelastrum pulchrum</i>	-0.2 to -0.1
<i>Rhodomonas lacustris</i> var. <i>nannoplanctica</i>	-2.5 to 1.2	<i>Cryptomonas brasiliensis</i>	-2.3 to -1
<i>Rusalka fusiformis</i>	-2.7 to -2.2	<i>Cryptomonas marssonii</i>	-2.5 to -1.9
<i>Scenedesmus abundans</i>	-1.4 to -1	<i>Elakatothrix gelatinosa</i>	1.1 to 1.2
<i>Scenedesmus arcuatus</i>	-0.7 to 0	<i>Hindakia tetrachotoma</i>	-2.3 to -1
<i>Scenedesmus ecornis</i>	-1.4 to 1.1	<i>Hydrodictyon reticulatum</i>	0.9 to 1.2
<i>Scenedesmus ellipticus</i>	-1.4 to 0.2	<i>Korshikoviella</i> <i>michailovskoensis</i>	1 to 1.2
<i>Scenedesmus longispina</i>	-1.6 to 1.2	<i>Microspora aequabilis</i>	0.9 to 1.2
<i>Scenedesmus magnus</i>	-1.4 to -1	<i>Monactinus simplex</i>	1 to 1.5
<i>Scenedesmus obliquus</i>	-1.1 to 1.2	<i>Monoraphidium arcuatum</i>	-2.5 to -1.9
<i>Scenedesmus quadricauda</i>	-1.8 to 1.1	<i>Monoraphidium griffithii</i>	-2.5 to -1.9
<i>Scenedesmus smithii</i>	-1.4 to 1.1	<i>Monoraphidium tortile</i>	-2.5 to -1.9
<i>Schroederia setigera</i>	-1.4 to 1.1	<i>Mougeotia scalaris</i>	0.9 to 1.2
<i>Siderocystopsis punctifera</i>	-1.4 to -1	<i>Mucidosphaerium pulchellum</i>	-2.5 to -1.9
<i>Sphaerocystis schroeteri</i>	-2.2 to 1.2	<i>Mychonastes elegans</i>	-2.3 to -1
<i>Sphaeroeca volvox</i>	-1.3 to -0.6	<i>Nephrocytium lunatum</i>	-0.2 to -0.1
<i>Synura echinulata</i>	-2.7 to -2	<i>Nitella opaca</i>	0.9 to 1.5
<i>Synura uvella</i>	-1.3 to -0.2	<i>Pandorina morum</i>	-0.2 to -0.1
<i>Tetrachlorella alternans</i>	-1.6 to -1	<i>Pannus microcystiformis</i>	-2.3 to -0.7
<i>Tetrachlorella incerta</i>	-2.3 to -2	<i>Pediastrum leonensis</i>	0.9 to 1.5
<i>Tetraedron minimum</i>	-2.5 to 1.2	<i>Scenedesmus annatus</i>	1.1 to 1.5
<i>Tetraedron triangulare</i>	-0.6 to 0.9	<i>Scenedesmus ecornis</i>	-2.5 to -1.9
<i>Tetrastrum staurogeniiforme</i>	-1.4 to 0.9	<i>Scenedesmus quadricauda</i>	-0.2 to -0.1
<i>Tetrastrum triangulare</i>	-0.6 to 1.2	<i>Spirogyra maxima</i>	0.9 to 1.5
<i>Trepomonas agilis</i>	-1.3 to -0.2	<i>Spirotaenia condensata</i>	1 to 1.2
<i>Tribonema affine</i>	-1.6 to -1.5	<i>Ulothrix lamellosa</i>	1.1 to 1.5
<i>Ulothrix aequalis</i>	-1.8 to -1.6	<i>Uronema acutum</i>	0.9 to 1.1
<i>Uroglenopsis americana</i>	-1.4 to -0.7	<i>Zygnema coeruleum</i>	1 to 1.5
<i>Willea wilhelmii</i>	-1.4 to -0.7		
(Sub)tropical		(f) Silicon-based algae	
<i>Actinastrum aciculare</i>	1 to 1.2	Cold	
<i>Ankistrodesmus falcatus</i>	1 to 1.4	<i>Achnanthes acares</i>	-2.5 to -2.3
		<i>Achnanthes didyma</i>	-2.5 to -1.1

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Achnanthes germainii</i>	-2.7 to 0.5	<i>Fragilaria capucina</i>	-2.7 to 0.5
<i>Achnanthes impexa</i>	-2.5 to -2	<i>Fragilaria tenera</i>	-2.5 to -1.5
<i>Achnanthes kriegeri</i>	-2.7 to -2.3	<i>Fragilaria crotonensis</i>	-2.5 to -1.2
<i>Achnanthes minutissima</i>	-2.5 to -2	<i>Fragilariforma neoproducta</i>	-2.3 to -2.2
<i>Achnanthes suchlandtii</i>	-2.5 to -1.4	<i>Fragilariforma virescens</i>	-2.5 to -1.9
<i>Achnantheidium biasolettianum</i>	-2.7 to 0.5	<i>Frustulia crassinervia</i>	-2.7 to -2
<i>Achnantheidium coarctatum</i>	-2.7 to -1.2	<i>Frustulia saxonica</i>	-2.7 to -2.3
<i>Achnantheidium minutissimum</i>	-2.5 to -1.1	<i>Gomphonema affine</i>	-1.8 to -0.9
<i>Amphora duseni</i>	-2.7 to -0.9	<i>Gomphonema clavatum</i>	-2.7 to 0.5
<i>Amphora pediculus</i>	-2.4 to -1.1	<i>Gomphonema gracile</i>	-1.8 to -1
<i>Asterionella formosa</i>	-2.5 to -1.5	<i>Gomphonema olivaceum</i>	-2.7 to -0.9
<i>Aulacoseira alpigena</i>	-2.7 to -1.9	<i>Gomphonema parvulum</i>	-1.8 to -0.9
<i>Aulacoseira lirata</i>	-2.7 to -2	<i>Hannaea arcus</i>	-2.5 to -1.2
<i>Caloneis bacillum</i>	-1.7 to -0.9	<i>Hantzschia amphioxys</i>	-2.7 to -0.4
<i>Cavinula pseudoscutiformis</i>	-2.5 to -2	<i>Hippodonta capitata</i>	-2 to -0.5
<i>Closterium acutum</i>	-2 to -1.1	<i>Hygropetra balfouriana</i>	-2.5 to -1.9
<i>Cosmarium laeve</i>	-2.3 to -1.1	<i>Luticola mutica</i>	-1.7 to -0.4
<i>Cosmarium margaritififerum</i>	-2 to -1.1	<i>Luticola muticopsis</i>	-2.7 to 0.5
<i>Cosmarium rectangulare</i>	-2.4 to -2	<i>Melosira italica</i>	-2.5 to -1.2
<i>Craticula halophila</i>	-1.8 to -0.4	<i>Navicula cincta</i>	-2 to -0.9
<i>Craticula molesta</i>	-2.7 to -2.3	<i>Navicula digitulus</i>	-2.5 to -2
<i>Craticula molestiformis</i>	-0.9 to -0.4	<i>Navicula elginensis</i>	-2.7 to -0.4
<i>Cyclotella comensis</i>	-2.5 to -2.1	<i>Navicula pseudosilicula</i>	-2 to -1.5
<i>Cyclotella meneghiniana</i>	-1.5 to -0.9	<i>Navicula schmassmannii</i>	-2.5 to -2
<i>Cyclotella pseudostelligera</i>	-2.5 to -1.1	<i>Neidium binodis</i>	-2.5 to -1.1
<i>Diademsis contenta</i>	-2.2 to -0.4	<i>Nitzschia acicularis</i>	-2.5 to -1.4
<i>Diatoma tenue</i>	-2.5 to -1.5	<i>Nitzschia capitellata</i>	-2.2 to 0.5
<i>Encyonema lange-bertalotii</i>	-2.7 to -1.9	<i>Nitzschia dissipata</i>	-2.5 to -1.2
<i>Encyonema silesiacum</i>	-2.5 to -1.1	<i>Nitzschia fonticola</i>	-2.4 to -1.1
<i>Eolimna minima</i>	-2.5 to -1.1	<i>Nitzschia inconspicua</i>	-2.7 to -0.4
<i>Eucocconeis quadratarea</i>	-2.7 to -0.2	<i>Nitzschia palea</i>	-2.7 to 0.5
<i>Eunotia bilunaris</i>	-2.5 to -2.3	<i>Nitzschia perminuta</i>	-2.7 to -1.9
<i>Eunotia exigua</i>	-2.5 to -2.3	<i>Orthoseira roeseana</i>	-2.7 to 0.5
<i>Eunotia glacialis</i>	-2.5 to -2.3	<i>Pinnularia biceps</i>	-2.7 to -2.3
<i>Eunotia meisteri</i>	-2.7 to -2.3	<i>Pinnularia borealis</i>	-2.7 to 0.5
<i>Eunotia muscicola</i>	-2.7 to -2.5	<i>Pinnularia krookii</i>	-2.2 to 0.5
<i>Eunotia praerupta</i>	-2.5 to -2	<i>Pinnularia maior</i>	-1.4 to -1.2

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Pinnularia mesolepta</i>	-2.7 to -2	<i>Aulacoseira alpigena</i>	-2.2 to -0.8
<i>Pinnularia microstauron</i>	-2.7 to 0.5	<i>Aulacoseira ambigua</i>	-2.7 to 1.6
<i>Pinnularia schoenfelderi</i>	-1.5 to 0.5	<i>Aulacoseira crenulata</i>	-2.7 to -1.7
<i>Planothidium delicatulum</i>	-2.7 to 0.5	<i>Aulacoseira distans</i>	-3 to 1.6
<i>Planothidium lanceolatum</i>	-2.7 to 0.5	<i>Aulacoseira granulata</i>	-2.2 to 1.1
<i>Psammothidium curtissimum</i>	-2.7 to -1.9	<i>Aulacoseira granulata</i> var. <i>angustissima</i>	-2.7 to -1
<i>Psammothidium helveticum</i>	-2.7 to -1.9	<i>Aulacoseira humilis</i>	-2.3 to -1.5
<i>Psammothidium lacusvulcani</i>	-2.5 to -1.1	<i>Aulacoseira islandica</i>	-2 to -0.7
<i>Psammothidium levanderi</i>	-2.7 to -2	<i>Aulacoseira italica</i>	-2.7 to 1.2
<i>Psammothidium marginulatum</i>	-2.7 to -2	<i>Aulacoseira lacustris</i>	-3 to -2
<i>Psammothidium subatomoides</i>	-2.7 to 0.5	<i>Aulacoseira lirata</i>	-2.3 to -1.5
<i>Pseudostaurosira brevistriata</i>	-2.5 to -1.1	<i>Aulacoseira nivalis</i>	-2.3 to -1.5
<i>Pseudostaurosira brevistriata</i> var. <i>inflata</i>	-2.3 to -1.1	<i>Aulacoseira perglabra</i>	-3 to 1.3
<i>Pseudostaurosira elliptica</i>	-2 to -1.8	<i>Aulacoseira paffiana</i>	-2.2 to -1.6
<i>Pseudostaurosira parasitica</i>	-2.5 to -1.1	<i>Aulacoseira subborealis</i>	-2.7 to -1
<i>Rhopalodia gibba</i>	-2.5 to -1.1	<i>Aulacoseira valida</i>	-2.2 to -1.6
<i>Rossithidium pusillum</i>	-2.5 to -1.2	<i>Aulacoseira voya</i>	-1.9 to -1.8
<i>Sellaphora bacillum</i>	-1.7 to -1.5	<i>Bacillaria paxillifera</i>	-2.2 to -0.5
<i>Sellaphora seminulum</i>	-2 to -1.9	<i>Brachysira brachysira</i>	-2.7 to -1
<i>Stauroneis anceps</i>	-2.7 to 0.5	<i>Brachysira neoexilis</i>	-2.7 to -1.5
<i>Stauroneis neohyalina</i>	-2.7 to -2	<i>Brachysira styriaca</i>	-2.7 to -1
<i>Staurosira construens</i>	-2.7 to -0.9	<i>Brachysira vitrea</i>	-2.7 to -1
<i>Staurosira construens</i> var. <i>exigua</i>	-2.5 to -1.1	<i>Caloneis silicula</i>	-2.2 to -1.5
<i>Staurosira venter</i>	-2.5 to -1.1	<i>Closterium aciculare</i>	-2.2 to -1
<i>Staurosirella lapponica</i>	-2.5 to -1.1	<i>Closterium acutum</i>	-1.6 to 1.2
<i>Staurosirella pinnata</i>	-2.5 to -1.1	<i>Closterium limneticum</i>	-1.4 to -1
<i>Tabellaria flocculosa</i>	-2.7 to -1.2	<i>Cocconeis neodiminuta</i>	-1.9 to -1.2
Temperate		<i>Cocconeis placentula</i>	-2.7 to 0
<i>Achnanthes saccula</i>	-2.7 to 1.3	<i>Cocconeis placentula</i> var. <i>euglypta</i>	-1.4 to -1.2
<i>Achnantheidium minutissimum</i>	-3 to 1.6	<i>Cosmarium asphaerosporum</i>	-2.3 to -2
<i>Actinella parva</i>	-2.7 to -1	<i>Cosmarium phaseolus</i>	-1.6 to -1.2
<i>Adlafia bryophila</i>	-2.7 to -1	<i>Ctenophora pulchella</i>	-0.7 to 0
<i>Amphora libyca</i>	-2.7 to -1.2	<i>Cyclostephanos dubius</i>	-2.7 to 0.9
<i>Amphora pediculus</i>	-2.2 to 1.3	<i>Cyclostephanos invisitatus</i>	-2.7 to -1
<i>Asterionella formosa</i>	-2.7 to 1.6	<i>Cyclostephanos tholiformis</i>	-2.7 to -0.8
<i>Asterionella ralfsii</i>	-2.7 to -1.5	<i>Cyclotella atomus</i>	-1.9 to 0.9
		<i>Cyclotella bodanica</i>	-3 to 1.3

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Cyclotella comensis</i>	-2.7 to -0.6	<i>Encyonopsis cesatii</i>	-2.2 to -2.1
<i>Cyclotella comta</i>	-2.2 to -0.4	<i>Encyonopsis microcephala</i>	-2.7 to 0.7
<i>Cyclotella cyclopuncta</i>	-2.7 to -0.8	<i>Eolimna minima</i>	-2.7 to 1.5
<i>Cyclotella distinguenda</i>	-2.7 to -0.8	<i>Epithemia adnata</i>	-1.6 to -0.8
<i>Cyclotella gordonensis</i>	-2.7 to -0.8	<i>Epithemia sorex</i>	-2.7 to -1
<i>Cyclotella meneghiniana</i>	-2.7 to 0.9	<i>Eunotia arculus</i>	-2.3 to -1.5
<i>Cyclotella michiganiana</i>	-2.7 to 1.1	<i>Eunotia bilunaris</i>	-2.7 to -1.5
<i>Cyclotella ocellata</i>	-2.4 to 1.2	<i>Eunotia exigua</i>	-2.1 to -2
<i>Cyclotella planctonica</i>	-2.7 to -1.2	<i>Eunotia flexuosa</i>	-2.7 to -1.5
<i>Cyclotella pseudostelligera</i>	-2.7 to 1.6	<i>Eunotia incisa</i>	-2.7 to -1
<i>Cyclotella radiosa</i>	-2.7 to -0.9	<i>Eunotia mucophila</i>	-3 to -2
<i>Cyclotella stelligeroides</i>	-2.3 to -1.7	<i>Eunotia naegelii</i>	-2.7 to -1
<i>Cyclotella styriaca</i>	-2.4 to -2.3	<i>Eunotia pectinalis</i>	-2.7 to -0.8
<i>Cyclotella tasmanica</i>	-2.7 to -1	<i>Fragilaria capucina</i>	-2.7 to 0
<i>Cyclotella tripartita</i>	-2.2 to -1.1	<i>Fragilaria capucina subsp. Rumpens</i>	-2.7 to -1
<i>Cyclotella wuethrichiana</i>	-2.2 to -1.8	<i>Fragilaria capucina var. vaucheriae</i>	-2.7 to -1
<i>Cylindrotheca closterium</i>	-1.4 to -1	<i>Fragilaria crotonensis</i>	-2.7 to 1.1
<i>Cymbella affinis</i>	-2 to -1.2	<i>Fragilaria nanana</i>	-2.7 to -1
<i>Cymbella cistula</i>	-2.7 to -1	<i>Fragilaria pseudoconstruens</i>	-2.2 to -1.9
<i>Cymbella hebridica</i>	-3 to -2	<i>Fragilaria radians</i>	-1.6 to -1.5
<i>Cymbella helvetica</i>	-2.2 to -1.5	<i>Fragilaria rhomboides</i>	-2.3 to -1.5
<i>Delicata delicatula</i>	-2.2 to -1.7	<i>Fragilaria tenera</i>	-2.7 to -1
<i>Denticula tenuis</i>	-2.1 to -1.7	<i>Fragilariforma exigua</i>	-2.7 to -1
<i>Diademsis contenta</i>	-2.7 to -1	<i>Fragilariforma virescens</i>	-3 to 1.6
<i>Diatoma hyemalis</i>	-2.2 to -1.5	<i>Frustulia rhomboides</i>	-3 to -1
<i>Diatoma mesodon</i>	-2.7 to -1	<i>Frustulia vulgaris</i>	-2.7 to -1
<i>Diatoma tenuis</i>	-2.7 to -0.5	<i>Gomphonema angustatum</i>	-2.7 to -1
<i>Diatoma vulgare</i>	-0.8 to 0	<i>Gomphonema clavatum</i>	-2.7 to -1
<i>Diatomella balfouriana</i>	-2.7 to -1	<i>Gomphonema gracile</i>	-2 to -1.6
<i>Diploneis ovalis</i>	-2.2 to -1.5	<i>Gomphonema lagenula</i>	-2.7 to -1
<i>Discostella glomerata</i>	-2.1 to -1.7	<i>Gomphonema parvulum</i>	-2.7 to -1
<i>Discostella stelligera</i>	-2.7 to 0.9	<i>Gomphonema pumilum</i>	-2.7 to -1
<i>Encyonema gaeumannii</i>	-3 to -2	<i>Gomphonema truncatum</i>	-2.2 to -1.5
<i>Encyonema gracile</i>	-2.7 to -1	<i>Gyrosigma acuminatum</i>	-1.4 to -0.8
<i>Encyonema mesianum</i>	-2.7 to -1	<i>Hantzschia amphioxys</i>	-0.6 to -0.5
<i>Encyonema minutum</i>	-2.7 to -1	<i>Karayevia clevei</i>	-2.7 to -1
<i>Encyonema silesiacum</i>	-3 to -1	<i>Karayevia oblongella</i>	-2.7 to -1

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Martyana martyi</i>	-2.7 to -1	<i>Nitzschia perminuta</i>	-2.7 to -1
<i>Mastogloia smithii</i>	-2.7 to -1	<i>Nitzschia pura</i>	-2.7 to -1.7
<i>Mayamaea agrestis</i>	-1.6 to 1.5	<i>Nitzschia recta</i>	-2.7 to -1
<i>Melosira ambigua</i>	-1.4 to 1.1	<i>Nitzschia sigma</i>	-1.6 to -1
<i>Melosira italica</i>	-2.7 to 1.6	<i>Nitzschia subacicularis</i>	-2.7 to -1
<i>Melosira solida</i>	-2.2 to -2	<i>Nitzschia tropica</i>	-2.7 to -1
<i>Melosira varians</i>	-2.2 to -2	<i>Pinnularia appendiculata</i>	-2.2 to -2.1
<i>Meridion circulare</i>	-3 to -1.5	<i>Pinnularia maior</i>	-2.2 to -1.5
<i>Navicula capitatoradiata</i>	-2.7 to -1	<i>Pinnularia microcephala</i>	-2.3 to -1.5
<i>Navicula cryptocephala</i>	-3 to 1.5	<i>Pinnularia microstauron</i>	-3 to -2
<i>Navicula cryptotenella</i>	-2.7 to -1	<i>Pinnularia subrostrata</i>	-1.4 to -1.2
<i>Navicula gottlandica</i>	-2.7 to -1	<i>Pinnularia sudetica</i>	-2.2 to -1.5
<i>Navicula gregaria</i>	-2.7 to -1	<i>Planothidium frequentissimum</i>	-2.7 to -1
<i>Navicula heimansioides</i>	-2.7 to -1	<i>Planothidium hauckianum</i>	-2.1 to -1.6
<i>Navicula notha</i>	-2.7 to -1	<i>Planothidium lanceolatum</i>	-2.7 to 1.1
<i>Navicula obsoleta</i>	-2.7 to -1	<i>Planothidium lemmermannii</i>	-1.9 to -1.7
<i>Navicula radiosa</i>	-2.7 to -0.5	<i>Psammothidium levanderi</i>	-2.7 to -1
<i>Navicula rhynchocephala</i>	-2.7 to 0	<i>Psammothidium subatomoides</i>	-2.7 to -1
<i>Navicula seminuloides</i>	1.1 to 1.5	<i>Pseudostaurosira brevistriata</i>	-3 to 1.3
<i>Navicula submuralis</i>	-1.9 to 1.3	<i>Pseudostaurosira brevistriata</i> <i>var. inflata</i>	-2.7 to -1
<i>Navicula subtilissima</i>	-3 to -1	<i>Pseudostaurosira elliptica</i>	-2.7 to -1
<i>Navicula trivialis</i>	-2.2 to -1.5	<i>Pseudostaurosira parasitica</i>	-2.7 to -1
<i>Navicula veneta</i>	-2.7 to -1	<i>Puncticulata bodanica</i>	-1.5 to -0.9
<i>Navicula viridula</i>	-1.4 to -1.2	<i>Rhizosolenia longiseta</i>	-1.4 to -0.7
<i>Nitzschia acicularis</i>	-2.7 to 0.9	<i>Rhoicosphenia abbreviata</i>	-2.7 to -1
<i>Nitzschia acidoclinata</i>	-2.7 to -1	<i>Rhopalodia gibba</i>	-1.8 to -1.2
<i>Nitzschia agnita</i>	-1.4 to -0.8	<i>Rhopalodia novae-zelandiae</i>	-2.7 to -1
<i>Nitzschia amphibia</i>	-2.7 to -1	<i>Rossithidium pusillum</i>	-2.7 to -1
<i>Nitzschia fonticola</i>	0.7 to 1.6	<i>Sellaphora pupula</i>	-2.7 to 1.6
<i>Nitzschia graciliformis</i>	-2.3 to -1.5	<i>Sellaphora seminulum</i>	-2.7 to 1.5
<i>Nitzschia gracilis</i>	-3 to -1	<i>Spondylosium moniliforme</i>	-2.2 to -2
<i>Nitzschia inconspicua</i>	-2.7 to -1	<i>Spondylosium planum</i>	-0.7 to -0.1
<i>Nitzschia lacuum</i>	-2 to -1.7	<i>Staurastrum arctiscon</i>	-2.2 to -2
<i>Nitzschia liebetruthii</i>	-2.7 to -1	<i>Staurastrum dorsidentiferum</i>	-2.2 to -2
<i>Nitzschia linearis</i>	-2.7 to -1	<i>Staurastrum limneticum</i>	-2.2 to -2
<i>Nitzschia palea</i>	-2.7 to 1.2	<i>Staurastrum manfeldtii</i>	-1.1 to 1.2
<i>Nitzschia paleacea</i>	-1.4 to -0.9	<i>Staurastrum sebalzii</i>	-0.7 to 0

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Staurastrum tetracerum</i>	-1.4 to -1	<i>Amphora inariensis</i>	-2 to -1.2
<i>Staurodesmus incus</i>	-2.5 to -2	<i>Amphora libyca</i>	-2 to 0.1
<i>Staurodesmus megacanthus</i>	-2.1 to -2	<i>Amphora perpusilla</i>	-2 to 0.1
<i>Stauroneis anceps</i>	-2.3 to -1.5	<i>Anomoeoneis sphaerophora</i>	-2 to 0.1
<i>Staurosira construens</i>	-2.7 to 1.6	<i>Caloneis bacillum</i>	-1.7 to 0.1
<i>Staurosira construens f. venter</i>	-2.7 to -1	<i>Cocconeis placentula</i>	-2 to 0.1
<i>Staurosira construens var. binodis</i>	-2.7 to -1	<i>Cocconeis placentula var. baikalensis</i>	-1.5 to 0.1
<i>Staurosira construens var. exigua</i>	-2.3 to -1.5	<i>Cocconeis placentula var. euglypta</i>	-2 to 0.1
<i>Staurosirella construens</i>	-1.4 to 1.3	<i>Cyclotella ocellata</i>	-2 to -0.4
<i>Staurosirella leptostauron</i>	-2.7 to -1	<i>Cyclotella radiosa</i>	-2 to 0.1
<i>Staurosirella pinnata</i>	-3 to 1.3	<i>Cymbella neoleptoceros</i>	-1.6 to -0.4
<i>Stephanodiscus alpinus</i>	-2.7 to -0.9	<i>Denticula kuetzingii</i>	-2 to -0.4
<i>Stephanodiscus carconensis</i>	-2.2 to -2	<i>Encyonema minutum</i>	-1.6 to 0.1
<i>Stephanodiscus complex</i>	-2.7 to -1.6	<i>Encyonopsis cesatii</i>	-1.6 to -0.4
<i>Stephanodiscus hantzschii</i>	-2.2 to 1.3	<i>Fragilaria capucina</i>	-1.7 to -0.4
<i>Stephanodiscus medius</i>	-2.2 to -0.9	<i>Fragilaria tenera</i>	-2 to 0.1
<i>Stephanodiscus minutulus</i>	-2.3 to 1.3	<i>Fragilariforma virescens</i>	-1.5 to 0.1
<i>Stephanodiscus neoastraea</i>	-2 to -0.9	<i>Gyrosigma acuminatum</i>	-1.8 to -1.5
<i>Stephanodiscus niagarae</i>	-2.2 to 1.6	<i>Halamphora thumensis</i>	-2 to -0.4
<i>Stephanodiscus parvus</i>	-2.7 to -0.7	<i>Hippodonta capitata</i>	-1.6 to 0.1
<i>Surirella linearis var. constricta</i>	-2.7 to -1	<i>Hippodonta hungarica</i>	-1.7 to -0.4
<i>Synedra nana</i>	-2.7 to -1.6	<i>Martyana martyi</i>	-1.5 to 0.1
<i>Synedra ulna</i>	-2.7 to -0.1	<i>Navicula cryptocephala</i>	-1.5 to 0.1
<i>Synedra utermohlii</i>	-0.7 to 0	<i>Navicula cryptotenella</i>	-2 to 0.1
<i>Tabellaria fenestrata</i>	-3 to 1.2	<i>Navicula eidrigiana</i>	-1.7 to -0.4
<i>Tabellaria flocculosa</i>	-3 to 1.2	<i>Navicula upsaliensis</i>	-1.7 to 0.1
<i>Thalassiosira pseudonana</i>	-0.5 to 0.2	<i>Navicula veneta</i>	-1.7 to 0.1
<i>Ulnaria acus</i>	-2.7 to 1.2	<i>Nitzschia bacillum</i>	-2 to 0.1
<i>Ulnaria delicatissima</i>	-2.3 to -0.9	<i>Nitzschia frustulum</i>	-1.7 to 0.1
<i>Ulnaria ulna</i>	-2.2 to 1.6	<i>Nitzschia lacuum</i>	-2 to 0.1
<i>Urosolenia eriensis</i>	-2.7 to 0.9	<i>Nitzschia palea</i>	-1.6 to -0.4
<i>Xanthidium antilopaeum</i>	-2.2 to -2	<i>Nitzschia sublinearis</i>	-1.6 to -0.4
<i>Xanthidium hastiferum</i>	-2.2 to -2	<i>Parlibellus cruciculus</i>	-1.6 to 0.1
		<i>Planothidium lanceolatum</i>	-1.7 to -0.4
Xeric		<i>Pseudostaurosira elliptica</i>	-2 to 0.1
<i>Achnanthes exigua</i>	-2 to -0.7	<i>Pseudostaurosira pseudoconstruens</i>	-2 to -0.8
<i>Achnanthes saccula</i>	-2 to -0.4	<i>Rhoicosphenia abbreviata</i>	-2 to 0.1

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Stauroneis obtusa</i>	-2 to -0.7	(g) Cyanobacteria in streams	
<i>Staurosira brevistriata</i>	-2 to -0.8	Temperate	
<i>Staurosira construens</i>	-2 to 0.1	<i>Chroococcus dispersus</i>	-1.2 to -0.9
<i>Staurosira construens f. venter</i>	-2 to -1.2	<i>Dolichospermum flosaquae</i>	-1.2 to -0.2
<i>Staurosirella leptostauron</i>	-2 to 0.1	<i>Jaaginema angustissimum</i>	-1.2 to -0.2
<i>Staurosirella pinnata</i>	-2 to -0.8	<i>Leptolyngbya tenuis</i>	0 to 0.2
<i>Stephanodiscus minutulus</i>	-2 to -0.8	<i>Limnococcus limneticus</i>	-0.7 to -0.1
<i>Surirella peisonis</i>	-1.6 to 0.1	<i>Microcystis aeruginosa</i>	-1.2 to -0.4
<i>Tryblionella apiculata</i>	-2 to 0.1	<i>Microcystis ichthyoblabe</i>	-1.1 to -0.2
		<i>Microcystis pulvereae</i>	-1.2 to -0.4
(Sub)tropical		<i>Oscillatoria limosa</i>	-1.2 to -0.3
<i>Achnanthydium minutissimum</i>	-0.2 to 0.9	(Sub)tropical	
<i>Asterionella formosa</i>	0.9 to 1.1	<i>Anabaena solitaria</i>	-1.8 to -1.2
<i>Aulacoseira ambigua</i>	-2.5 to -1.9	<i>Aphanocapsa delicatissima</i>	-1.3 to -0.7
<i>Aulacoseira distans</i>	-2.5 to -1.9	<i>Aphanocapsa holsatica</i>	-1.3 to -1
<i>Aulacoseira granulata</i>	-2.5 to 0.9	<i>Aphanothece stagnina</i>	-1.2 to -0.8
<i>Closterium acerosum</i>	1.3 to 1.5	<i>Calothrix epiphytica</i>	-1.3 to -0.8
<i>Closterium acutum</i>	-2.3 to -1	<i>Calothrix stagnalis</i>	-1.3 to -1
<i>Closterium depressum</i>	1.2 to 1.5	<i>Chroococcus minutus</i>	-1.3 to -0.7
<i>Closterium dianaee</i>	1.2 to 1.5	<i>Chroococcus turgidus</i>	-3 to -0.7
<i>Closterium lineatum</i>	1.2 to 1.5	<i>Coelosphaerium kuetzingianum</i>	-1.3 to -1
<i>Closterium sphaerosporum</i>	1 to 1.5	<i>Cylindrospermopsis raciborskii</i>	-1.8 to -1.2
<i>Cocconeis neodiminuta</i>	1 to 1.2	<i>Dolichospermum affine</i>	-1.8 to -1.2
<i>Diatoma vulgare</i>	0.9 to 1.5	<i>Dolichospermum spiroides</i>	-1.8 to -1.2
<i>Fragilaria capucina</i>	0.1 to 0.9	<i>Geitlerinema splendidum</i>	-3 to -1
<i>Fragilariopsis oceanica</i>	0.9 to 1.5	<i>Leptochaete stagnalis</i>	-1.3 to -0.8
<i>Frustulia rhomboides</i>	0.9 to 1.5	<i>Leptolyngbya boryana</i>	-1.3 to -1
<i>Gomphonema acuminatum</i>	0.9 to 1.2	<i>Leptolyngbya lagerheimii</i>	-1.2 to -0.8
<i>Meuniera membranacea</i>	0.9 to 1.5	<i>Leptolyngbya subtilis</i>	-1.3 to -0.8
<i>Nitzschia bilobata</i>	1 to 1.5	<i>Leptolyngbya tenuis</i>	-1.3 to -0.8
<i>Nitzschia palea</i>	-2.5 to -1.9	<i>Limnococcus limneticus</i>	-3 to -0.7
<i>Pinnularia viridis</i>	0.9 to 1.2	<i>Lyngbya birgei</i>	-1.2 to -0.8
<i>Tabellaria fenestrata</i>	1 to 1.5	<i>Lyngbya major</i>	-3 to -1
<i>Ulnaria capitata</i>	0.9 to 1	<i>Lyngbya martensiana</i>	-1.8 to -1.2
<i>Urosolenia eriensis</i>	-2.5 to -1.9	<i>Merismopedia elegans</i>	-1.3 to -0.8
<i>Urosolenia longiseta</i>	-2.5 to -1.9	<i>Merismopedia glauca</i>	-1.8 to -1.2

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Merismopedia tenuissima</i>	-1.8 to -0.8	<i>Etheostoma nigrum</i>	-1.4 to 0.5
<i>Microcystis aeruginosa</i>	-1.8 to -0.7	<i>Etheostoma olmstedii</i>	-1 to -0.6
<i>Microcystis protocystis</i>	-3 to -1	<i>Etheostoma simoterum</i>	-1.2 to -0.4
<i>Oscillatoria anguina</i>	-1.3 to -1	<i>Etheostoma spectabile</i>	-1.4 to 0.5
<i>Oscillatoria sancta</i>	-1.8 to -1.2	<i>Gambusia affinis</i>	-1.4 to 0.5
<i>Phormidium willei</i>	-3 to -1	<i>Hypentelium nigricans</i>	-1.4 to 0.5
<i>Planktolynghya contorta</i>	-1.3 to -0.8	<i>Ictalurus punctatus</i>	-1.4 to 0.5
<i>Planktolynghya limnetica</i>	-1.8 to -1	<i>Lepomis auritus</i>	-1.2 to -0.4
<i>Pseudanabaena galeata</i>	-1.3 to -0.7	<i>Lepomis cyanellus</i>	-1.4 to 0.5
<i>Pseudanabaena limnetica</i>	-1.2 to -0.8	<i>Lepomis gibbosus</i>	-1.4 to 0.5
<i>Pseudanabaena mucicola</i>	-3 to -1	<i>Lepomis macrochirus</i>	-1.4 to 0.5
<i>Raphidiopsis mediterranea</i>	-1.8 to -1.2	<i>Lepomis megalotis</i>	-1.4 to 0.5
<i>Snowella lacustris</i>	-1.3 to -1	<i>Lepomis microlophus</i>	-1.4 to 0.5
(h) Fish in streams		<i>Luxilus chrysocephalus</i>	-1.4 to 0.5
Cold		<i>Luxilus cornutus</i>	-1.4 to 0.5
<i>Salmo trutta</i>	-2 to -1.4	<i>Micropterus salmoides</i>	-1.4 to 0.5
Temperate		<i>Nocomis biguttatus</i>	-1.4 to 0.5
<i>Ambloplites rupestris</i>	-1.2 to -0.4	<i>Nocomis leptocephalus</i>	-1 to -0.6
<i>Ameiurus melas</i>	-1.4 to 0.5	<i>Notemigonus crysoleucas</i>	-1.4 to 0.5
<i>Ameiurus natalis</i>	-1.4 to 0.5	<i>Notropis albeolus</i>	-1 to -0.6
<i>Anguilla rostrata</i>	-1 to -0.6	<i>Notropis buccatus</i>	-1.4 to 0.5
<i>Aphanius iberus</i>	-2 to -1.6	<i>Notropis procne</i>	-1 to -0.6
<i>Aphredoderus sayanus</i>	-1 to -0.6	<i>Percina maculata</i>	-1.4 to 0.5
<i>Campostoma anomalum</i>	-1.4 to 0.5	<i>Pimephales notatus</i>	-1.4 to 0.5
<i>Campostoma oligolepis</i>	-1.7 to -0.4	<i>Pimephales promelas</i>	-1.4 to 0.5
<i>Carpionodes cyprinus</i>	-1.4 to 0.5	<i>Rhinichthys atratulus</i>	-1.4 to 0.5
<i>Catostomus commersonii</i>	-1.4 to 0.5	<i>Rhinichthys obtusus</i>	-1.2 to -0.4
<i>Cottus bairdii</i>	-1.4 to 0.5	<i>Semotilus atromaculatus</i>	-1.4 to 0.5
<i>Culaea inconstans</i>	-1.4 to 0.5	<i>Umbra limi</i>	-1.4 to 0.5
<i>Cyprinella whipplei</i>	-1.4 to 0.5	(i) Invertebrates in streams	
<i>Cyprinus carpio</i>	-1.4 to 0.5	Cold	
<i>Erimyzon oblongus</i>	-1 to -0.6	<i>Lymnaea peregra</i>	-1.8 to -1.4
<i>Esox americanus</i>	-1.4 to 0.5	Temperate	
<i>Etheostoma blennioides</i>	-1.4 to 0.5	<i>Ablabesmyia longistyla</i>	-1.3 to 0.2
<i>Etheostoma caeruleum</i>	-1.4 to 0.5	<i>Ablabesmyia monilis</i>	-1.5 to 0.5

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Ablabesmyia phatta</i>	-1.3 to -0.4	<i>Anisus vorticulus</i>	-1.5 to 0.1
<i>Acentrella insignificans</i>	-1.7 to 0	<i>Anodonta anatina</i>	-1.3 to -0.1
<i>Acerpenna pygmaea</i>	-1.9 to -1.8	<i>Anopheles messeae</i>	-1.3 to -0.6
<i>Acilius canaliculatus</i>	-1.2 to -0.6	<i>Antarctoperla michaelsoni</i>	-2.2 to -0.9
<i>Acricotopus lucens</i>	-1.5 to 0.3	<i>Aplexa hypnorum</i>	-1.3 to 0.1
<i>Acroloxus lacustris</i>	-1.3 to 0.2	<i>Apsectrotanytus trifascipennis</i>	-1.5 to 1.2
<i>Acroneuria abnormis</i>	-1.8 to -1.7	<i>Aquarius najas</i>	-1.2 to -0.4
<i>Adicella reducta</i>	-1.2 to -0.6	<i>Aquarius paludulum</i>	-1.3 to -0.6
<i>Aeshna cyanea</i>	-2 to 0.3	<i>Arctopsyche grandis</i>	-1.7 to -0.1
<i>Aeshna mixta</i>	-1.5 to -0.5	<i>Argyroneta aquatica</i>	-1.3 to 0.3
<i>Agabus bipustulatus</i>	-1.7 to 0.2	<i>Arrenurus albator</i>	-1.4 to 0.2
<i>Agabus chalconatus</i>	-1.3 to 0.2	<i>Arrenurus bifidicodulus</i>	-0.7 to -0.5
<i>Agabus didymus</i>	-2 to 0.1	<i>Arrenurus buccinator</i>	-1.5 to -0.2
<i>Agabus guttatus</i>	-0.8 to -0.6	<i>Arrenurus crassicaudatus</i>	-1.5 to -0.1
<i>Agabus paludosus</i>	-1.7 to -0.2	<i>Arrenurus cylindratus</i>	-1.5 to -0.3
<i>Agabus sturmii</i>	-1.5 to 0.6	<i>Arrenurus globator</i>	-2 to 0.2
<i>Agabus undulatus</i>	-1.4 to 0.1	<i>Arrenurus knauthei</i>	-1.2 to -0.7
<i>Agapetus fuscipes</i>	-1.7 to -0.5	<i>Arrenurus latus</i>	-1.3 to -0.6
<i>Agnetina capitata</i>	-1.6 to -1.5	<i>Arrenurus leuckarti</i>	-1.2 to -1
<i>Agraylea multipunctata</i>	-1.3 to -0.3	<i>Arrenurus securiformis</i>	-1.4 to -1
<i>Agraylea sexmaculata</i>	-1.3 to -0.6	<i>Arrenurus sinuator</i>	-1.3 to -0.2
<i>Agrypnia pagetana</i>	-1.3 to -0.4	<i>Arrenurus zachariae</i>	-1 to -0.9
<i>Amphichorema zotheculum</i>	-2.2 to -1.4	<i>Ascomorpha ecaudis</i>	-1.1 to 0.6
<i>Amphinemura banksi</i>	-1.7 to -0.1	<i>Asellus aquaticus</i>	-1.8 to 1.2
<i>Anabolia nervosa</i>	-1.7 to 0.6	<i>Asplanchna brightwellii</i>	-1.1 to 0.6
<i>Anacaena bipustulata</i>	-1.3 to -0.5	<i>Atherix ibis</i>	-0.8 to -0.1
<i>Anacaena globulus</i>	-1.5 to 0.9	<i>Atherix pachypus</i>	-1.7 to -0.1
<i>Anacaena limbata</i>	-1.5 to 0.5	<i>Athripsodes aterrimus</i>	-2 to 0.5
<i>Anacaena lutescens</i>	-1.5 to -0.1	<i>Athripsodes cinereus</i>	-1.2 to 0
<i>Anatopynia plumipes</i>	-0.5 to 1	<i>Atyaephyra desmaresti</i>	-1.3 to -0.1
<i>Anax imperator</i>	-1.4 to -1.3	<i>Aubertoperla illiesi</i>	-2.2 to -1.4
<i>Ancyclus fluviatilis</i>	-1.3 to 0.4	<i>Baetis bicaudatus</i>	-1.7 to 0.2
<i>Andesiops torrens</i>	-2 to -1	<i>Baetis brunneicolor</i>	-1.5 to -1.4
<i>Andogyrus seriatopunctatus</i>	-2.2 to -0.9	<i>Baetis intercalaris</i>	-1.3 to -1.2
<i>Anisus leucostoma</i>	-1.3 to 0.6	<i>Baetis rhodani</i>	-1.3 to 0.1
<i>Anisus spirorbis</i>	-1 to 0.5	<i>Baetis scambus</i>	-0.9 to -0.1
<i>Anisus vortex</i>	-2 to 0.6	<i>Baetis tricaudatus</i>	-1.7 to 0.7

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Baetis vernus</i>	-1.7 to 0.8	<i>Caenis robusta</i>	-1.3 to 0.5
<i>Bandakia concreta</i>	-1 to -0.7	<i>Callicorixa praeusta</i>	-1.3 to 1.2
<i>Bathymphalus contortus</i>	-1.4 to 0.6	<i>Calopteryx splendens</i>	-1.3 to 0
<i>Bdellocephala punctata</i>	-0.9 to -0.5	<i>Calopteryx virgo</i>	-1.5 to 0
<i>Beauchampiella eudactylota</i>	-1.1 to 0.6	<i>Cataclysta lemnata</i>	-2 to 0.1
<i>Beraea maurus</i>	-1.7 to -0.7	<i>Centroptilum luteolum</i>	-1.3 to -0.4
<i>Beraea pullata</i>	-1.4 to -0.2	<i>Centroptilum pennulatum</i>	-1.3 to -1.2
<i>Beraeodes minutus</i>	-1.3 to 0.1	<i>Cephalodella catellina</i>	-1.1 to 0.6
<i>Bidessus unistriatus</i>	-1.5 to 0.2	<i>Cercyon convexiusculus</i>	-1.3 to -1.2
<i>Bithynia leachi</i>	-2 to 0.3	<i>Chaetarthria seminulum</i>	-1.3 to 0.3
<i>Bithynia leachii</i>	-1.8 to -0.8	<i>Chaetopteryx villosa</i>	-1.7 to -0.5
<i>Bithynia tentaculata</i>	-2 to 0.7	<i>Chaoborus crystallinus</i>	-1.4 to 0.1
<i>Boophthora erythrocephala</i>	-1.5 to 0.2	<i>Chaoborus flavicans</i>	-1.3 to -0.5
<i>Boyeria vinosa</i>	-1 to -0.6	<i>Chilenoperla semitincta</i>	-2.2 to -1.4
<i>Brachionus ahlstromi</i>	-1.1 to 0.6	<i>Chilina patagonica</i>	-2 to -1
<i>Brachionus angularis</i>	-1.1 to 0.6	<i>Chiloporter penai</i>	-1.7 to -1
<i>Brachionus austrogenitus</i>	-1.1 to 0.6	<i>Chimarra aterrima</i>	-1.6 to -1.5
<i>Brachionus bidentata</i>	-1.1 to 0.6	<i>Chimarra obscura</i>	-1.4 to -1.3
<i>Brachionus budapestinensis</i>	-1.1 to 0.6	<i>Chimarra socia</i>	-1.8 to -1.7
<i>Brachionus calyciflorus</i>	-1.1 to 0.6	<i>Chimarra utahensis</i>	-1.7 to -0.1
<i>Brachionus caudatus</i>	-1.1 to 0.6	<i>Chironomus bernensis</i>	-1.4 to -0.1
<i>Brachionus havanaensis</i>	-1.1 to 0.6	<i>Chironomus commutatus</i>	-1.3 to -0.2
<i>Brachionus plicatilis</i>	-1.1 to 0.6	<i>Chironomus luridus</i>	-1.7 to -0.7
<i>Brachionus quadridentatus</i>	-1.1 to 0.6	<i>Chironomus nudatarsus</i>	-1.3 to -0.2
<i>Brachionus rubens</i>	-1.1 to 0.6	<i>Chironomus nudiventris</i>	-1.3 to -0.2
<i>Brachionus urceolaris</i>	-0.4 to 0.6	<i>Chironomus obtusidens</i>	-1.3 to -0.7
<i>Brachycentrus americanus</i>	-1.7 to -0.1	<i>Chironomus plumosus</i>	-0.5 to -0.4
<i>Brachycentrus appalachia</i>	-1.7 to -1.6	<i>Chironomus riparius</i>	-1.7 to -0.7
<i>Brachycentrus occidentalis</i>	-1.7 to -0.1	<i>Chrysops caecutiens</i>	-1.3 to -0.9
<i>Brachypoda versicolor</i>	-2 to -0.2	<i>Cladotanytarsus mancus</i>	-1.3 to -0.6
<i>Brachysetodes major</i>	-2.2 to -0.9	<i>Clinotanytus nervosus</i>	-1.7 to 0.2
<i>Branchiodrilus hortensis</i>	-1.3 to -0.3	<i>Cloeon dipterum</i>	-2 to 0.6
<i>Branchiura sowerbyi</i>	-1.3 to -0.1	<i>Cloeon simile</i>	-1.4 to 0.1
<i>Brillia flavifrons</i>	-1.3 to 0.5	<i>Cnetha costata</i>	-1.7 to -0.7
<i>Brillia modesta</i>	-1.7 to 0.1	<i>Cnetha latipes</i>	-1.7 to -0.5
<i>Caenis horaria</i>	-2 to 0.6	<i>Coelostoma orbiculare</i>	-1.2 to 0.1
<i>Caenis luctuosa</i>	-1.3 to 0	<i>Coenagrion puella</i>	-0.9 to 0.6

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Coenagrion pulchellum</i>	-1.3 to 0.2	<i>Dero digitata</i>	-1.3 to 0.3
<i>Colurella colurus</i>	-1.1 to 0.6	<i>Dero dorsalis</i>	-1.3 to 0.3
<i>Colymbetes fuscus</i>	-1.3 to 0.6	<i>Deuterophlebia coloradensis</i>	-1.7 to -0.1
<i>Conchapelopia melanops</i>	-1.7 to 0.5	<i>Dicranophoroides caudatus</i>	-0.4 to 0.6
<i>Conochilus coenobasis</i>	-1.1 to 0.6	<i>Dicranophorus halbachi</i>	-0.4 to 0.6
<i>Conochilus unicornis</i>	-1.1 to 0.6	<i>Dicranophorus robustus</i>	-0.4 to 0.6
<i>Copelatus haemorrhoidalis</i>	-0.9 to -0.6	<i>Dicranota bimaculata</i>	-1.7 to 0.1
<i>Coquillettida richardii</i>	-1.5 to -1.3	<i>Dicrotendipes neomodestus</i>	-1 to -0.8
<i>Corbicula fluminalis</i>	-1.3 to -0.2	<i>Dicrotendipes nervosus</i>	-1.3 to -0.1
<i>Corbicula fluminea</i>	-1.3 to -0.1	<i>Dicrotendipes notatus</i>	-1.5 to -0.2
<i>Corixa affinis</i>	-1.5 to 1	<i>Dikerogammarus villosus</i>	-1.3 to -0.1
<i>Corixa dentipes</i>	-1.3 to 0.3	<i>Dina lineata</i>	-1.2 to -0.7
<i>Corixa punctata</i>	-2 to 1	<i>Diplocladius cultriger</i>	-1.7 to 0.2
<i>Corophium curvispinum</i>	-1.3 to -0.1	<i>Diplodontus scapularis</i>	-1.3 to -0.4
<i>Corydalis cornutus</i>	-1.6 to -1.5	<i>Dixa dilatata</i>	-1.2 to -1.1
<i>Corynoneura lobata</i>	-1.1 to -0.4	<i>Dixa maculata</i>	-1.7 to -0.8
<i>Corynoneura scutellata</i>	-1.3 to -0.7	<i>Dixella filicornis</i>	-1.3 to -1.2
<i>Crangonyx pseudogracilis</i>	-1.8 to -0.3	<i>Dreissena polymorpha</i>	-1.8 to -0.1
<i>Crenobia alpina</i>	-1.7 to -0.7	<i>Drunella coloradensis</i>	-1.7 to -0.1
<i>Cricotopus bicinctus</i>	-1.7 to 0.7	<i>Drunella cornutella</i>	-1.7 to -1.6
<i>Cricotopus intersectus</i>	-1.3 to -0.7	<i>Drunella doddsi</i>	-1.7 to -0.1
<i>Cricotopus sylvestris</i>	-1.7 to 0.7	<i>Drunella walkeri</i>	-0.8 to 0
<i>Cricotopus tremulus</i>	-1.2 to -1	<i>Dryops luridus</i>	-1.5 to 0.1
<i>Cricotopus trifascia</i>	-1.7 to 0.7	<i>Dubiraphia vittata</i>	-1 to -0.6
<i>Cricotopus trifasciatus</i>	-0.8 to -0.1	<i>Dugesia gonocephala</i>	-1.2 to -0.8
<i>Cricotopus vierriensis</i>	-1.3 to -1.2	<i>Dugesia lugubris</i>	-2 to 0.2
<i>Crunoecia irrorata</i>	-1.7 to -0.7	<i>Dugesia polychroa</i>	-1.3 to 0.2
<i>Cryptochironomus defectus</i>	-1.3 to -0.3	<i>Dugesia tigrina</i>	-1.8 to -0.2
<i>Cryptochironomus fulvus</i>	-1.4 to -0.6	<i>Dytiscus marginalis</i>	-1.1 to 0.1
<i>Cryptotendipes usmaensis</i>	-1.3 to -0.5	<i>Echinogammarus berilloni</i>	-1.3 to -0.8
<i>Culex pipiens</i>	-1.3 to 0.3	<i>Ecnomus tenellus</i>	-1.3 to -0.1
<i>Culiseta annulata</i>	-1.3 to 0.3	<i>Ectopria nervosa</i>	-1 to -0.8
<i>Cymatia coleoptrata</i>	-1.2 to 0.2	<i>Einfeldia dissidens</i>	-1.3 to -0.7
<i>Cymbiodyta marginella</i>	-1.3 to -1	<i>Einfeldia pagana</i>	-1 to -0.2
<i>Cyrnus flavidus</i>	-1.7 to 0.2	<i>Eiseniella tetraedra</i>	-1.7 to 0.2
<i>Cyrnus trimaculatus</i>	-1.3 to 0.3	<i>Elmis aenea</i>	-1.5 to -0.1
<i>Dendrocoelum lacteum</i>	-1.7 to 0.6	<i>Elmis maugetii</i>	-0.9 to -0.8

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Elodes minuta</i>	-1.7 to -0.4	<i>Ferrissia walkeri</i>	-1.8 to -0.4
<i>Elophila nymphaeata</i>	-1.1 to -0.2	<i>Filinia opoliensis</i>	-1.1 to 0.6
<i>Enallagma cyathigerum</i>	0.1 to 0.6	<i>Forelia liliacea</i>	-1 to -0.2
<i>Endochironomus albipennis</i>	-1.4 to 0.2	<i>Forelia variegator</i>	-1.3 to -0.2
<i>Endochironomus dispar</i>	-0.9 to -0.1	<i>Galba truncatula</i>	-1.7 to 0.2
<i>Endochironomus tendens</i>	-1.4 to 0.2	<i>Gammarus fossarum</i>	-1.7 to 0
<i>Enochrus affinis</i>	-0.8 to -0.7	<i>Gammarus pulex</i>	-2 to 0.6
<i>Enochrus melanocephalus</i>	-1.2 to -0.7	<i>Gammarus roeseli</i>	-1 to -0.2
<i>Enochrus testaceus</i>	-1.3 to 0.1	<i>Gammarus roeselii</i>	-1.5 to 0
<i>Enoicyla pusilla</i>	-0.8 to -0.5	<i>Gammarus tigrinus</i>	-1.8 to 0
<i>Epeorus albertae</i>	-1.7 to -0.1	<i>Gerris argentatus</i>	-1.3 to -0.6
<i>Epeorus deceptivus</i>	-1.7 to -0.1	<i>Gerris gibbifer</i>	-2 to -0.7
<i>Epeorus longimanus</i>	-1.7 to -0.1	<i>Gerris lacustris</i>	-2 to 0.9
<i>Ephemera danica</i>	-1.7 to -0.1	<i>Gerris odontogaster</i>	-1.4 to -0.1
<i>Ephemera vulgata</i>	-0.8 to -0.2	<i>Gerris thoracicus</i>	-1.5 to 0
<i>Ephemerella ignita</i>	-0.9 to 0	<i>Glossiphonia complanata</i>	-2 to 0.6
<i>Ephemerella inermis</i>	-1.7 to -0.1	<i>Glossiphonia heteroclita</i>	-2 to 0.6
<i>Ephemerella subvaria</i>	-1.5 to -1.4	<i>Glyptotaelius pellucidus</i>	-1.7 to -0.5
<i>Ephoron leukon</i>	-1.7 to -1.6	<i>Glyptotendipes barbipes</i>	-1.5 to -0.4
<i>Epiphanes clavatula</i>	-1.1 to 0.6	<i>Glyptotendipes pallens</i>	-2 to -0.2
<i>Erpobdella nigricollis</i>	-1.3 to -1	<i>Glyptotendipes paripes</i>	-1 to -0.7
<i>Erpobdella octoculata</i>	-2 to 0.8	<i>Goera pilosa</i>	-1.2 to -0.2
<i>Erpobdella punctata</i>	-1.5 to 0.7	<i>Goniobasis livescens</i>	-0.8 to -0.3
<i>Erpobdella testacea</i>	-2 to 0.6	<i>Graptodytes pictus</i>	-2 to 0.6
<i>Erpobdella vilnensis</i>	-0.9 to -0.2	<i>Guttipelopia guttipennis</i>	-1.3 to -0.6
<i>Erythromma najas</i>	-1.3 to 0.2	<i>Gyraulus albus</i>	-1.8 to 0.6
<i>Euchlanis dilatata</i>	-1.1 to 0.6	<i>Gyraulus crista</i>	-1.3 to 0.2
<i>Eukiefferiella brevicar</i>	-1.7 to -1	<i>Gyraulus laevis</i>	-0.8 to 0.1
<i>Eukiefferiella calvescens</i>	-1.3 to -0.6	<i>Gyraulus riparius</i>	-1.3 to 0.2
<i>Eukiefferiella claripennis</i>	-1.4 to -0.1	<i>Gyrinus marinus</i>	-2 to 0.3
<i>Eukiefferiella discoloripes</i>	-1.3 to -0.6	<i>Gyrinus substriatus</i>	-2 to 0
<i>Eusimulium angustipes</i>	-1.3 to -0.5	<i>Habrophlebia fusca</i>	-1 to -0.4
<i>Eusimulium aureum</i>	-1.3 to 0.1	<i>Haementeria costata</i>	-0.5 to -0.1
<i>Euthyas truncata</i>	-1.2 to -0.8	<i>Haemopsis sanguisuga</i>	-1.4 to 0.4
<i>Eylais extendens</i>	-1.4 to 0.2	<i>Halesus radiatus</i>	-1.7 to -0.3
<i>Eylais hamata</i>	-1.5 to -0.1	<i>Halipilus flavicollis</i>	-1.5 to 0.6
<i>Eylais setosa</i>	-1.4 to 0.2	<i>Halipilus fluviatilis</i>	-1.5 to 0.6

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Haliphus fulvus</i>	-0.9 to 0.6	<i>Hyaella curvispina</i>	-1.8 to -1.3
<i>Haliphus heydeni</i>	-2 to 0.5	<i>Hydora annectens</i>	-2.2 to -1.2
<i>Haliphus immaculatus</i>	-2 to 0.6	<i>Hydrachna cruenta</i>	-1.5 to -0.2
<i>Haliphus laminatus</i>	-2 to 0.5	<i>Hydraena assimilis</i>	-1 to -0.9
<i>Haliphus lineatocollis</i>	-2 to 0.6	<i>Hydraena riparia</i>	-1.3 to -1.2
<i>Haliphus lineolatus</i>	-1.1 to 0.2	<i>Hydraena testacea</i>	-1.3 to 0.2
<i>Haliphus obliquus</i>	-1.5 to -0.5	<i>Hydrobius fuscipes</i>	-1.5 to 0.7
<i>Haliphus ruficollis</i>	-2 to 0.2	<i>Hydrochara caraboides</i>	-1.4 to -1.2
<i>Haliphus wehnckei</i>	-2 to 0.2	<i>Hydrochus angustatus</i>	-1.3 to -0.4
<i>Harnischia curtilamellata</i>	-1.3 to -0.4	<i>Hydrochus carinatus</i>	-0.9 to -0.7
<i>Hebrus ruficeps</i>	-1.3 to -0.9	<i>Hydrodroma despiciens</i>	-1.4 to 0.3
<i>Helicopsyche borealis</i>	-1.7 to -0.1	<i>Hydrodroma torrenticola</i>	-0.8 to -0.6
<i>Helobdella stagnalis</i>	-2 to 1.2	<i>Hydroglyphus geminus</i>	-1.3 to -0.6
<i>Helochaers lividus</i>	-1.5 to 0.1	<i>Hydrometra stagnorum</i>	-1.7 to 0.6
<i>Helochaers punctatus</i>	-1.4 to 0.1	<i>Hydromyza livens</i>	-1.3 to -0.1
<i>Helophorus aequalis</i>	-1.4 to 0.9	<i>Hydrophilus piceus</i>	-0.2 to 0.6
<i>Helophorus aquaticus</i>	-1.3 to 0.3	<i>Hydroporus angustatus</i>	-1.3 to -0.5
<i>Helophorus brevipalpis</i>	-1.4 to 0.7	<i>Hydroporus discretus</i>	-1.3 to -0.6
<i>Helophorus flavipes</i>	-1.7 to 0.6	<i>Hydroporus erythrocephalus</i>	-2 to -0.2
<i>Helophorus grandis</i>	-1.3 to -0.3	<i>Hydroporus gyllenhalii</i>	-1.4 to -0.5
<i>Helophorus minutus</i>	-2 to 0.3	<i>Hydroporus incognitus</i>	-1.4 to -0.3
<i>Helophorus obscurus</i>	-1.3 to 0.3	<i>Hydroporus memnonius</i>	-1.5 to -0.5
<i>Helophorus strigifrons</i>	-1.4 to -0.9	<i>Hydroporus nigrita</i>	-1.3 to -1.2
<i>Hemiclepsis marginata</i>	-1.5 to 0.2	<i>Hydroporus palustris</i>	-2 to 1
<i>Hemiosus dejeanii</i>	-2.2 to -0.9	<i>Hydroporus planus</i>	-1.7 to 0.4
<i>Hesperocorixa castanea</i>	-0.8 to 0.3	<i>Hydropsyche angustipennis</i>	-1.7 to 0.4
<i>Hesperocorixa linnaei</i>	-1.2 to 0.5	<i>Hydropsyche betteni</i>	-1.2 to -0.6
<i>Hesperocorixa sahlbergi</i>	-1.4 to 0.6	<i>Hydropsyche instabilis</i>	-0.5 to -0.2
<i>Hesperoperla pacifica</i>	-1.7 to -0.1	<i>Hydropsyche morosa</i>	-1.5 to -1.4
<i>Heterotantarsus apicalis</i>	-1.5 to -0.5	<i>Hydropsyche pellucidula</i>	-1.2 to 0
<i>Heterotrissocladius marcidus</i>	-1.7 to 0	<i>Hydropsyche saxonica</i>	-1.2 to 0
<i>Hexarthra intermedia</i>	-1.1 to 0.6	<i>Hydropsyche scalaris</i>	-1.5 to -1.4
<i>Hexarthra mira</i>	-1.1 to 0.6	<i>Hydropsyche siltalai</i>	-0.8 to -0.3
<i>Hippeutis complanatus</i>	-1.4 to 0.6	<i>Hydropsyche slossonae</i>	-1.3 to -1.2
<i>Holocentropus dubius</i>	-1.3 to -0.2	<i>Hydropsyche sparna</i>	-1.2 to -1
<i>Holocentropus picicornis</i>	-1.3 to 0.6	<i>Hydroptila spatulata</i>	-1 to -0.8
<i>Hyaella azteca</i>	-1.5 to 0	<i>Hydryphantes ruber</i>	-1.3 to 0.2

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Hygrobates fluviatilis</i>	-1.3 to -0.6	<i>Lecane decipiens</i>	-1.1 to 0.6
<i>Hygrobates longipalpis</i>	-1.7 to -0.1	<i>Lecane elsa</i>	-1.1 to 0.6
<i>Hygrobates nigromaculatus</i>	-1.7 to 0.2	<i>Lecane flexilis</i>	-1.1 to 0.6
<i>Hygrobates trigonicus</i>	-1.2 to -0.4	<i>Lecane furcata</i>	-1.1 to 0.6
<i>Hygrobia hermanni</i>	-2 to 0	<i>Lecane hamata</i>	-1.1 to 0.6
<i>Hygrotus decoratus</i>	-2 to -0.3	<i>Lecane hastata</i>	-1.1 to 0.6
<i>Hygrotus inaequalis</i>	-1.5 to 0.7	<i>Lecane leontina</i>	-1.1 to 0.6
<i>Hygrotus versicolor</i>	-1.5 to 0.6	<i>Lecane ludwigii</i>	-1.1 to 0.6
<i>Hyphydrus ovatus</i>	-2 to 0.6	<i>Lecane lunaris</i>	-1.1 to 0.6
<i>Ilybius fenestratus</i>	-1.3 to -0.1	<i>Lecane papuana</i>	-1.1 to 0.6
<i>Ilybius fuliginosus</i>	-1.7 to 0.2	<i>Lecane proiecta</i>	-0.4 to 0.6
<i>Ilybius quadriguttatus</i>	-1.2 to -0.5	<i>Lecane quadridentata</i>	-1.1 to 0.6
<i>Ilyodrilus templetoni</i>	-1.3 to 0.1	<i>Lecane scutata</i>	-1.1 to 0.6
<i>Ironoquia dubia</i>	-1.3 to -1	<i>Lecane signifera</i>	-1.1 to 0.6
<i>Ischnura elegans</i>	-1.5 to 0.5	<i>Lecane stenroosi</i>	-1.1 to 0.6
<i>Isonychia bicolor</i>	-1.6 to -1.5	<i>Lecane tenuiseta</i>	-1.1 to 0.6
<i>Keratella americana</i>	-1.1 to 0.6	<i>Lepadella acuminata</i>	-0.4 to 0.6
<i>Keratella cochlearis</i>	-1.1 to 0.6	<i>Lepadella latusimus</i>	-1.1 to 0.6
<i>Keratella lenzi</i>	-1.1 to 0.6	<i>Lepadella patella</i>	-1.1 to 0.6
<i>Keratella tropica</i>	-1.1 to 0.6	<i>Lepadella quadricarinata</i>	-1.1 to 0.6
<i>Kiefferulus tendipediformis</i>	-1.3 to 0.6	<i>Leptocerus tineiformis</i>	-1.8 to -0.8
<i>Klapopteryx kuscheli</i>	-2.2 to -1.4	<i>Leptophlebia vespertina</i>	-0.4 to -0.2
<i>Laccobius bipunctatus</i>	-1.5 to 0.7	<i>Lestes sponsa</i>	-1.5 to -0.7
<i>Laccobius minutus</i>	-1.5 to 0.3	<i>Lestes viridis</i>	-1.3 to 0.6
<i>Laccophilus hyalinus</i>	-2 to 0.6	<i>Libellula depressa</i>	-1 to -0.5
<i>Laccophilus minutus</i>	-1.7 to 1	<i>Limnebius nitidus</i>	-0.9 to -0.8
<i>Lasiocephala basalis</i>	-0.9 to -0.3	<i>Limnebius truncatellus</i>	-1.4 to -0.2
<i>Lebertia inaequalis</i>	-1.5 to -0.1	<i>Limnephilus centralis</i>	-1.2 to -1
<i>Lebertia insignis</i>	-1.2 to 0.2	<i>Limnephilus decipiens</i>	-1.3 to -0.3
<i>Lebertia pusilla</i>	-1.2 to -0.9	<i>Limnephilus extricatus</i>	-1.3 to -0.5
<i>Lebertia rivulorum</i>	-0.9 to -0.3	<i>Limnephilus lunatus</i>	-1.7 to 0.6
<i>Lebertia stigmatifera</i>	-1.4 to -0.7	<i>Limnephilus rhombicus</i>	-1.3 to -0.2
<i>Lecane aculeata</i>	-1.1 to 0.6	<i>Limnesia connata</i>	-0.4 to -0.2
<i>Lecane bulla</i>	-1.1 to 0.6	<i>Limnesia fulgida</i>	-1.3 to -0.5
<i>Lecane closterocerca</i>	-1.1 to 0.6	<i>Limnesia koenikei</i>	-1.5 to 0.2
<i>Lecane cornuta</i>	-1.1 to 0.6	<i>Limnesia maculata</i>	-2 to 0.3
<i>Lecane curvicornis</i>	-1.1 to 0.6	<i>Limnesia undulata</i>	-1.5 to 0.3

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Limnius volckmari</i>	-1.4 to -0.8	<i>Microtendipes pedellus</i>	-1.4 to -0.4
<i>Limnodrilus claparedeanus</i>	-1.5 to -0.1	<i>Microtendipes rydalensis</i>	-1.7 to -1.6
<i>Limnodrilus hoffmeisteri</i>	-1.7 to 0.4	<i>Microvelia reticulata</i>	-2 to -0.2
<i>Limnodrilus udekemianus</i>	-1.5 to -0.1	<i>Mideopsis crassipes</i>	-1.3 to -0.3
<i>Limnomysis benedeni</i>	-1.8 to -0.6	<i>Mideopsis orbicularis</i>	-1.4 to -0.2
<i>Limnoperla jaffueli</i>	-2.2 to -0.9	<i>Molanna angustata</i>	-1.3 to 0.2
<i>Lithoglyphus naticoides</i>	-1 to -0.6	<i>Monommata longiseta</i>	-1.1 to 0.6
<i>Lophocharis salpina</i>	-1.1 to 0.6	<i>Monopelopia tenuicalcar</i>	-1.5 to -0.1
<i>Luchoelmis cekalovici</i>	-2.2 to -0.9	<i>Moorbdella fervida</i>	-0.8 to 0.7
<i>Lumbriculus variegatus</i>	-2 to 0.5	<i>Musculium lacustre</i>	-1.4 to 0.7
<i>Lymnaea diaphana</i>	-1.8 to -1.3	<i>Mystacides azureus</i>	-1.3 to -0.6
<i>Lymnaea stagnalis</i>	-1.5 to 0.6	<i>Mystacides longicornis</i>	-1.4 to 0.2
<i>Lype phaeopa</i>	-1.3 to 0	<i>Mystacides niger</i>	-1.3 to 0.2
<i>Lype reducta</i>	-1.4 to -0.3	<i>Mytilina bisulcata</i>	-1.1 to 0.6
<i>Macronychus glabratus</i>	-1 to -0.6	<i>Mytilina ventralis</i>	-1.1 to 0.6
<i>Macropelopia adauca</i>	-2 to -0.7	<i>Nais barbata</i>	-0.3 to 0.2
<i>Macropelopia nebulosa</i>	-1.5 to -0.1	<i>Nais communis</i>	-1.8 to -0.6
<i>Marstoniopsis scholtzi</i>	-1.3 to -0.6	<i>Nais elinguis</i>	-1.7 to 0.6
<i>Mastigoptila longicornuta</i>	-2.2 to -0.9	<i>Nais pardalis</i>	-1.2 to -0.7
<i>Meridialaris chiloeensis</i>	-2 to -1.6	<i>Nais variabilis</i>	-1.8 to -0.8
<i>Meridialaris laminata</i>	-2 to -1.3	<i>Nanocladius bicolor</i>	-1.3 to -0.3
<i>Mesovelia furcata</i>	-1.3 to -0.6	<i>Nanocladius rectinervis</i>	-1.2 to -0.3
<i>Metrichia neotropicalis</i>	-2.2 to -0.9	<i>Nebrioporus depressus</i>	-1.7 to 0.6
<i>Metriocnemus hirticollis</i>	-0.7 to -0.5	<i>Nemoura avicularis</i>	-1.5 to -0.1
<i>Microchironomus tener</i>	-1.3 to -0.2	<i>Nemoura cambrica</i>	-1.3 to -1
<i>Micronecta minutissima</i>	-1 to -0.4	<i>Nemoura cinerea</i>	-1.7 to 0.5
<i>Micronecta scholtzi</i>	-1.3 to -0.2	<i>Nemurella pictetii</i>	-1.5 to -0.4
<i>Micropsectra apposita</i>	-1.3 to -0.2	<i>Neoatopsyche chilensis</i>	-2.2 to -1.4
<i>Micropsectra atrofasciata</i>	-2 to -0.3	<i>Neomysis integer</i>	-0.8 to -0.7
<i>Micropsectra bidentata</i>	-1.2 to -0.7	<i>Neoplanorbis carinatus</i>	-1.8 to 0.6
<i>Micropsectra dives</i>	-1.3 to -1.2	<i>Neopsilochorema tricarinatum</i>	-2.2 to -1.4
<i>Micropsectra fusca</i>	-1.7 to -0.5	<i>Nepa cinerea</i>	-1.5 to 0.7
<i>Micropsectra notescens</i>	-1.4 to -0.2	<i>Neumania deltoides</i>	-1 to -0.2
<i>Micropsectra polita</i>	-1.9 to -1.8	<i>Neumania imitata</i>	-1.3 to -0.2
<i>Micropterna lateralis</i>	-1.7 to -0.5	<i>Neumania limosa</i>	-2 to -0.2
<i>Micropterna sequax</i>	-1.7 to 0.1	<i>Neureclipsis bimaculata</i>	-1.3 to 0.3
<i>Microtendipes chloris</i>	-1.4 to 0.1	<i>Nigronia serricornis</i>	-1 to -0.6

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Noterus clavicornis</i>	-1.4 to 0.1	<i>Paramerina cingulata</i>	-1.5 to -0.7
<i>Noterus crassicornis</i>	-1.4 to 0.3	<i>Parametricnemus lundbecki</i>	-1.2 to -0.6
<i>Notholca acuminata</i>	-0.4 to 0.6	<i>Parametricnemus stylatus</i>	-1.4 to -0.8
<i>Notidobia ciliaris</i>	-1.2 to -0.3	<i>Parapopynx stratiotata</i>	-1.1 to -0.2
<i>Notonecta maculata</i>	-1.5 to -0.3	<i>Parasericostoma ovale</i>	-2.2 to -0.9
<i>Notonecta obliqua</i>	-1.4 to -0.6	<i>Paratanytarsus austriacus</i>	-0.8 to -0.5
<i>Notonecta viridis</i>	-1.4 to -0.4	<i>Paratanytarsus confusus</i>	-1.4 to -1.3
<i>Notoperlopsis femina</i>	-2.2 to -1.4	<i>Paratanytarsus dissimilis</i>	-1.3 to -0.1
<i>Nousia delicata</i>	-2 to -1.5	<i>Paratanytarsus grimmii</i>	-1.3 to -0.6
<i>Ochthebius bicolon</i>	-1.4 to 0.3	<i>Paratanytarsus lauterborni</i>	-0.8 to -0.3
<i>Ochthebius minimus</i>	-1.5 to -0.4	<i>Paratanytarsus tenellulus</i>	-1.2 to -0.5
<i>Odagmia ornata</i>	-1.7 to 0.4	<i>Paratanytarsus tenuis</i>	-1 to -0.3
<i>Odagmia spinosa</i>	-1.3 to -0.1	<i>Paratendipes albimanus</i>	-1.3 to 0.1
<i>Odontomesa fulva</i>	-1.3 to 0.2	<i>Paratrichocladus rufiventris</i>	-1.3 to 0
<i>Oecetis furva</i>	-1.3 to -0.5	<i>Pedicia rivosa</i>	-1.5 to -0.5
<i>Oecetis lacustris</i>	-1.2 to 0.5	<i>Peltodytes caesus</i>	-2 to 0.6
<i>Oecetis ochracea</i>	-1.3 to 0.3	<i>Penaphlebia chilensis</i>	-2 to -1.5
<i>Oligotricha striata</i>	-1 to -0.7	<i>Perla genualis</i>	-2.2 to -1.4
<i>Omphiscola glabra</i>	-1.3 to 0.1	<i>Phaenopsectra dyari</i>	-1.4 to -1.3
<i>Ophidonais serpentina</i>	-1.7 to 1.2	<i>Phryganea bipunctata</i>	-1.4 to -0.3
<i>Optioservus fastiditus</i>	-1.4 to -1.3	<i>Physa acuta</i>	-1.3 to 0.8
<i>Optioservus ovalis</i>	-1.2 to -1	<i>Physa fontinalis</i>	-2 to 1
<i>Orconectes limosus</i>	-1.3 to -0.1	<i>Physella acuta</i>	-1.8 to -0.2
<i>Orectochilus villosus</i>	-1.1 to -0.1	<i>Piona alpicola</i>	-1.3 to -0.4
<i>Orthocladus dentifer</i>	-1.5 to -1.4	<i>Piona carnea</i>	-0.8 to -0.5
<i>Oulimnius rivularis</i>	-2 to -0.5	<i>Piona coccinea</i>	-1.4 to 0.2
<i>Oulimnius tuberculatus</i>	-1.3 to -0.1	<i>Piona conglobata</i>	-1.3 to 0.2
<i>Oxyethira bidentata</i>	-1.5 to -0.9	<i>Piona imminuta</i>	-0.7 to -0.2
<i>Pagastia orthogonia</i>	-1.4 to -1.3	<i>Piona neumani</i>	-1.3 to -0.2
<i>Parachironomus arcuatus</i>	-1.3 to -0.3	<i>Piona rotundoides</i>	-1.3 to -0.2
<i>Paracladius conversus</i>	-1.7 to 0.2	<i>Piona stjoerdalensis</i>	-0.8 to -0.7
<i>Paracladopelma camptolabis</i>	-1.5 to -0.9	<i>Piona variabilis</i>	-2 to -0.1
<i>Paracladopelma laminata</i>	-1.3 to 0.1	<i>Pionacercus vatrax</i>	-0.6 to -0.2
<i>Paracladopelma nigrifula</i>	-1.5 to 0.1	<i>Pionopsis lutescens</i>	-1.5 to 0.2
<i>Paragnetina media</i>	-1.3 to -1.2	<i>Piscicola geometra</i>	-2 to 0.5
<i>Paralauterborniella nigrohalteralis</i>	-1.3 to -0.7	<i>Pisidium amnicum</i>	-1.3 to -0.1
<i>Paraleptophlebia mollis</i>	-1.6 to -1.5	<i>Pisidium casertanum</i>	-2 to -0.1

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Pisidium henslowanum</i>	-1.3 to 0.2	<i>Potamopyrgus antipodarum</i>	-1.8 to 0.1
<i>Pisidium milium</i>	-1.2 to -0.2	<i>Potamoithrix hammoniensis</i>	-1.3 to -0.1
<i>Pisidium moitessierianum</i>	-1.3 to -0.1	<i>Potamoithrix moldaviensis</i>	-1.4 to -0.1
<i>Pisidium nitidum</i>	-1.3 to -0.2	<i>Potthastia gaedii</i>	-1.2 to -1
<i>Pisidium personatum</i>	-1.4 to -0.7	<i>Potthastia longimana</i>	-1.4 to 0.5
<i>Pisidium pulchellum</i>	-1 to -0.2	<i>Proasellus coxalis</i>	-1.8 to 0.4
<i>Pisidium subtruncatum</i>	-1.3 to -0.1	<i>Proasellus meridianus</i>	-2 to 0.6
<i>Pisidium supinum</i>	-1.3 to -0.2	<i>Procladius choreus</i>	-1.5 to -0.6
<i>Planaria torva</i>	-1.8 to -1.2	<i>Procloeon bifidum</i>	-1 to -0.4
<i>Planorbarius corneus</i>	-2 to 0.6	<i>Prodiamesa olivacea</i>	-1.7 to 1.2
<i>Planorbis planorbis</i>	-2 to 0.6	<i>Progomphus obscurus</i>	-1 to -0.6
<i>Platambus maculatus</i>	-1.4 to -0.1	<i>Promoresia elegans</i>	-0.8 to -0.3
<i>Platiumus patulus</i>	-1.1 to 0.6	<i>Prostoma graecense</i>	-1.6 to -1.5
<i>Platyncemis pennipes</i>	-1.3 to -0.1	<i>Psammoryctides barbatus</i>	-1.2 to 0.4
<i>Platylabus quadricornis</i>	-1.1 to 0.6	<i>Psectrocladius obvius</i>	-1.2 to -0.7
<i>Plectrocnemia conspersa</i>	-1.7 to -0.3	<i>Psectrocladius platypus</i>	-1 to -0.7
<i>Ploesoma truncatum</i>	-1.1 to 0.6	<i>Psectrocladius psilopterus</i>	-2 to -0.7
<i>Podura aquatica</i>	-1.3 to -0.4	<i>Psectrotanyptus varius</i>	-2 to 1.2
<i>Polycelis felina</i>	-1.5 to -0.5	<i>Psephenus herricki</i>	-1 to -0.8
<i>Polycelis nigra</i>	-1.3 to 0.3	<i>Pseudanodonta complanata</i>	-1.2 to -0.2
<i>Polycelis tenuis</i>	-1.7 to 0.5	<i>Psychomyia flavida</i>	-1.7 to -0.1
<i>Polycentropus irroratus</i>	-0.5 to -0.4	<i>Pteronarcella badia</i>	-1.7 to -0.1
<i>Polypedilum aviceps</i>	-1.7 to -1.6	<i>Pteronarcys californica</i>	-1.7 to -0.1
<i>Polypedilum bicrenatum</i>	-1.3 to -0.2	<i>Ptychoptera contaminata</i>	-1.3 to 0.4
<i>Polypedilum convictum</i>	-1.3 to -0.6	<i>Pyrrhosoma nymphula</i>	-2 to -0.5
<i>Polypedilum flavum</i>	-1.2 to -1	<i>Quistodrilus multisetosus</i>	-1.3 to -0.2
<i>Polypedilum illinoense</i>	-1 to -0.8	<i>Radix auricularia</i>	-1.3 to 0.2
<i>Polypedilum laetum</i>	-1.7 to -1	<i>Radix balthica</i>	-1 to -0.2
<i>Polypedilum nubeculosum</i>	-1.3 to -0.2	<i>Radix ovata</i>	-1.8 to 0.2
<i>Polypedilum scalaenum</i>	-1.7 to -0.1	<i>Radix peregra</i>	-2 to 0.8
<i>Polypedilum sordens</i>	-1.3 to -0.3	<i>Ranatra linearis</i>	-1.3 to -0.6
<i>Polypedilum uncinatum</i>	-1 to -0.5	<i>Rhantus exsoletus</i>	-2 to 0.6
<i>Pompholyx sulcata</i>	-1.1 to 0.6	<i>Rhantus suturalis</i>	-1.1 to 0.1
<i>Porhydrus lineatus</i>	-0.2 to 0.1	<i>Rheocricotopus chalybeatus</i>	-1.7 to -0.1
<i>Potamoperla myrmidon</i>	-2.2 to -0.9	<i>Rheocricotopus effusus</i>	-1.1 to -0.7
<i>Potamophylax nigricornis</i>	-1.7 to -0.7	<i>Rheocricotopus fuscipes</i>	-1.7 to 0
<i>Potamophylax rotundipennis</i>	-1.7 to -0.5	<i>Rheocricotopus robacki</i>	-1.5 to -1.4

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Rheotanytarsus pellucidus</i>	-1.6 to -1.5	<i>Sperchon clupeiifer</i>	-1.3 to -0.4
<i>Rheotanytarsus photophilus</i>	-1.3 to -0.9	<i>Sperchon compactilis</i>	-1.7 to -0.7
<i>Rhithrogena hageni</i>	-1.7 to -0.1	<i>Sperchon glandulosus</i>	-1.4 to -0.7
<i>Rhyacodrilus coccineus</i>	-1.7 to -0.4	<i>Sperchon setiger</i>	-1.7 to -0.3
<i>Rhyacophila brunnea</i>	-1.7 to -0.1	<i>Sperchon squamosus</i>	-1.7 to -0.9
<i>Rhyacophila fasciata</i>	-0.9 to -0.7	<i>Sphaerium corneum</i>	-1.5 to 0.6
<i>Rhyacophila fuscula</i>	-1.6 to -1.5	<i>Sphaerium novaezelandiae</i>	-1.3 to 0.1
<i>Rhyacophila vaccua</i>	-1.7 to -0.1	<i>Sphaerium solidum</i>	-1.3 to -0.2
<i>Segmentina nitida</i>	-1.3 to 0.6	<i>Spirosperma ferox</i>	-1.2 to 0
<i>Sericostoma personatum</i>	-1.7 to -0.4	<i>Stagnicola palustris</i>	-1.4 to 1.2
<i>Serratella deficiens</i>	-1.4 to -1.3	<i>Stenelmis crenata</i>	-1 to -0.8
<i>Serratella serrata</i>	-1.7 to -1.6	<i>Stenonema mediopunctatum</i>	-1.5 to -1.4
<i>Sialis fuliginosa</i>	-1.5 to -0.7	<i>Stenonema modestum</i>	-1.6 to -0.6
<i>Sialis lutaria</i>	-2 to 0.6	<i>Stenonema terminatum</i>	-1.6 to -1.5
<i>Sigara distincta</i>	-2 to 0.6	<i>Stenonema vicarium</i>	-1.3 to -1.2
<i>Sigara falleni</i>	-2 to 0.8	<i>Stethelmis kaszabi</i>	-2.2 to -1.7
<i>Sigara fossarum</i>	-2 to -0.7	<i>Stictochironomus maculipennis</i>	-1.3 to -0.4
<i>Sigara hellensii</i>	-0.5 to 0.1	<i>Stictotarsus duodecimpustulatus</i>	-1.3 to 0.6
<i>Sigara lateralis</i>	-1.3 to 0.3	<i>Stylaria lacustris</i>	-2 to 0.6
<i>Sigara limitata</i>	-0.7 to 1	<i>Stylodrilus heringianus</i>	-1.4 to 0.1
<i>Sigara nigrolineata</i>	-1.5 to 1.2	<i>Sublettea coffmani</i>	-1.6 to -1.5
<i>Sigara scotti</i>	-2 to -0.7	<i>Symposiocladius lignicola</i>	-1.7 to -1.2
<i>Sigara semistriata</i>	-2 to 1.2	<i>Synorthocladius semivirens</i>	-1.3 to -1.2
<i>Sigara striata</i>	-2 to 1.2	<i>Taeniopteryx metequi</i>	-1 to -0.6
<i>Silo nigricornis</i>	-1.7 to -0.3	<i>Tanypus kraatzi</i>	-1.3 to 0.5
<i>Simulium argyreatum</i>	-1.2 to -0.3	<i>Tanypus punctipennis</i>	-1.3 to -0.2
<i>Simulium jenningsi</i>	-1.3 to -1.2	<i>Tanytarsus ejuncidus</i>	-1 to -0.9
<i>Simulium morsitans</i>	-1.2 to -0.8	<i>Tanytarsus eminulus</i>	-1.3 to -0.3
<i>Simulium tuberosum</i>	-1.7 to -1.6	<i>Tanytarsus glabrescens</i>	-1.4 to -1.3
<i>Simulium venustum</i>	-1 to -0.6	<i>Tanytarsus guerlus</i>	-1.4 to -1.3
<i>Simulium vittatum</i>	-1 to -0.8	<i>Tanytarsus verralli</i>	-1.5 to -1.3
<i>Sinanthrerina spinosa</i>	-1.1 to 0.6	<i>Testudinella patina</i>	-1.1 to 0.6
<i>Slavina appendiculata</i>	-1.3 to -0.5	<i>Theodoxus fluviatilis</i>	-0.9 to -0.6
<i>Smicridea annulicornis</i>	-2.2 to -0.9	<i>Theromyzon tessulatum</i>	-2 to 0.5
<i>Smicridea dithyra</i>	-1.5 to -0.9	<i>Thienemanniella flaviforceps</i>	-1.2 to -0.5
<i>Smicridea frequens</i>	-2.2 to -1	<i>Tinodes assimilis</i>	-1.4 to -0.9
<i>Spercheus emarginatus</i>	-1.3 to 0.5	<i>Tinodes waeneri</i>	-1.3 to -0.7

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Tiphys latipes</i>	-1.2 to -0.7	<i>Valvata piscinalis</i>	-1.7 to 0.6
<i>Tiphys ornatus</i>	-1.4 to 0.2	<i>Viviparus contectus</i>	-1.3 to 0.5
<i>Tiphys scaurus</i>	-0.7 to -0.3	<i>Viviparus viviparus</i>	-1.5 to -0.3
<i>Tipula abdominalis</i>	-1 to -0.6	<i>Wettina podagrica</i>	-1.4 to -0.7
<i>Tipula lateralis</i>	-1.5 to 0.5	<i>Wilhelmia equina</i>	-0.1 to 0
<i>Tipula luna</i>	-0.9 to -0.3	<i>Wolga spinifera</i>	-1.1 to 0.6
<i>Tipula luteipennis</i>	-0.8 to 0.1	<i>Xenochironomus xenolabis</i>	-1.3 to -0.1
<i>Tipula maxima</i>	-1.5 to -0.7	<i>Zaitzevia parvula</i>	-1.7 to -0.1
<i>Tipula melanoceros</i>	-1.3 to -0.5	<i>Zapada cinctipes</i>	-1.7 to -0.1
<i>Tipula pruinos</i>	-1 to 0.9	<i>Zavreliomyia barbatipes</i>	-1 to -0.8
<i>Triaenodes bicolor</i>	-2 to -0.1		
<i>Tribelos jucundus</i>	-1 to -0.6	(Sub)tropical	
<i>Trichocerca bicristata</i>	-1.1 to 0.6	<i>Boyeria vinosa</i>	-0.4 to 0.1
<i>Trichocerca gracilis</i>	-1.1 to 0.6	<i>Calopteryx maculata</i>	-0.4 to 0.1
<i>Trichocerca pusilla</i>	-0.4 to 0.6	<i>Derovatellus lentus</i>	-0.4 to -0.1
<i>Trichocerca rattus</i>	-0.4 to 0.6	<i>Gynacantha nervosa</i>	-0.4 to 0.1
<i>Trichocerca similis</i>	-1.1 to 0.6	<i>Mesovelina mulsanti</i>	-0.4 to 0.1
<i>Trichocerca stylata</i>	-1.1 to 0.6	<i>Rhagovelia choreutes</i>	-0.4 to 0.1
<i>Trichocerca tigris</i>	-1.1 to 0.6	<i>Schizothrix calcicola</i>	-1.3 to -1
<i>Trichocerca weberi</i>	-1.1 to 0.6	<i>Sialis fuliginosa</i>	-1 to -0.2
<i>Trichotria tetractis</i>	-1.1 to 0.6	<i>Tropisternus lateralis nimbatus</i>	-0.4 to -0.2
<i>Tricorythodes minutus</i>	-1.7 to 0.7		
<i>Trocheta bykowskii</i>	-1.2 to 0.8	(j) Macrophytes in streams	
<i>Trocheta pseudodina</i>	-1.5 to -0.9	Temperate	
<i>Tubifex tubifex</i>	-1.7 to 0.4	<i>Agrostis stolonifera</i>	-2.7 to -2.4
<i>Tvetenia bavarica</i>	-1.2 to -1	<i>Amblystegium fluviatile</i>	-1.9 to -0.5
<i>Tvetenia calvescens</i>	-1.3 to -0.8	<i>Amblystegium riparium</i>	-1.5 to -0.6
<i>Tvetenia discoloripes</i>	-1.4 to -1.1	<i>Apium repens</i>	-2.7 to -2.4
<i>Unio crassus</i>	-1.2 to -0.3	<i>Brachythecium rivulare</i>	-1.6 to -0.3
<i>Unio pictorum</i>	-1.3 to 0.2	<i>Butomus umbellatus</i>	-0.3 to -0.2
<i>Unio tumidus</i>	-1.3 to -0.1	<i>Callitriche hamulata</i>	-1.6 to -0.5
<i>Unionicola aculeata</i>	-1.2 to -0.2	<i>Callitriche platycarpa</i>	-1.6 to -0.3
<i>Unionicola crassipes</i>	-1.3 to -0.1	<i>Callitriche stagnalis</i>	-1.6 to -0.5
<i>Unionicola minor</i>	-1.3 to -0.2	<i>Caltha palustris</i>	-2.5 to -2.4
<i>Unionicola tricuspis</i>	-1.3 to -0.6	<i>Ceratophyllum demersum</i>	-0.9 to -0.3
<i>Valvata cristata</i>	-1.3 to 0.2	<i>Cratoneuron commutatum</i>	-2.7 to -2.4
<i>Valvata macrostoma</i>	-1.4 to -0.4	<i>Fontinalis antipyretica</i>	-2.7 to -0.1

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Fontinalis squamosa</i>	-1.6 to -0.3	<i>Eudorina elegans</i>	-0.5 to -0.1
<i>Glyceria fluitans</i>	-2.5 to -0.1	<i>Hariotina reticulata</i>	-1.2 to -0.4
<i>Heteranthera dubia</i>	-1.6 to -1.3	<i>Lemanea fluviatilis</i>	-1.9 to -0.7
<i>Hygrohypnum ochraceum</i>	-1.6 to -0.3	<i>Monactinus simplex</i>	-1.2 to -0.1
<i>Juncus subnodulosus</i>	-2.5 to -2.4	<i>Pediastrum boryanum</i>	-1.2 to -0.1
<i>Lemna minor</i>	-2.4 to -0.3	<i>Scenedesmus ellipsoideus</i>	-1.1 to -0.3
<i>Mentha aquatica</i>	-2.7 to -2.4	<i>Scenedesmus quadricauda</i>	-0.4 to -0.1
<i>Myosotis scorpioides</i>	-2.5 to -2.4	<i>Scenedesmus tetracerum</i>	-1.2 to -0.1
<i>Myriophyllum spicatum</i>	-1 to -0.2	<i>Ulva intestinalis</i>	-0.9 to -0.3
<i>Najas marina</i>	-1 to -0.3		
<i>Nasturtium officinale</i>	-2.7 to -2.4	(Sub)tropical	
<i>Nuphar lutea</i>	-0.9 to -0.3	<i>Actinastrum gracillimum</i>	-1.8 to -1.2
<i>Phragmites australis</i>	-2.5 to -2.4	<i>Acutodesmus acuminatus</i>	-1.3 to -1
<i>Potamogeton crispus</i>	-1 to -0.3	<i>Ankistrodesmus falcatus</i>	-1.2 to -0.7
<i>Potamogeton nodosus</i>	-1 to -0.3	<i>Ankistrodesmus fustiformis</i>	-1.8 to -1.2
<i>Potamogeton perfoliatus</i>	-0.9 to -0.4	<i>Audouinella hermannii</i>	-3 to -1
<i>Ranunculus aquatilis</i>	-1.6 to -0.3	<i>Botryococcus braunii</i>	-3 to -1
<i>Ranunculus fluitans</i>	-0.8 to -0.5	<i>Botryococcus protuberans</i>	-1.8 to -1.2
<i>Ranunculus peltatus</i>	-1.6 to -0.1	<i>Closteriopsis acicularis</i>	-1.8 to -1.2
<i>Ranunculus penicillatus</i>	-1.5 to -0.3	<i>Coelastrum microporum</i>	-1.2 to -0.8
<i>Ranunculus trichophyllus</i>	-2.5 to -2.4	<i>Coenococcus planctonicus</i>	-1.8 to -1.2
<i>Rhynchosstegium riparioides</i>	-2.7 to -0.1	<i>Coleochaete orbicularis</i>	-1.3 to -0.7
<i>Scapania undulata</i>	-1.9 to -0.7	<i>Crucigenia quadrata</i>	-1.8 to -0.8
<i>Sparganium emersum</i>	-1 to -0.3	<i>Crucigenia tetrapedia</i>	-1.8 to -1.2
<i>Stuckenia pectinata</i>	-1 to -0.3	<i>Crucigeniella rectangularis</i>	-1.8 to -1.2
<i>Vallisneria americana</i>	-1.6 to -1.3	<i>Cryptomonas brasiliensis</i>	-1.8 to -1.2
<i>Vallisneria spiralis</i>	-0.9 to -0.3	<i>Cryptomonas nordstedtii</i>	-1.8 to -1.2
<i>Veronica anagallis-aquatica</i>	-2.5 to -2.4	<i>Desmodesmus abundans</i>	-1.3 to -1
<i>Veronica beccabunga</i>	-2.7 to -2.4	<i>Dictyosphaerium ehrenbergianum</i>	-1.8 to -1.2
(k) Non-silicon-based algae		<i>Elakatothrix gelifacta</i>	-1.3 to -1
Temperate		<i>Eudorina elegans</i>	-1.8 to -1.2
<i>Actinastrum hantzschii</i>	-1.2 to -0.3	<i>Gloeocystis banneergattensis</i>	-3 to -1
<i>Chlamydomonas angulosa</i>	-1.2 to -0.1	<i>Gonium pectorale</i>	-1.2 to -0.8
<i>Chlamydomonas globosa</i>	-1.2 to -0.4	<i>Hariotina reticulata</i>	-1.2 to -0.8
<i>Cladophora glomerata</i>	-1 to 0	<i>Hydrosera whampoensis</i>	-3 to -1
<i>Cryptomonas erosa</i>	-1.2 to 0.1	<i>Kirchneriella obesa</i>	-1.8 to -1.2
		<i>Kirchneriella roselata</i>	-1.8 to -1.2

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Klebsormidium subtilissimum</i>	-1.3 to -1	<i>Achnanthydium rivulare</i>	-1.7 to 0
<i>Korshikoviella limnetica</i>	-1.1 to -0.7	<i>Amphora inariensis</i>	-1.4 to 0.1
<i>Monactinus simplex</i>	-1.3 to -1	<i>Amphora ovalis</i>	-1.3 to -1
<i>Monoraphidium arcuatum</i>	-1.8 to -1.2	<i>Amphora pediculus</i>	-1.3 to 0.2
<i>Monoraphidium contortum</i>	-1.8 to -1.2	<i>Amphora perpusilla</i>	-1.3 to -0.7
<i>Monoraphidium convolutum</i>	-1.8 to -1.2	<i>Asterionella formosa</i>	-1.2 to -0.4
<i>Monoraphidium fontinale</i>	-1.8 to -1.2	<i>Aulacoseira granulata</i>	-1.2 to 0.4
<i>Monoraphidium irregulare</i>	-1.8 to -0.8	<i>Aulacoseira italica</i>	-1.2 to -0.1
<i>Monoraphidium komarkovae</i>	-1.8 to -1.2	<i>Aulacoseira varians</i>	-1.2 to -0.1
<i>Monoraphidium minutum</i>	-1.8 to -1.2	<i>Bacillaria paxillifera</i>	-1.1 to 0.4
<i>Monoraphidium tortile</i>	-1.8 to -1.2	<i>Caloneis bacillum</i>	-1.3 to 0.2
<i>Mucidosphaerium pulchellum</i>	-1.8 to -1.2	<i>Cocconeis pediculus</i>	-1.4 to 0
<i>Nephrocycitium lunatum</i>	-1.8 to -1.2	<i>Cocconeis placentula</i>	-1.6 to 0.2
<i>Pandorina morum</i>	-1.3 to -1	<i>Cyclostephanos dubius</i>	-1.2 to -0.1
<i>Parapediastrum biradiatum</i>	-1.3 to -1	<i>Cyclotella atomus</i>	-0.8 to 0.3
<i>Pediastrum duplex</i>	-3 to -0.7	<i>Cyclotella comta</i>	-1.2 to -0.1
<i>Pseudopediastrum boryanum</i>	-1.3 to -0.7	<i>Cyclotella meneghiniana</i>	-1.2 to 0.2
<i>Scenedesmus bijuga</i>	-1.3 to -0.8	<i>Cyclotella pseudostelligera</i>	-1.1 to 0.3
<i>Scenedesmus obliquus</i>	-1.2 to -0.8	<i>Cymatopleura elliptica</i>	-1.2 to -0.5
<i>Scenedesmus quadricauda</i>	-3 to -0.7	<i>Cymatopleura solea</i>	-1.2 to -0.1
<i>Schizomeris leibleinii</i>	-1.2 to -0.8	<i>Cymbella affinis</i>	-1.3 to -0.9
<i>Sphaerocystis planctonica</i>	-3 to -1	<i>Cymbella prostrata</i>	-1.3 to -1.2
<i>Sphaerocystis schroeteri</i>	-3 to -1	<i>Cymbella tumida</i>	-1.4 to -0.1
<i>Stauridium tetras</i>	-1.3 to -1	<i>Diademsis contenta</i>	-1.7 to -1
<i>Tetraedron minimum</i>	-1.3 to -0.7	<i>Diatoma vulgare</i>	-1.4 to 0.1
<i>Tetraedron trigonum</i>	-1.2 to -0.8	<i>Didymosphenia geminata</i>	-3 to -0.2
<i>Ulothrix tenerrima</i>	-1.2 to -0.8	<i>Discostella stelligera</i>	-1.2 to -0.4
(l) Silicon-based algae		<i>Encyonema minutum</i>	-1.5 to 0
Temperate		<i>Eolimna minima</i>	-1.5 to 0.2
<i>Achnanthes abundans</i>	-1.7 to -1	<i>Eolimna rutneri</i>	-1.1 to 0.3
<i>Achnanthes cotteriensis</i>	-1.7 to -1	<i>Epithemia adnata</i>	-1.2 to -0.1
<i>Achnanthes exigua</i>	-1.1 to 0.3	<i>Eunotia intermedia</i>	-1.7 to -1.4
<i>Achnanthes lapidosa</i>	-1.7 to -1.4	<i>Fallacia pygmaea</i>	-0.3 to 0
<i>Achnanthes subhudsonis</i>	-1.3 to 0.2	<i>Fragilaria capucina</i>	-1.1 to 0.2
<i>Achnanthydium biasolettianum</i>	-0.8 to -0.2	<i>Fragilaria crotonensis</i>	-1.2 to -0.1
<i>Achnanthydium minutissimum</i>	-2.7 to 0	<i>Frustulia rhomboides</i>	-1.7 to -1
		<i>Frustulia vulgare</i>	-1.2 to 0.2

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Geissleria decussis</i>	-1.4 to 0	<i>Navicula tripunctata</i>	-1.4 to 0.1
<i>Gomphonema angustatum</i>	-1 to -0.5	<i>Navicula trivialis</i>	-1.1 to 0.3
<i>Gomphonema clavatum</i>	-1.5 to -1	<i>Navicula veneta</i>	-1.7 to -0.5
<i>Gomphonema kobayashiae</i>	-1.1 to 0.3	<i>Nitzschia acicularis</i>	-0.5 to -0.1
<i>Gomphonema minutum</i>	-1.4 to 0.1	<i>Nitzschia amphibia</i>	-1.1 to 0.3
<i>Gomphonema olivaceum</i>	-0.7 to -0.2	<i>Nitzschia archibaldii</i>	-1.4 to 0.1
<i>Gomphonema parvulum</i>	-1.7 to 0.1	<i>Nitzschia capitellata</i>	-1.1 to 0.3
<i>Gomphonema parvulum</i> f. <i>saprophilum</i>	-1.3 to -1	<i>Nitzschia confinis</i>	-0.7 to -0.3
<i>Gyrosigma acuminatum</i>	-1.2 to 0.1	<i>Nitzschia constricta</i>	-1 to -0.3
<i>Hippodonta capitata</i>	-1.1 to 0.2	<i>Nitzschia dissipata</i>	-1.2 to 0.2
<i>Karayevia oblongella</i>	-1.7 to -0.5	<i>Nitzschia fonticola</i>	-1.6 to 0
<i>Luticola goeppertiana</i>	-0.8 to 0.4	<i>Nitzschia frustulum</i>	-1.7 to -0.1
<i>Mayamaea agrestis</i>	-1.1 to 0.3	<i>Nitzschia inconspicua</i>	-1.7 to 0.3
<i>Mayamaea atomus</i>	-1.5 to 0.2	<i>Nitzschia liebethuthii</i>	-1.3 to 0.2
<i>Melosira varians</i>	-1.3 to 0.2	<i>Nitzschia linearis</i>	-1.4 to 0
<i>Navicula antonii</i>	-1.6 to 0	<i>Nitzschia palea</i>	-1.7 to 0.2
<i>Navicula canalis</i>	-1.2 to 0.3	<i>Nitzschia paleacea</i>	-0.3 to -0.1
<i>Navicula capitatoradiata</i>	-1.3 to 0.1	<i>Nitzschia recta</i>	-1.3 to 0.3
<i>Navicula cincta</i>	-0.8 to -0.7	<i>Nitzschia supralitorea</i>	-1.7 to -0.5
<i>Navicula cryptocephala</i>	-1.5 to 0.1	<i>Planothidium conspicuum</i>	-1.2 to 0.3
<i>Navicula cryptotenella</i>	-1.7 to 0.1	<i>Planothidium frequentissimum</i>	-1.7 to 0.2
<i>Navicula erifuga</i>	-1.2 to 0.2	<i>Planothidium lanceolatum</i>	-1.3 to 0.2
<i>Navicula germainii</i>	-1.2 to 0.2	<i>Reimeria sinuata</i>	-1.4 to 0.1
<i>Navicula gregaria</i>	-1.2 to 0.2	<i>Rhoicosphenia abbreviata</i>	-1.7 to 0.2
<i>Navicula heimansioides</i>	-1.7 to -1.4	<i>Sellaphora pupula</i>	-1.1 to 0.3
<i>Navicula ingenua</i>	-1.1 to 0.2	<i>Sellaphora seminulum</i>	-1.7 to 0.3
<i>Navicula menisculus</i>	-0.3 to 0	<i>Staurastrum tetracerum</i>	-1.2 to -0.4
<i>Navicula perminuta</i>	-1.3 to 0.2	<i>Staurosira construens</i>	-1.1 to 0.2
<i>Navicula radiosa</i>	-0.9 to -0.6	<i>Staurosirella pinnata</i>	-1.2 to 0.1
<i>Navicula recens</i>	-1 to 0.2	<i>Stephanodiscus hantzschii</i>	-1.2 to -0.1
<i>Navicula rhynchocephala</i>	-1.2 to -0.1	<i>Surirella brebissonii</i>	-1.3 to -0.5
<i>Navicula rostellata</i>	-1.2 to 0.2	<i>Surirella linearis</i>	-1.1 to -0.1
<i>Navicula schroeteri</i>	-1.7 to -0.5	<i>Surirella minuta</i>	-1.4 to -0.6
<i>Navicula subminuscula</i>	-1.1 to 0.2	<i>Surirella splendida</i>	-1.2 to -0.4
<i>Navicula symmetrica</i>	-1.2 to 0.2	<i>Synedra ulna</i>	-1.3 to 0.1
<i>Navicula texana</i>	-0.6 to -0.1	<i>Tabularia fasciculata</i>	-1.4 to -1
<i>Navicula tridentula</i>	-1.7 to -0.5	<i>Ulnaria acus</i>	-1.2 to -0.1

Supporting information

Species	¹⁰ log TP	Species	¹⁰ log TP
(Sub)tropical		<i>Eunotia intermedia</i>	-3 to -0.1
<i>Achnanthes exigua</i>	-3 to -0.1	<i>Eunotia monodon</i>	-3 to -0.4
<i>Achnanthes inflata</i>	-1.9 to -1	<i>Eunotia papilio</i>	-2.2 to -0.4
<i>Achnanthes rupestris</i>	-1.8 to -0.7	<i>Eunotia pectinalis</i>	-3 to -0.1
<i>Achnantheidium biasolettianum</i>	-3 to -0.1	<i>Eunotia praerupta</i>	-3 to -0.4
<i>Achnantheidium minutissimum</i>	-3 to -0.1	<i>Eunotia sudetica</i>	-3 to -0.1
<i>Achnantheidium subsalsum</i>	-1.9 to -0.7	<i>Fallacia monoculata</i>	-2 to 0.7
<i>Amphipleura lindheimeri</i>	-3 to -0.7	<i>Fragilaria capucina</i>	-3 to 0.5
<i>Amphora copulata</i>	-3 to -0.1	<i>Fragilaria crotonensis</i>	-1.2 to -0.7
<i>Amphora ovalis</i>	-1.1 to -0.7	<i>Fragilaria gouldarii</i>	-3 to -1
<i>Aulacoseira agassizii</i>	-3 to -0.1	<i>Frustulia rhomboides</i>	-3 to -0.1
<i>Aulacoseira alpigena</i>	-3 to -0.1	<i>Frustulia saxonica</i>	-3 to -0.1
<i>Aulacoseira ambigua</i>	-3 to -0.4	<i>Frustulia vulgaris</i>	-3 to -0.1
<i>Aulacoseira distans</i>	-3 to 0.7	<i>Gomphonema acuminatum</i>	-3 to 0.7
<i>Aulacoseira granulata</i>	-3 to 0.5	<i>Gomphonema angustatum</i>	-3 to 0.5
<i>Aulacoseira herzogii</i>	-1.8 to -1.2	<i>Gomphonema augur</i>	-3 to -0.1
<i>Caloneis hyalina</i>	-2.2 to -1.5	<i>Gomphonema augur var. turris</i>	-2.2 to -0.4
<i>Caloneis limosa</i>	-1.3 to -1	<i>Gomphonema gracile</i>	-3 to -0.1
<i>Cocconeis placentula</i>	-1.9 to -0.7	<i>Gomphonema intricatum</i>	-1.8 to -1
<i>Conticribra weissflogii</i>	-3 to -0.4	<i>Gomphonema minuta</i>	-1.2 to -0.8
<i>Craticula cuspidata</i>	-3 to 0.7	<i>Gomphonema olivaceum</i>	-3 to -0.1
<i>Cyclotella meneghiniana</i>	-3 to 0.7	<i>Gomphonema parvulum</i>	-3 to 0.7
<i>Cyclotella pseudostelligera</i>	-3 to 0.7	<i>Gyrosigma scalproides</i>	-1.8 to -0.7
<i>Cymatopleura solea</i>	-1.3 to -1	<i>Hantzschia amphioxys</i>	-3 to -0.1
<i>Cymbella tumida</i>	-1.8 to -0.7	<i>Luticola goeppertiana</i>	-3 to 0.7
<i>Cymbopleura naviculiformis</i>	-3 to -0.1	<i>Melosira lineata</i>	-1.8 to -1
<i>Diademsis contenta</i>	-3 to 0.7	<i>Melosira varians</i>	-3 to -0.1
<i>Diademsis dissimilis</i>	-3 to -0.4	<i>Navicula clementis</i>	-3 to -0.1
<i>Diatoma anceps</i>	-3 to -0.1	<i>Navicula cryptocephala</i>	-3 to 0.1
<i>Diatoma vulgare</i>	-3 to -0.1	<i>Navicula cryptotenella</i>	-3 to 0.7
<i>Discostella stelligera</i>	-2.2 to -1.2	<i>Navicula oblonga</i>	-3 to -0.1
<i>Encyonema neomesianum</i>	-3 to -0.1	<i>Navicula radiosa</i>	-3 to -0.1
<i>Encyonema silesiacum</i>	-3 to 0.7	<i>Navicula rostellata</i>	-3 to -0.1
<i>Encyonema ventricosum</i>	-3 to -1	<i>Navicula schroeteri</i>	-1.8 to -0.7
<i>Eunotia bilunaris</i>	-3 to 0.5	<i>Navicula viridula</i>	-1.8 to -0.7
<i>Eunotia camelus</i>	-3 to -0.1	<i>Neidium affine</i>	-3 to -0.1
		<i>Neidium ampliatum</i>	-1.8 to -1.5

Appendix S5.2

Species	¹⁰ log TP	Species	¹⁰ log TP
<i>Nitzschia acicularis</i>	-1.8 to -1.2	<i>Thalassiosira proschkinae</i>	-1.3 to -0.7
<i>Nitzschia amphibia</i>	-1.9 to -0.7	<i>Ulnaria delicatissima</i>	-1.3 to -0.7
<i>Nitzschia gracilis</i>	-1.8 to -1.2	<i>Ulnaria ulna</i>	-3 to 0.7
<i>Nitzschia linearis</i>	-3 to 0.2	<i>Urosolenia eriensis</i>	-1.8 to -1.2
<i>Nitzschia obtusa</i>	-1.8 to -0.7	<i>Urosolenia longiseta</i>	-1.8 to -1.2
<i>Nitzschia palea</i>	-3 to 0.7		
<i>Nitzschia recta</i>	-3 to 0.7		
<i>Nitzschia scalaris</i>	-3 to -0.1		
<i>Nupela praecipua</i>	-3 to 0.7		
<i>Orthoseira dendroteres</i>	-3 to -0.4		
<i>Pinnularia brauniana</i>	-3 to 0.7		
<i>Pinnularia divergens</i>	-3 to -0.1		
<i>Pinnularia gibba</i>	-3 to 0.7		
<i>Pinnularia lata</i>	-3 to -0.1		
<i>Pinnularia legumen</i>	-3 to -0.1		
<i>Pinnularia mesolepta</i>	-1.8 to -1.2		
<i>Pinnularia microstauron</i>	-2.2 to 0.7		
<i>Pinnularia rupestris</i>	-1.8 to -1.2		
<i>Pinnularia subcapitata</i>	-2 to 0.7		
<i>Planothidium dubium</i>	-3 to -0.1		
<i>Planothidium heteroideum</i>	-3 to -0.1		
<i>Planothidium lanceolatum</i>	-3 to 0.7		
<i>Psammothidium subatomoides</i>	-3 to 0.2		
<i>Rhoicosigma compactum</i>	-1.8 to -0.1		
<i>Rhoicosphenia abbreviata</i>	-3 to 0.7		
<i>Rhopalodia gibba</i>	-1.2 to -0.7		
<i>Sellaphora pupula</i>	-3 to 0.7		
<i>Stauroneis phoenicenteron</i>	-3 to -0.1		
<i>Staurosira construens</i>	-1.9 to -0.9		
<i>Stephanodiscus hantzschii</i>	-1.3 to -0.7		
<i>Surirella angusta</i>	-3 to -0.1		
<i>Surirella biseriata</i>	-1.8 to -0.7		
<i>Surirella linearis</i>	-3 to -0.1		
<i>Surirella minuta</i>	-3 to -0.4		
<i>Surirella robusta</i>	-3 to -0.1		
<i>Surirella tenera</i>	-3 to -0.7		
<i>Synedra ulna</i>	-3 to 0.5		

Supporting information

Table S5.2.3 Overview of the relative number of species which are also found exclusively at TP levels below the defined optimum TP level (C_{opt}), at both TP conditions below and above C_{opt} , and at conditions exclusively above C_{opt} .

Region	Freshwater type	Trophic group	Exclusively below C_{opt}	Below and above C_{opt}	Exclusively above C_{opt}
(Sub)tropical	Lake	Autotroph	0.55	0.41	0.04
(Sub)tropical	Lake	Heterotroph	0.22	0.33	0.44
(Sub)tropical	River	Autotroph	0.01	0.91	0.08
(Sub)tropical	River	Heterotroph	0.11	0.11	0.78
Cold	Lake	Autotroph	0.22	0.72	0.06
Cold	Lake	Heterotroph	0.07	0.89	0.04
Cold	River	Heterotroph	0	0.5	0.5
Temperate	Lake	Autotroph	0.2	0.69	0.12
Temperate	Lake	Heterotroph	0.17	0.67	0.16
Temperate	River	Autotroph	0.15	0.79	0.07
Temperate	River	Heterotroph	0.09	0.78	0.13
Xeric	Lake	Autotroph	0	0.93	0.07
Xeric	Lake	Heterotroph	0	0.5	0.5

Appendix S5.2

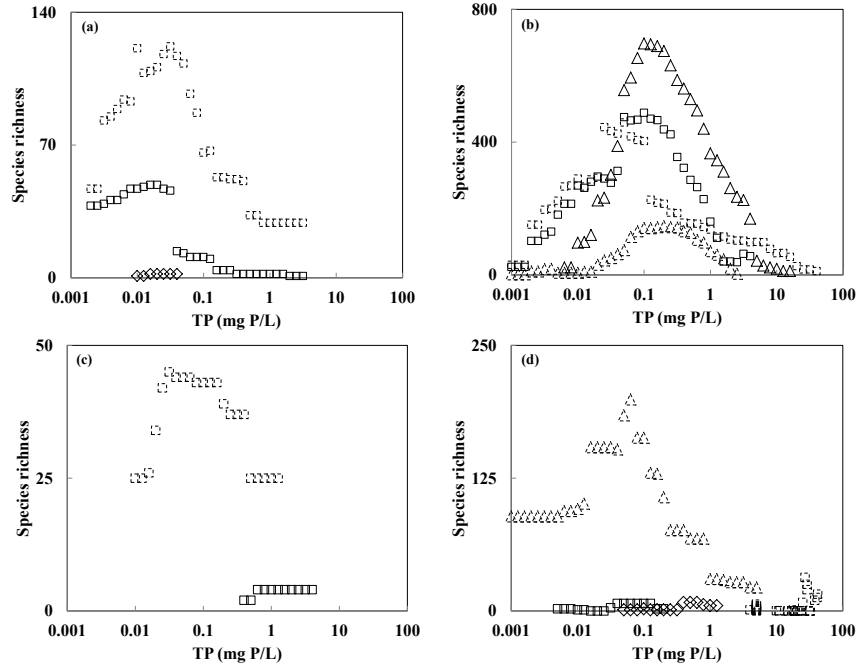


Figure S5.2.1 Scatter plots of species richness – total phosphorus (TP) concentration across regions. Species richness – TP relationships used to identify C_{opt} (shown in Table 5.1 in the main text) and the empirical relative species richness (eRSR) used to derive the calculated relative species richness (cRSR) for (a) cold, (b) temperate, (c) xeric, and (d) (sub)tropical regions. Lakes and streams are shown in square and triangle symbols and autotrophs and heterotrophs are shown in dashed and continuous marker lines.

Appendix S5.3 Internal validation and method testing at multiple spatial scales and different taxonomic groups

In a first step of the internal validation, we repeated the method we applied for the regions as described in the main text for more specific spatial scales. These are regions within realms, ecoregions within regions, and studies within regions. For example, the temperate region (Figure 2 of main text), is distributed among different world realms (Neotropical, Palearctic, etc). Here, evaluated how the log-logistic coefficients α and β differed across the different spatial units (Tables S5.3.1 – S5.3.4).

In a second step of the internal validation, we repeated the method for more specific taxonomic groups. We divided autotrophs into cyanobacteria, silicon-based algae, non-silicon-based algae, and macrophytes, and heterotrophs into fish and invertebrates. Again, we evaluated how the log-logistic coefficients α and β across the different taxonomic units (Tables S5.3.5 – S5.3.8).

Table S5.3.1 Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R^2 and p-value of the regressions at the (a) ecoregion level, (b) study, and (c) realm level of spatial aggregation for autotrophs in lakes.

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	R^2 / p-value
(a) Ecoregion								
Cold								
Barents Sea Drainages [#]	1	7	7	0.004 to 0.079	0.01	1.59 (-3.26 to 6.44)	-1.63 (-4.21 to 0.94)	0.57 / <0.001
Canadian Arctic Archipelago	1	36	32	0.002 to 0.025	0.005	-1.94 (-2.02 to -1.85)	-0.10 (-0.17 to -0.02)	0.90 / <0.001
Iceland - Jan Mayen [#]	1	35	34	0.003 to 0.079	0.005	-0.96 (-1.05 to -0.87)	-0.32 (-0.39 to -0.25)	0.95 / <0.001
Northern Baltic Drainages	3	19	17	0.01 to 0.398	0.01	-1.22 (-3.45 to 1.00)	-0.01 (-0.81 to 0.79)	0.95 / <0.001
Temperate								

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Alaska & Canada Pacific Coastal [#]	1	13	13	0.006 to 0.013	0.006	No successful fit with the log-logistic regression		
Biwa Ko [#]	1	23	23	0.006 to 0.01	0.006	No successful fit with the log-logistic regression		
Central & Western Europe	20	79	64	0.002 to 1.585	0.05	-0.52 (-0.57 to -0.48)	-0.28 (-0.33 to -0.24)	0.97 / <0.001
Dniester - Lower Danube [#]	1	6	6	0.025 to 0.2	0.05	-0.57 (-1.07 to -0.06)	-0.36 (-0.84 to 0.12)	0.68 / <0.001
Eastern Iberia	2	66	43	0.002 to 15.849	0.316	1.10 (1.02 to 1.18)	-0.36 (-0.44 to -0.28)	0.93 / <0.001
English - Winnipeg Lakes	3	36	34	0.006 to 0.398	0.013	-1.26 (-1.35 to -1.16)	-0.16 (-0.19 to -0.12)	0.99 / <0.001
Gulf of Venice Drainages	3	41	41	0.003 to 0.032	0.006	-1.59 (-1.83 to -1.36)	-0.27 (-0.54 to 0.00)	0.73 / <0.001
Italian Peninsula & Islands [#]	1	40	40	0.025 to 0.1	0.04	No successful fit with the log-logistic regression		
Laguna dos Patos [#]	1	1	10	0.02 to 0.158	0.02	No successful fit with the log-logistic regression		
Laurentian Great Lakes	4	52	52	0.002 to 0.025	0.016	-1.60 (-1.61 to -1.60)	-0.010 (-0.013 to 0.001)	1.00 / <0.001
Lower Parana	2	15	14	0.01 to 1.585	0.02	-0.98 (-1.00 to -0.95)	-0.05 (-0.07 to -0.03)	0.98 / <0.001
Lower Yangtze	5	50	47	0.013 to 0.631	0.05	-0.64 (-0.71 to -0.58)	-0.24 (-0.30 to -0.18)	0.95 / <0.001
New Zealand [#]	1	98	98	0.002 to 0.1	0.002	No successful fit with the log-logistic regression		
Northeast US & Southeast Canada Atlantic Drainages [#]	2	88	88	0.002 to 0.05	0.025	-1.05 (-1.91 to -0.19)	-0.14 (-0.54 to 0.26)	0.77 / 0.001
Northern British Isles	6	43	25	0.002 to 0.079	0.02	-1.38 (-1.44 to -1.32)	-0.13 (-0.19 to -0.08)	0.96 / <0.001
Oregon & Northern California Coastal [#]	1	27	27	0.025 to 0.032	0.025	No successful fit with the log-logistic regression		

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Scotia - Fundy	1	54	33	0.003 to 6.31	0.003	0.60 (0.30 to 0.89)	-0.83 (-1.12 to -0.54)	0.77 / <0.001
Southern Baltic Lowlands [#]	2	117	117	0.02 to 0.2	0.025	No successful fit with the log-logistic regression		
St.Lawrence	3	36	36	0.001 to 0.032	0.005	-1.55 (-1.70 to -1.41)	-0.23 (-0.39 to -0.08)	0.83 / <0.001
Upper Danube	3	27	21	0.006 to 0.316	0.01	-0.90 (-0.16 to -0.63)	-0.71 (-1.10 to -0.32)	0.71 / <0.001
Upper Mackenzie [#]	3	25	16	0.005 to 39.811	0.013	2.29 (-1.86 to 6.44)	-5.69 (-14.86 to 3.48)	0.51 / <0.001
Upper Mississippi [#]	1	16	16	0.04 to 0.063	0.04	No successful fit with the log-logistic regression		
Volga – Ural [#]	3	3	3	0.05 to 0.126	0.063	-0.80 (-1.61 to 0.02)	-0.22 (-1.03 to 0.59)	0.67 / 0.018
Western Iberia	5	59	59	0.02 to 15.849	0.2	0.60 (0.45 to 0.75)	-0.48 (-0.65 to -0.31)	0.84 / <0.001
Western Transcaucasia [#]	1	27	27	0.05 to 0.2	0.05	-0.65 (-0.74 to -0.57)	-0.13 (-0.21 to -0.05)	0.92 / <0.001
Xeric								
Western Mongolia	2	45	45	0.01 to 1.259	0.032	0.03 (-0.07 to 0.14)	-0.39 (-0.50 to -0.28)	0.91 / <0.001
(Sub)tropical								
Florida Peninsula [#]	1	5	5	0.032 to 0.2	0.05	-0.67 (-0.70 to -0.64)	-0.08 (-0.11 to -0.05)	0.97 / <0.001
Iguassu [#]	1	15	15	0.003 to 0.013	0.003	No successful fit with the log-logistic regression		
Northeastern Caatinga & Coastal Drainages [#]	3	26	16	0.005 to 0.794	0.631	No successful fit with the log-logistic regression		
Papaloapan [#]	1	3	3	0.631 to 7.943	1.259	No successful fit with the log-logistic regression		
Southeastern Ghats [#]	1	46	42	7.943 to 31.623	15.849	1.58	-0.20	0.72 / <0.001

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Western Taiwan [#]	1	5	5	0.005 to 0.079	0.005	(0.98 to 2.18) No successful fit with the log-logistic regression	(-0.78 to 0.39)	0.013
(b) Study Cold								
Devlin & Finkelstein (2011) [#]		36	32	0.002 to 0.013	0.005	-1.85 (-2.22 to -1.49)	-0.21 (-0.57 to 0.16)	0.72 / 0.002
Hessen & Leu (2006) [#]		7	7	0.004 to 0.079	0.01	1.59 (-3.26 to 6.44)	-1.63 (-4.21 to 0.94)	0.57 / <0.001
Izaguirre <i>et al.</i> (1993) [#]		13	12	0.025 to 0.398	0.2	-0.01 (-1.87 to 1.85)	-0.2 (-1.31 to 0.77)	0.66 / 0.003
Karst-Riddoch <i>et al.</i> (2009) [#]		35	34	0.003 to 0.079	0.005	-0.96 (-1.05 to -0.87)	-0.32 (-0.39 to -0.25)	0.95 / <0.001
Mäkelä <i>et al.</i> (2004) [#]		16	16	0.01 to 0.05	0.01	No successful fit with the log-logistic regression		
Oirik (1998) [#]		2	2	0.126 to 0.398	0.126	No successful fit with the log-logistic regression		
Suutari <i>et al.</i> (2009) [#]		1	1	0.025 to 0.251	0.025	No successful fit with the log-logistic regression		
Vinocur & Pizarro (2000)		71	65	0.002 to 3.162	0.032	-0.01 (-0.15 to 0.12)	-0.70 (-0.87 to -0.54)	0.88 / <0.001
Temperate								
Armstrong <i>et al.</i> (2003) [#]		4	4	0.013 to 0.063	0.013	-1.19 (-1.19 to -1.19)	-0.01 (-0.008 to -0.007)	1.00 / <0.001
Bagella <i>et al.</i> (2010) [#]		27	27	0.05 to 0.2	0.05	-0.65 (-0.74 to -0.57)	-0.13 (-0.21 to -0.05)	0.92 / <0.001
Bennion <i>et al.</i> (1995) [#]		10	10	0.01 to 0.032	0.02	-1.17 (-6.35 to 4.01)	-0.16 (-2.35 to 2.04)	0.71 / 0.032
Cabecinha <i>et al.</i> (2009a)		51	51	0.04 to 15.849	0.2	0.60 (0.41 to 0.79)	-0.53 (-0.75 to -0.31)	0.79 / <0.001
Cabecinha <i>et al.</i> (2009b)		22	22	0.02 to 7.943	0.158	0.61 (0.41 to 0.81)	-0.43 (-0.65 to -0.22)	0.78 / <0.001

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Capers <i>et al.</i> (2009) [#]		77	77	0.025 to 0.05	0.025	No successful fit with the log-logistic regression		
Caputo <i>et al.</i> (2008) [#]		15	7	0.006 to 3.162	0.025	No successful fit with the log-logistic regression		0.99 / <0.001
Casco <i>et al.</i> (2009)		14	14	0.01 to 0.126	0.02	(-0.99 to -0.96)	(-0.06 to -0.04)	0.88 / <0.001
Chen <i>et al.</i> (2008) [#]		11	5	0.005 to 0.079	0.025	(-1.07 to -1.07)	(-0.18 to -0.18)	0.88 / <0.001
Coops <i>et al.</i> (2008)		4	4	0.04 to 0.2	0.05	No successful fit with the log-logistic regression		
Dasi <i>et al.</i> (1998) [#]		41	37	0.025 to 15.849	0.398	1.21	(-0.32 to -0.04)	0.87 / <0.001
De Backer <i>et al.</i> (2010) [#]		2	2	0.04 to 0.316	0.126	(1.09 to 1.34)	(-0.43 to -0.20)	<0.001
Del Pozo <i>et al.</i> (2010) [#]		1	1	0.05 to 6.31	0.05	No successful fit with the log-logistic regression		
DeNicola <i>et al.</i> (2004)		15	6	0.005 to 0.063	0.016	(-1.51 to -1.51)	(-0.09 to -0.09)	0.95 / <0.001
Edlund <i>et al.</i> (2009) [#]		16	16	0.04 to 0.063	0.04	(-1.56 to -1.45)	(-0.14 to -0.04)	<0.001
Ek Dahl <i>et al.</i> (2007)		20	20	0.002 to 0.025	0.008	No successful fit with the log-logistic regression		
Free <i>et al.</i> (2009) [#]		4	4	0.002 to 0.063	0.003	(-1.609 to -1.608)	(-0.007 to -0.006)	1.00 / <0.001
Gacia <i>et al.</i> (1994)		13	13	0.002 to 0.316	0.006	(-1.04 to -1.04)	(-0.19 to -0.19)	0.83 / <0.001
Gregory-Eaves <i>et al.</i> (2003) [#]		13	13	0.006 to 0.013	0.006	(-1.55 to -1.55)	(-0.19 to -0.19)	0.92 / <0.001
Haberman <i>et al.</i> (2010) [#]		1	1	0.02 to 0.2	0.02	(-1.63 to -1.47)	(-0.26 to -0.12)	<0.001
Hausmann & Pienitz (2007) [#]		20	20	0.001 to 0.01	0.001	No successful fit with the log-logistic regression		
Hazewinkel <i>et al.</i> (2008) [#]		11	11	5.012 to 39.811	19.953	No successful fit with the log-logistic regression		
Hiit <i>et al.</i> (2010) [#]		19	17	0.01 to 0.05	0.032	(-1.17 to -1.17)	(-0.39 to -0.39)	0.76 / <0.001
Holz <i>et al.</i> (1997) [#]		2	2	0.126 to 0.398	0.126	1.68	(-0.70 to -0.08)	0.77 / 0.009
Hough & Thompson (1996) [#]		18	18	0.016 to 0.025	0.016	(1.21 to 2.15)	(-0.62 to 0.26)	<0.001
Hsieh <i>et al.</i> (2010) [#]		23	23	0.006 to 0.01	0.006	No successful fit with the log-logistic regression		

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Joniak <i>et al.</i> (2007) [#]		3	3	0.016 to 0.251	0.079	No successful fit with the log-logistic regression		
Kirilova <i>et al.</i> (2008) [#]		11	11	0.02 to 0.126	0.063	No successful fit with the log-logistic regression		
Kirilova <i>et al.</i> (2010) [#]		11	9	0.032 to 0.316	0.063	No successful fit with the log-logistic regression		
Köster & Pienitz (2006) [#]		11	11	0.002 to 0.032	0.002	-0.73 (-0.93 to -0.53)	-0.16 (-0.36 to 0.04)	0.71 / 0.001
Kuczyńska-Kippen & Joniak (2010b) [#]		6	6	0.025 to 1.585	0.063	No successful fit with the log-logistic regression		
Leitão & Légize (2000) [#]		13	13	0.04 to 0.2	0.04	0.74 (0.29 to 1.19)	-0.42 (-0.66 to -0.18)	0.78 / <0.001
Lewin & Smoliński (2006) [#]		18	18	0.01 to 1	0.079	No successful fit with the log-logistic regression		
Mäemets <i>et al.</i> (2010) [#]		116	116	0.025 to 0.1	0.025	0.13 (-0.11 to 0.36)	-0.46 (-0.67 to -0.25)	0.83 / <0.001
McIntire <i>et al.</i> (2007) [#]		27	27	0.025 to 0.032	0.025	No successful fit with the log-logistic regression		
Moser <i>et al.</i> (2000) [#]		12	12	0.005 to 0.032	0.005	No successful fit with the log-logistic regression		
Moss <i>et al.</i> (2005) [#]		7	7	0.04 to 0.398	0.1	No successful fit with the log-logistic regression		
Naselli-Flores & Barone (1998) [#]		40	40	0.025 to 0.1	0.04	-0.41 (-0.71 to -0.11)	-0.39 (-0.79 to 0.01)	0.73 / <0.001
Nedbalová <i>et al.</i> (2006) [#]		11	11	0.002 to 0.01	0.006	No successful fit with the log-logistic regression		
Nixdorf & Deneke (1997) [#]		3	3	0.05 to 0.126	0.063	-1.89 (-4.11 to 0.33)	-0.13 (-1.88 to 1.62)	0.72 / 0.097
Özkan <i>et al.</i> (2010) [#]		4	4	0.025 to 0.063	0.025	-0.80 (-1.61 to 0.02)	-0.22 (-1.03 to 0.59)	0.67 / 0.018
Pacheco <i>et al.</i> (2010) [#]		1	1	0.02 to 0.158	0.02	No successful fit with the log-logistic regression		
Peretyatko <i>et al.</i> (2009) [#]		6	6	0.05 to 0.631	0.126	No successful fit with the log-logistic regression		
Pla <i>et al.</i> (2005) [#]		31	31	0.006 to 0.025	0.006	-0.27 (-0.28 to -0.26)	-0.04 (-0.050 to -0.035)	1.00 / <0.001
Reid (2005) [#]		98	98	0.002 to 0.1	0.002	No successful fit with the log-logistic regression		
Romo <i>et al.</i> (2007) [#]		3	3	0.016 to 0.02	0.016	No successful fit with the log-logistic regression		
Sager & Lachavanne (2009) [#]		4	3	0.003 to 0.079	0.01	No successful fit with the log-logistic regression		
Sass <i>et al.</i> (2010)		10	10	0.001 to 0.1	0.001	-1.14 (-1.14 to -1.14)	-0.22 (-0.22 to -0.22)	0.74 / 0.001

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Schagerl <i>et al.</i> (2010) [#]		10	10	0.006 to 0.316	0.016	(-1.34 to -0.95)	(-0.41 to 0.02)	<0.001
Schlegel <i>et al.</i> (1998) [#]		1	1	0.063 to 0.251	0.063	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	<0.001
Serieyssol <i>et al.</i> (2009) [#]		10	10	0.013 to 0.016	0.013	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	<0.001
Song <i>et al.</i> (2010) [#]		4	4	0.079 to 0.398	0.079	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	<0.001
Srivastava <i>et al.</i> (1995) [#]		54	33	0.003 to 6.31	0.003	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	<0.001
St. Jacques <i>et al.</i> (2005) [#]		11	11	0.002 to 0.025	0.002	0.60	-0.83	0.77 /
Tarkowska-Kukuryk (2011) [#]		10	10	0.05 to 0.398	0.2	(0.30 to 0.89)	(-1.12 to -0.54)	<0.001
Tolotti <i>et al.</i> (2006) [#]		22	22	0.003 to 0.01	0.005	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	0.70 /
Tracy <i>et al.</i> (2003) [#]		18	18	0.016 to 0.02	0.016	-0.53	-0.14	0.080
Trevisan <i>et al.</i> (2010) [#]		22	22	0.006 to 0.032	0.006	-1.11	-0.31	0.65 /
Trigal <i>et al.</i> (2009) [#]		4	4	0.063 to 1.995	0.063	(-4.96 to 2.75)	(-1.52 to 0.90)	<0.001
Unrein <i>et al.</i> (2010) [#]		1	1	0.251 to 1.585	0.251	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	<0.001
Wunsam & Schmidt (1995) [#]		11	11	0.002 to 0.251	0.004	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	<0.001
Xu <i>et al.</i> (2005)		13	13	0.05 to 0.631	0.05	-0.88	-0.16	0.91 /
Yang <i>et al.</i> (2006) [#]		26	26	0.04 to 0.158	0.05	(-0.94 to -0.82)	(-0.22 to -0.11)	<0.001
Ye <i>et al.</i> (2007)		9	9	0.013 to 0.2	0.025	0.20	-0.28	0.80 /
Xeric						(-0.16 to 0.56)	(-0.46 to -0.09)	<0.001
						-0.82	-0.24	0.71 /
						(-1.12 to -0.52)	(-0.58 to 0.11)	0.001
Shinneman <i>et al.</i> (2009a) [#]		8	8	0.01 to 0.158	0.01	-0.74	-0.13	0.89 /
Shinneman <i>et al.</i> (2009b) [#]		40	40	0.01 to 1.259	0.032	(-0.82 to -0.66)	(-0.20 to -0.06)	<0.001
						-0.78	-0.22	0.82 /
						(-0.92 to -0.63)	(-0.36 to -0.09)	<0.001

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
(Sub)tropical								
Bouvy <i>et al.</i> (2003)		13	13	0.005 to 0.2	0.005	-0.95 (-0.99 to -0.90)	-0.13 (-0.17 to -0.08)	0.94 / <0.001
Caballero <i>et al.</i> (2006) [#]		3	3	0.631 to 7.943	1.259	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
Chellappa <i>et al.</i> (2008) [#]		16	16	0.631 to 0.794	0.631	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
da Silva <i>et al.</i> (2005) [#]		15	15	0.003 to 0.013	0.003	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
Havens <i>et al.</i> (1996) [#]		5	5	0.032 to 0.2	0.05	-0.67 (-0.70 to -0.64)	-0.08 (-0.11 to -0.05)	0.97 / <0.001
Rajagopal <i>et al.</i> (2010) [#]		46	42	7.943 to 31.623	15.849	1.58 (0.98 to 2.18)	-0.20 (-0.78 to 0.39)	0.72 / 0.013
Wu & Kow (2010) [#]		5	5	0.005 to 0.079	0.005	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
(c) Realm								
Cold								
Neartic	2	36	32	0.002 to 0.025	0.005	-1.94 (-2.02 to -1.85)	-0.10 (-0.17 to -0.02)	0.90 / <0.001
Palaartic	6	61	56	0.003 to 0.398	0.01	-1.16 (-1.19 to -1.13)	-0.09 (-0.12 to -0.07)	0.98 / <0.001
Temperate								
Australasia [#]	1	98	98	0.002 to 0.1	0.002	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
Neartic	21	241	191	0.001 to 39.811	0.025	-1.09 (-1.34 to -0.84)	-0.88 (-1.15 to -0.61)	0.77 / <0.001
Neotropic	3	16	15	0.01 to 1.585	0.02	-0.96 (-0.99 to -0.94)	-0.06 (-0.07 to -0.04)	0.99 / <0.001
Palaartic	56	410	294	0.002 to 15.849	0.05	-0.40 (-0.53 to -0.28)	-0.57 (-0.70 to -0.44)	0.89 / <0.001
Xeric								
Western Mongolia	2	45	45	0.01 to 1.259	0.032	0.03	-0.39	0.91 /

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Realm						(-0.07 to 0.14)	(-0.50 to -0.28)	<0.001
Palaearctic	1	5	5	0.01 to 1.259	0.032	0.03 (-0.07 to 0.14)	-0.39 (-0.50 to -0.28)	0.91 / <0.001
(Sub)tropical								
Indo-Malay [#]	2	50	42	0.005 to 31.623	15.849	1.57 (0.98 to 2.18)	-0.20 (-0.78 to 0.39)	0.72 / 0.013
Neartic [#]	1	5	5	0.032 to 0.2	0.05	-0.67 (-0.70 to -0.64)	-0.08 (-0.11 to -0.05)	0.97 / <0.001
Neotropical	5	42	27	0.003 to 7.943	0.005	-1.31 (-1.54 to -1.09)	-0.6 (-0.83 to -0.37)	0.77 / <0.001

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10⁴ coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[†] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{corrected, Total}}$, as defined by Schabender & Pierce (2001)

Table S5.3.2 Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R² and p-value of the regressions at the (a) ecoregion level, (b) study, and (c) realm level of spatial aggregation for autotrophs in streams.

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
(a) Ecoregion								

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Temperate								
Bass Strait Drainages [#]	1	27	25	0.02 to 0.316	0.04	-0.44 (-0.68 to -0.19)	-0.33 (-0.55 to -0.10)	0.78 / <0.001
Central & Western Europe	8	31	30	0.013 to 0.794	0.158	-0.26 (-0.30 to -0.21)	-0.08 (-0.12 to -0.04)	0.95 / <0.001
Gulf of Venice Drainages [#]	3	1	11	0.002 to 0.02	0.002	No successful fit with the log-logistic regression		
Northeast US & Southeast Canada Atlantic Drainages [#]	1	67	67	0.02 to 2.512	0.158	No successful fit with the log-logistic regression		
Southeastern Korean Peninsula	2	36	36	0.063 to 0.794	0.079	-0.11 (-0.17 to -0.06)	-0.14 (-0.19 to -0.08)	0.93 / <0.001
St.Lawrence*	1	2	2	0.025 to 0.05	0.025	No successful fit with the log-logistic regression		
Upper Danube [#]	2	14	14	0.002 to 0.004	0.003	No successful fit with the log-logistic regression		
Upper Mississippi	1	44	26	0.04 to 1.585	0.501	-0.07 (-0.10 to -0.04)	-0.08 (-0.11 to -0.05)	0.98 / <0.001
Upper Saskatchewan [#]	1	1	29	0.001 to 0.631	0.001	No successful fit with the log-logistic regression		
(Sub)tropical								
Florida Peninsula	1	64	64	0.05 to 0.2	0.079	-0.75 (-0.84 to -0.67)	-0.10 (-0.19 to 0.00)	0.92 / 0.001
Iguassu [#]	1	23	23	0.001 to 0.1	0.001	No successful fit with the log-logistic regression		
Papaloapan [#]	1	31	31	0.013 to 0.2	0.016	-0.6 (-0.69 to -0.50)	-0.15 (-0.23 to -0.08)	0.9 / <0.001
Upper Parana	3	122	122	0.001 to 5.012	0.016	-0.29 (-0.41 to -0.18)	-0.54 (-0.66 to -0.42)	0.91 / <0.001
(b) Studies								

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Temperate								
Cantonati & Spitale (2009) [#]	1	1	1	0.002 to 0.02	0.002	-0.34 (-0.45 to -0.22)	-0.15 (-0.27 to -0.03)	0.83 / <0.001
Fabris <i>et al.</i> (2009) [#]	14	14	14	0.002 to 0.004	0.003	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	<0.001
Ha <i>et al.</i> (2002) [#]	27	27	27	0.063 to 0.794	0.079	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	0.99 /
Ha <i>et al.</i> (1998) [#]	22	22	22	0.063 to 0.398	0.063	0.00 (-0.02 to 0.03)	-0.12 (-0.14 to -0.11)	<0.001
Kirkwood <i>et al.</i> (2007) [#]	1	1	1	0.001 to 0.631	0.001	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	<0.001
Leland & Porter (2000) [#]	44	44	26	0.04 to 1.585	0.501	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	0.98 /
Lewin (2006) [#]	1	1	1	0.501 to 0.631	0.501	-0.07 (-0.10 to -0.04)	-0.08 (-0.11 to -0.05)	<0.001
Newall & Walsh (2005) [#]	27	25	25	0.02 to 0.316	0.04	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	0.78 /
Ponader <i>et al.</i> (2007)	67	67	67	0.02 to 2.512	0.158	-0.44 (-0.68 to -0.19)	-0.33 (-0.55 to -0.10)	<0.001
Thiébaud (2006) [#]	30	30	30	0.013 to 0.794	0.158	0.24 (0.23 to 0.24)	-0.06 (-0.07 to -0.06)	1.00 / <0.001
Vis <i>et al.</i> (2008) [#]	2	2	2	0.025 to 0.05	0.025	-0.27 (-0.31 to -0.22)	-0.08 (-0.12 to -0.04)	0.96 / <0.001
(Sub)tropical								
Bere & Tundisi (2011) [#]	78	78	78	0.001 to 5.012	0.016	0.11 (0.03 to 0.19)	-0.28 (-0.36 to -0.20)	0.91 / <0.001
Bere & Tundisi (2010) [#]	12	12	12	0.01 to 3.162	0.063	1.44 (0.85 to 2.03)	-0.45 (-0.67 to -0.22)	0.79 / <0.001
Dunn <i>et al.</i> (2008) [#]	64	64	64	0.05 to 0.2	0.079	-0.75 (-0.84 to -0.67)	-0.10 (-0.19 to 0.00)	0.92 / 0.001
Perbiche-Neves <i>et al.</i> (2011) [#]	23	23	23	0.001 to 0.1	0.001	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	0.001
Train & Rodrigues (1998) [#]	55	55	55	0.016 to 0.063	0.016	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ^{2†} / p-value
Vázquez <i>et al.</i> (2011) [#]		31	31	0.013 to 0.2	0.016	-0.6 (-0.69 to -0.50)	-0.15 (-0.23 to -0.08)	0.90 / <0.001
(c) Realm								
Temperate								
Australasia [#]	1	27	25	0.02 to 0.316	0.04	-0.44 (-0.68 to -0.19)	-0.33 (-0.55 to -0.10)	0.78 / <0.001
Neartic	6	97	84	0.001 to 2.512	0.501	0.19 (0.17 to 0.22)	-0.09 (-0.12 to -0.07)	0.99 / <0.001
Palaearctic	19	80	66	0.002 to 0.794	0.158	-0.20 (-0.22 to -0.17)	-0.11 (-0.14 to -0.09)	0.98 / <0.001
(Sub)tropical								
Neartic [#]	1	64	64	0.05 to 0.2	0.079	-0.75 (-0.84 to -0.67)	-0.10 (-0.19 to 0.00)	0.92 / 0.001
Neotropic [#]	5	154	154	0.001 to 5.012	0.016	-0.45 (-0.55 to -0.36)	-0.47 (-0.56 to -0.38)	0.94 / <0.001

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10th coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[†] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{corrected, Total}}$, as defined by Schabenberger & Pierce (2001)

Table S5.3.3 Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R² and p-value of the regressions at the (a) ecoregion level, (b) study, and (c) realm level of spatial aggregation for heterotrophs in lakes.

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
(a) Ecoregion								
Cold								
Barents Sea Drainages	1	2	2	0.002 to 0.063	0.003	-1.34 (-1.47 to -1.22)	-0.24 (-0.37 to -0.10)	0.82 / <0.001
Northern Baltic Drainages	10	51	44	0.002 to 1.585	0.013	-1.43 (-1.46 to -1.40)	-0.03 (-0.05 to 0.00)	0.94 / <0.001
Temperate								
Bonaerensean Drainages [#]	1	4	4	1 to 3.981	1.585	No successful fit with the log-logistic regression		
Central & Western Europe	29	383	335	0.001 to 3.162	0.1	-0.24 (-0.26 to -0.21)	-0.21 (-0.24 to -0.19)	0.99 / <0.001
Dniester - Lower Danube	1	29	27	0.01 to 1.259	0.1	-0.23 (-0.40 to -0.06)	-0.36 (-0.57 to -0.15)	0.79 / <0.001
Eastern Iberia	4	15	14	0.013 to 0.398	0.05	-0.87 (-0.99 to -0.75)	-0.24 (-0.36 to -0.11)	0.85 / <0.001
English - Winnipeg Lakes [#]	2	1	3	0.004 to 0.006	0.004	No successful fit with the log-logistic regression		
Gulf of Venice Drainages [#]	1	14	14	0.003 to 0.01	0.005	-1.28 (-4.46 to 1.90)	-0.30 (-1.47 to 0.87)	0.65 / 0.001
Laguna dos Patos [#]	1	14	13	0.025 to 0.398	0.032	-0.38 (-0.49 to -0.26)	-0.17 (-0.27 to -0.06)	0.82 / <0.001
Laurentian Great Lakes [#]	1	37	37	0.005 to 0.02	0.005	No successful fit with the log-logistic regression		
Lower Parana	5	11	6	0.013 to 3.162	0.2	0.34 (-0.89 to 1.58)	-1.20 (-3.92 to 1.52)	0.52 / <0.001
Lower Yangtze [#]	6	145	95	0.002 to 0.794	0.025	0.06 (-0.75 to 0.87)	-1.23 (-2.33 to -0.13)	0.59 / <0.001
Middle Missouri [#]	1	1	5	0.003 to 0.008	0.003	No successful fit with the log-logistic regression		
Northeast US &	1	6	6	0.008 to 0.05	0.008	No successful fit with the log-logistic regression		

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Cold								
Ask <i>et al.</i> (2009) [#]		1	1	0.006 to 0.025	0.006	No successful fit with the log-logistic regression		
Erös <i>et al.</i> (2009) [#]		1	1	0.01 to 0.063	0.01	No successful fit with the log-logistic regression		
Jansson <i>et al.</i> (2010) [#]		2	2	0.006 to 0.01	0.006	No successful fit with the log-logistic regression		
Jyväsjärvi <i>et al.</i> (2009) [#]		31	31	0.002 to 0.032	0.002	No successful fit with the log-logistic regression		
Nyström <i>et al.</i> (2006) [#]		8	8	0.006 to 0.05	0.016	-1.21 (-1.27 to -1.14)	-0.09 (-0.13 to -0.04)	0.96 / <0.001
Olin <i>et al.</i> (2002) [#]		7	7	0.013 to 0.126	0.013	-0.885 (-0.886 to -0.884)	-0.0085 (-0.009 to -0.008)	1.00 / <0.001
Olin <i>et al.</i> (2010) [#]		10	10	0.006 to 0.05	0.016	-1.29 (-1.5 to -1.08)	-0.20 (-0.42 to 0.01)	0.8 / <0.001
Persson <i>et al.</i> (2004) [#]		3	3	0.002 to 0.01	0.002	No successful fit with the log-logistic regression		
Rydin <i>et al.</i> (2008) [#]		6	6	0.002 to 0.006	0.004	No successful fit with the log-logistic regression		
Vakkilainen <i>et al.</i> (2004)		3	3	0.079 to 1.585	0.251	-0.41 (-0.82 to -0.01)	-0.49 (-1.18 to 0.19)	0.59 / 0.001
Van Geest <i>et al.</i> (2007)		2	2	0.002 to 0.063	0.003	-1.34 (-1.47 to -1.22)	-0.24 (-0.37 to -0.1)	0.82 / <0.001
Vinocur & Pizarro (2000) [#]		1	1	0.016 to 3.162	0.016	No successful fit with the log-logistic regression		
Temperature								
Bagella <i>et al.</i> (2010) [#]		23	23	0.05 to 0.2	0.1	-0.68 (-0.76 to -0.60)	-0.23 (-0.30 to -0.16)	0.94 / <0.001
Beklioglu & Tan (2008)		2	2	0.079 to 0.631	0.079	-0.79	-0.15	0.72 /

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Bertolo <i>et al.</i> (2005) [#]		1	1	0.004 to 0.016	0.004	(-1.11 to -0.47)	(-0.60 to 0.30)	0.052
Carol <i>et al.</i> (2006) [#]		15	14	0.013 to 0.398	0.05	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	0.85 / <0.001
Casas <i>et al.</i> (2011) [#]		1	1	0.01 to 0.04	0.01	(-0.99 to -0.75)	(-0.36 to -0.11)	0.85 / <0.001
Casco <i>et al.</i> (2009) [#]		2	2	0.013 to 0.126	0.013	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
Castro & Gonçalves (2007) [#]		13	13	0.079 to 0.316	0.079	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
Čerba <i>et al.</i> (2010) [#]		10	10	0.01 to 1.259	0.01	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
Cheng <i>et al.</i> (2010) [#]		36	36	0.005 to 0.251	0.063	(-0.37 to -0.02)	(-0.61 to -0.25)	0.80 / <0.001
Coops <i>et al.</i> (2008) [#]		8	8	0.04 to 0.2	0.05	-0.5	-0.13	0.87 / <0.001
Cottene <i>et al.</i> (2001) [#]		6	6	0.2 to 0.501	0.251	(-0.64 to -0.36)	(-0.24 to -0.02)	<0.001
Cronin <i>et al.</i> (2006) [#]		1	1	0.003 to 0.008	0.013	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	0.96 / 0.001
De Backer <i>et al.</i> (2010) [#]		14	13	0.04 to 0.631	0.251	(-0.35 to -0.15)	(-0.17 to 0.01)	0.92 / <0.001
Frost <i>et al.</i> (2003) [#]		2	2	0.004 to 0.158	0.01	(-0.29 to -0.12)	(-0.19 to -0.01)	<0.001
Füreder <i>et al.</i> (2006) [#]		54	54	3.162 to 3.981	3.162	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
Gelinas & Pinel-Alloul (2008) [#]		6	6	0.004 to 0.025	0.008	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
Haberman <i>et al.</i> (2010) [#]		5	5	0.02 to 0.2	0.02	-1.78	-0.13	0.86 / 0.001
Iglesias <i>et al.</i> (2011) [#]		14	13	0.025 to 2.512	0.032	(-1.90 to -1.67)	(-0.25 to -0.01)	0.94 / <0.001
Jeppesen <i>et al.</i> (1998) [#]		6	6	0.398 to 1	0.501	No successful fit with the log-logistic regression	No successful fit with the log-logistic regression	
Kirilova <i>et al.</i> (2010) [#]		14	13	0.032 to 0.316	0.032	(-0.36 (-0.43 to -0.30)	(-0.18 to -0.07)	<0.001
Korosi <i>et al.</i> (2008) [#]		37	37	0.005 to 0.02	0.005	0.19 (-0.51 to 0.90)	(-0.51 to 0.25)	0.78 / 0.002
Kuczyńska-Kippen & Joniak (2010a)		13	13	0.001 to 0.790	0.1	(-0.74 to -0.44)	(-0.36 to -0.04)	0.78 / <0.001
						-0.60	-0.21	0.72 /

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Kuczyńska-Kippen & Joniak (2010) [#]		14	14	0.1 to 0.316	0.1	(-0.84 to -0.36)	(-0.50 to 0.09)	0.002
Liu & Wang (2007) [#]		18	18	0.158 to 0.316	0.251	No successful fit with the log-logistic regression		0.78 / <0.001
Lund <i>et al.</i> (2010) [#]		11	11	0.04 to 0.251	0.04	(-0.38 to -0.01)	(-0.45 to -0.06)	
May (1995) [#]		21	21	0.002 to 0.251	0.002	No successful fit with the log-logistic regression		
May & O'Hare (2005) [#]		10	10	0.005 to 0.016	0.005	No successful fit with the log-logistic regression		
McGarrigle & Champ (1999) [#]		7	7	0.008 to 0.04	0.01	No successful fit with the log-logistic regression		
Meerhoff <i>et al.</i> (2003) [#]		4	4	0.158 to 0.251	0.158	-1.32	(-0.12	0.84 / <0.001
Mehner <i>et al.</i> (2005) [#]		9	9	0.013 to 0.251	0.013	(-1.47 to -1.17)	(-0.23 to 0.00)	
Mehner <i>et al.</i> (2007) [#]		30	30	0.006 to 0.631	0.006	No successful fit with the log-logistic regression		
Mieczan (2010) [#]		1	1	0.025 to 0.398	0.025	No successful fit with the log-logistic regression		
Nedbalová <i>et al.</i> (2006) [#]		35	34	0.002 to 0.01	0.006	No successful fit with the log-logistic regression		
Özkan <i>et al.</i> (2010) [#]		3	3	0.025 to 0.063	0.025	-1.89	(-0.13	0.72 / 0.093
Pereira <i>et al.</i> (2002) [#]		29	24	0.001 to 1.259	1	(-4.19 to 0.42)	(-1.90 to 1.64)	
Post <i>et al.</i> (2008) [#]		6	6	0.008 to 0.05	0.008	No successful fit with the log-logistic regression		
Prchalová <i>et al.</i> (2008) [#]		16	16	0.02 to 0.032	0.02	No successful fit with the log-logistic regression		
Quinlan & Smol (2010) [#]		2	2	0.003 to 0.032	0.003	No successful fit with the log-logistic regression		
STOWA (2010) [#]		259	241	0.01 to 3.162	0.05	No successful fit with the log-logistic regression		
Rosso <i>et al.</i> (2010) [#]		5	5	0.794 to 1.259	0.794	-0.21	(-0.28 to -0.21)	0.99 / <0.001
Sayer <i>et al.</i> (2010) [#]		7	7	0.1 to 0.501	0.1	(-0.25 to -0.17)	(-0.28 to -0.21)	1.00 / <0.001
Schulz <i>et al.</i> (2006) [#]		1	1	0.063 to 1	0.063	0.11	(-0.008	0.65 / <0.001
Shao <i>et al.</i> (2001) [#]		48	48	0.2 to 0.794	0.398	(0.10 to 0.12)	(-0.015 to 0.000)	
Sosnovsky & Quirós (2009) [#]		5	5	1 to 3.981	1.585	No successful fit with the log-logistic regression		
St. Jacques <i>et al.</i> (2005) [#]		9	9	0.002 to 0.025	0.002	No successful fit with the log-logistic regression		

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Stephen <i>et al.</i> (2004) [#]		1	8	0.2 to 1	0.2	No successful fit with the log-logistic regression		
Tarkowska-Kukuryk, M (2011) [#]		10	10	0.05 to 0.398	0.05	No successful fit with the log-logistic regression		0.86 / <0.001
Tátrai <i>et al.</i> (2008) [#]		11	11	0.032 to 0.063	0.032	-0.03 (-0.31 to 0.26)	-0.32 (-0.48 to -0.16)	
Tolotti <i>et al.</i> (2006) [#]		14	14	0.003 to 0.01	0.005	No successful fit with the log-logistic regression		
Tonn <i>et al.</i> (2004)		12	11	0.01 to 0.251	0.01	-1.28 (-4.46 to 1.90)	-0.30 (-1.47 to 0.87)	0.65 / 0.0006
Trigal <i>et al.</i> (2009)		2	2	0.063 to 1.995	0.063	-0.84 (-1.03 to -0.65)	-0.38 (-0.59 to -0.17)	0.78 / <0.001
Vakkilainen <i>et al.</i> (2004) [#]		5	3	0.05 to 1	0.2	No successful fit with the log-logistic regression		
Vidaković & Bogut (2004) [#]		9	9	0.1 to 1	0.1	No successful fit with the log-logistic regression		
Wang <i>et al.</i> (2007) [#]		35	35	0.002 to 0.025	0.002	No successful fit with the log-logistic regression		
Wen <i>et al.</i> (2011) [#]		24	24	0.016 to 0.1	0.016	No successful fit with the log-logistic regression		
Zambrano <i>et al.</i> (2006) [#]		11	11	0.032 to 0.501	0.079	No successful fit with the log-logistic regression		
Xeric								
Jocqué <i>et al.</i> (2007) [#]		5	5	0.398 to 3.981	0.631	No successful fit with the log-logistic regression		
(Sub)tropical								
Catalano <i>et al.</i> (2010) [#]		4	4	0.04 to 0.126	0.04	No successful fit with the log-logistic regression		
Havens <i>et al.</i> (1996) [#]		3	3	0.032 to 0.2	0.032	-0.65 (-0.75 to -0.55)	-0.11 (-0.20 to -0.02)	0.85 / <0.001
Lucca <i>et al.</i> (2010)		2	2	0.005 to 0.013	0.005	-1.93 (-2.06 to -1.80)	-0.09 (-0.23 to 0.05)	0.83 / 0.002
(c) Realm								
Cold								
Palaearctic	13	53	48	0.002 to 1.585	0.013	-1.39 (-1.45 to -1.34)	-0.10 (-0.14 to -0.05)	0.93 / <0.001

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Temperate								
Neartic	11	68	65	0.002 to 0.251	0.01	-1.54 (-1.61 to -1.48)	-0.13 (-0.19 to -0.07)	0.93 / <0.001
Neotropical	5	22	19	0.013 to 3.981	0.158	-0.04 (-0.18 to 0.10)	-0.43 (-0.6 to -0.26)	0.84 / <0.001
Palaearctic	56	615	464	0.001 to 3.981	0.1	-0.19 (-0.23 to -0.15)	-0.24 (-0.28 to -0.20)	0.98 / <0.001
Xeric								
Neartic [#]	1	5	5	0.398 to 3.981	0.501	No successful fit with the log-logistic regression		
(Sub)tropical								
Neartic	2	7	7	0.032 to 0.2	0.04	-0.82 (-0.86 to -0.78)	-0.03 (-0.07 to 0.01)	0.91 / <0.001
Neotropical	2	2	2	0.005 to 0.013	0.005	-1.93 (-2.06 to -1.80)	-0.09 (-0.23 to 0.05)	0.83 / 0.002

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10⁶ coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

$$Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected Total}}, \text{ as defined by Schabenberger \& Pierce (2001)}$$

Table S5.3.4 Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R² and p-value of the regressions at the (a) ecoregion level, (b) study, and (c) realm level of spatial aggregation for heterotrophs in streams.

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
(a) Ecoregion								
Cold								
Iceland - Jan Mayen [#]	1	33	33	0.01 to 0.04	0.016	No successful fit with the log-logistic regression		
Temperate								
Appalachian Piedmont [#]	1	30	30	0.1 to 0.251	0.1	No successful fit with the log-logistic regression		
Central & Western Europe	10	573	520	0.01 to 15.849	0.158	0.02 (-0.01 to 0.05)	-0.30 (-0.32 to -0.27)	0.99 / <0.001
Laurentian Great Lakes [#]	1	34	34	0.04 to 3.162	0.04	No successful fit with the log-logistic regression		
Lower Parana [#]	1	77	77	0.079 to 3.981	0.398	No successful fit with the log-logistic regression		
Middle Missouri	1	33	33	0.02 to 5.012	0.2	0.03 (-0.06 to 0.11)	-0.11 (-0.18 to -0.03)	<0.001 <0.001
New Zealand [#]	2	2	2	0.05 to 1.259	0.05	No successful fit with the log-logistic regression		
Northeast US & Southeast Canada Atlantic Drainages	1	70	20	0.013 to 0.501	0.1	-0.84 (-0.92 to -0.75)	-0.10 (-0.18 to -0.02)	0.87 / 0.001
Patagonia	5	35	33	0.006 to 0.126	0.02	-1.02 (-1.12 to -0.93)	-0.22 (-0.32 to -0.11)	0.90 / <0.001
Southern Iberia [#]	1	1	5	0.01 to 0.025	0.01	No successful fit with the log-logistic regression		
Tennessee [#]	1	7	7	0.02 to 0.398	0.063	No successful fit with the log-logistic regression		
(Sub)tropical								
Florida Peninsula [#]	2	8	7	0.05 to 1.259	0.398	0.21 (0.02 to 0.39)	-0.15 (-0.29 to -0.01)	0.87 / <0.001
Upper Parana [#]	1	1	9	0.1 to 0.631	0.1	No successful fit with the log-logistic regression		

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Bere & Tundisi (2010) [#]		1	1	0.1 to 0.631	0.1	No successful fit with the log-logistic regression	-0.15	0.87 /
Cowell <i>et al.</i> (2004) [#]		7	7	0.398 to 1.259	0.398	(0.02 to 0.39)	(-0.29 to -0.01)	<0.001
Dunn <i>et al.</i> (2008) [#]		1	1	0.05 to 0.1	0.05	No successful fit with the log-logistic regression		
(c) Realm								
Cold								
Palaearctic [#]	1	2	2	0.01 to 0.04	0.016	No successful fit with the log-logistic regression		
Temperate								
Australasia [#]	2	2	2	0.05 to 1.259	0.05	No successful fit with the log-logistic regression		
Neartic	5	156	107	0.013 to 5.012	0.1	0.02 (-0.07 to 0.11)	-0.39 (-0.48 to -0.30)	0.93 / <0.001
Neotropic [#]	6	112	86	0.006 to 3.981	0.079	No successful fit with the log-logistic regression		
Palaearctic	17	574	520	0.01 to 15.849	0.158	0.02 (-0.01 to 0.05)	-0.30 (-0.32 to -0.27)	0.99 / <0.001
(Sub)tropical								
Neartic [#]	2	8	7	0.05 to 1.259	0.398	0.21 (0.02 to 0.39)	-0.15 (-0.29 to -0.01)	0.87 / <0.001
Neotropic [#]	3	1	9	0.1 to 0.631	0.1	No successful fit with the log-logistic regression		

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^u coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[†] $Pseudo - R^2 = 1 - \frac{SS_{Residual}}{SS_{CorrectedTotal}}$, as defined by Schabbenberger & Pierce (2001)

Table S5.3.5 Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R^2 and p value of the regressions at different levels of spatial aggregation for different taxonomic groups of autotrophs in lakes.

Aggregation level	Studies	Species	SR_{max}	TP range	C_{opt}	α (95% CI)	β (95% CI)	R^2 / p-value
(a) Cyanobacteria								
Cold	3	28	25	0.002 to 3.162	0.03	-0.28 (-0.39 to -0.17)	-0.5 (-0.61 to -0.39)	0.89 / <0.001
Temperate	20	28	20	0.006 to 12.589	0.06	-0.33 (-0.5 to -0.16)	-0.75 (-0.96 to -0.54)	0.80 / <0.001
(Sub)tropical	6	36	17	0.003 to 31.623	0.05	-0.71 (-1.63 to 0.22)	-1.72 (-3.29 to -0.16)	0.16 / <0.001
(b) Macrophyte								
Cold [#]	3	17	17	0.01 to 0.251	0.03	-1.22 (-2.28 to -0.17)	-0.01 (-0.39 to -0.37)	0.99 / <0.001
Temperate	27	253	233	0.001 to 6.31	0.05	-0.81 (-0.89 to -0.73)	-0.29 (-0.37 to -0.21)	0.90 / <0.001
(c) Non-silicon-based algae								
Cold	4	17	15	0.002 to 3.162	0.03	-0.17 (-0.27 to -0.06)	-0.54 (-0.66 to -0.42)	0.90 / <0.001
Temperate	31	115	62	0.002 to 15.849	0.1	0.65 (0.53 to 0.77)	-0.71 (-0.84 to -0.57)	0.90 / <0.001
(Sub)tropical	4	34	19	0.003 to 31.623	12.59	1.47 (1.27 to 1.67)	-0.16 (-0.39 to 0.07)	0.75 / 0.025
(d) Silicon-based algae								
Cold	4	101	79	0.002 to 3.162	0.01	-0.89	-0.56	0.93 /

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
Temperate	40	218	181	0.001 to 39.811	0.01	(-0.99 to -0.8) -0.59 (-0.74 to -0.44)	(-0.65 to -0.47) -0.73 (-0.89 to -0.58)	<0.001 0.86 / <0.001
Xeric	2	45	45	0.01 to 1.259	0.03	0.03 (-0.07 to 0.14)	-0.39 (-0.50 to -0.28)	0.90 / <0.0001
(Sub)tropical [#]	5	25	13	0.003 to 31.623	15.85	No successful fit with the log-logistic regression		

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10^α coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[†] $Pseudo - R^2 = 1 - \frac{SS_{residual}}{SS_{Corrected Total}}$, as defined by Schabenberger & Pierce (2001)

Table S5.3.6 Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R² and p value of the regressions at different levels of spatial aggregation for different taxonomic groups of autotrophs in streams.

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ² / p-value
(a) Cyanobacteria								
Temperate	4	9	7	0.063 to 1.585	0.08	-0.19 (-0.23 to -0.16)	-0.09 (-0.12 to -0.05)	0.96 / <0.001
(Sub)tropical	3	37	37	0.001 to 0.2	0.06	-0.87 (-0.95 to -0.8)	-0.13 (-0.20 to -0.05)	0.93 / <0.001
(b) Macrophyte								
Temperate [#]	4	42	27	0.002 to 0.794	0.16	0.26 (-0.3 to -0.21)	-0.07 (-0.11 to -0.04)	0.95 / <0.001
(c) Non-silicon-based algae								
Temperate	5	14	13	0.013 to 1.259	0.4	-0.11 (-0.18 to -0.04)	-0.10 (-0.16 to -0.03)	0.94 / 0.003

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ^{2†} / p-value
(Sub)tropical	3	53	52	0.001 to 0.2	0.06	-0.96 (-1.06 to -0.86)	-0.14 (-0.24 to -0.04)	0.88 / <0.001
(d) Silicon-based algae								
Temperate	7	117	101	0.001 to 2.512	0.1	0.12 (0.08 to 0.15)	-0.15 (-0.18 to -0.12)	0.97 / <0.001
(Sub)tropical	6	113	110	0.001 to 5.012	0.06	-0.11 (-0.19 to -0.04)	-0.4 (-0.48 to -0.33)	0.95 / <0.001

[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10⁴ coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C_{opt} to upper boundary of surveyed TP concentration)

[†] $Pseudo - R^2 = 1 - \frac{SS_{Residual}}{SS_{CorrectedTotal}}$, as defined by Schabenberger & Pierce (2001)

Table S5.3.7 Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R^{2†} and p value of the regressions at different levels of spatial aggregation for different taxonomic groups of heterotrophs in lakes.

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ^{2†} / p-value
(a) Fish								
Cold	9	14	13	0.002 to 0.126	0.01	-1.02 (-1.11 to -0.93)	-0.28 (-0.38 to -0.19)	0.92 / <0.001
Temperate	27	109	93	0.002 to 3.981	0.04	-0.35 (-0.39 to -0.32)	-0.23 (-0.26 to -0.19)	0.98 / <0.001
(Sub)tropical [#]	2	4	4	0.04 to 0.126	0.04	No successful fit with the log-logistic regression		
(b) Invertebrate								
Cold	8	40	37	0.002 to 3.162	0.01	-1.44 (-1.47 to -1.41)	-0.02 (-0.03 to -0.01)	0.97 / <0.001
Temperate	38	573	399	0.001 to 3.981	0.1	-0.16 (-0.21 to -0.11)	-0.25 (-0.29 to -0.20)	0.98 / <0.001
Xeric [#]	1	5	5	0.398 to 3.981	0.63	No successful fit with the log-logistic regression		
(Sub)tropical [#]	3	5	3	0.005 to 0.2	0.03	-0.65 (-0.75 to -0.55)	-0.11 (-0.20 to -0.02)	0.82 / <0.001

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ^{2†} / p-value
[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10 ^α coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C _{opt} to upper boundary of surveyed TP concentration)								
[†] Pseudo - R ² = 1 - $\frac{SS_{Residual}}{SS_{Corrected Total}}$, as defined by Schabenberger & Pierce (2001)								

Table S5.3.8 Number of studies and of species, maximized species richness (SR_{max}), range of total phosphorus (TP) occurrence, optimum TP (C_{opt}), log-logistic coefficients α and β (and their confidence intervals, CI), R^{2†} and p value of the regressions at different levels of spatial aggregation for different taxonomic groups of heterotrophs in streams.

Aggregation level	Studies	Species	SR _{max}	TP range	C _{opt}	α (95% CI)	β (95% CI)	R ^{2†} / p-value
(a) Fish								
Cold [#]	6	1	7	0.01 to 0.04	0.01	No successful fit with the log-logistic regression		
Temperate [#]	4	47	46	0.01 to 3.162	0.1	1.00 (0.46 to 1.54)	-0.74 (-1.14 to -0.34)	0.65 / <0.001
(b) Invertebrate								
Cold [#]	1	1	5	0.016 to 0.04	0.02	No successful fit with the log-logistic regression		
Temperate	13	788	651	0.006 to 15.849	0.1	0.09 (0.05 to 0.13)	-0.32 (-0.36 to -0.29)	0.99 / <0.001
(Sub)tropical [#]	3	9	8	0.05 to 1.259	0.4	0.13 (-0.02 to 0.29)	-0.15 (-0.29 to -0.29)	0.83 / <0.001
[#] Regression was not successfully derived since either β coefficient is not significantly different from zero at a 95% confidence level or 10 ^α coefficient was outside the TP concentration range of the empirical relative species richness, eRSR (defined by C _{opt} to upper boundary of surveyed TP concentration)								
[†] Pseudo - R ² = 1 - $\frac{SS_{Residual}}{SS_{Corrected Total}}$, as defined by Schabenberger & Pierce (2001)								

Supporting information

Appendix S6.1 Stressor – response relationships

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.* (2013a) (species-specific TP threshold levels are shown in Table S5.2.2, chapter 5 of this thesis). 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

$$PNOF_w = \frac{1}{1 + e^{-\left(\frac{\log_{10} C_w - \alpha_w}{\beta_w}\right)}} \quad (S6.1.1)$$

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 (Figure 6.1, main text).

Appendix S6.2

Appendix S6.2 Selection of grids and of concentration monitoring data

We selected European grids (resolution: $0.5^\circ \times 0.5^\circ$) that were located within one of the three European temperate zones (i.e. temperate coastal rivers, temperate floodplain rivers and wetlands, or temperate upland rivers), defined by Abell *et al.* (2008), Figure S6.2.1. These temperate regions comprise a large number of water bodies which are monitored for TP levels by the European Environment Agency, EEA (2013b). 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 (2013b). The locations of the monitoring stations reporting mean annual TP data are shown in Figure S6.2.2. 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 Figure S6.2.3.

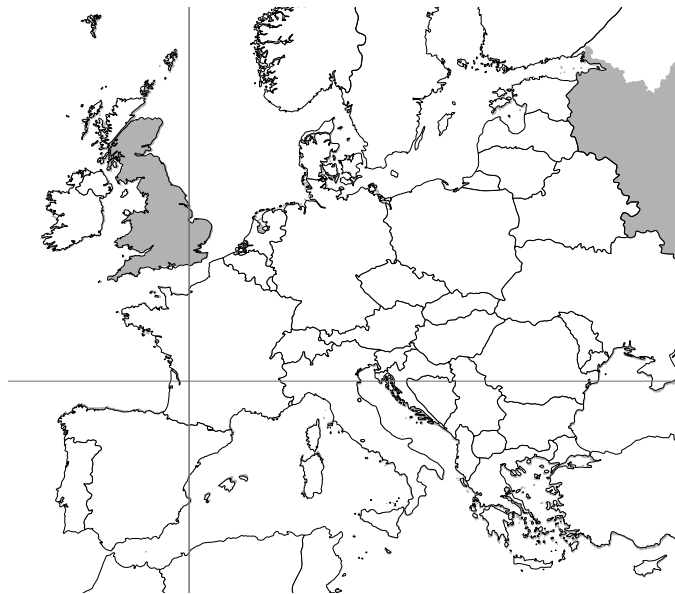


Figure S6.2.1 Temperate European zone (dark grey).

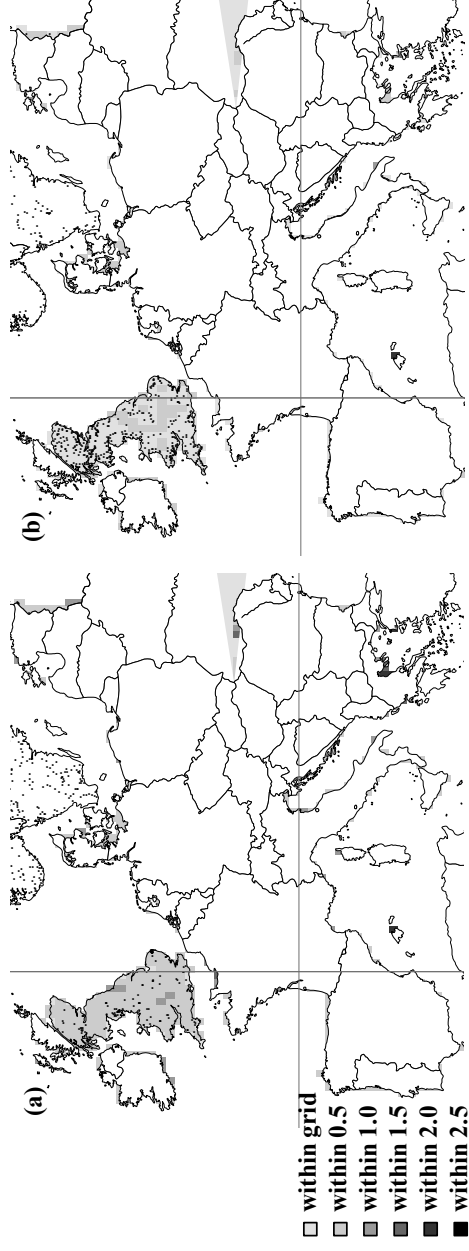


Figure S6.2.2 Distance from grids to their nearest (a) lake ($n = 2451$) and (b) stream ($n = 9525$) monitoring station (dots) in Europe. The percentage of grids with a lake monitoring station within the grid and within a distance of 0.5° , 1.0° , 1.5° , 2.0° , and 2.5° , respectively, is 34%, 46%, 13%, 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 $<1\%$.

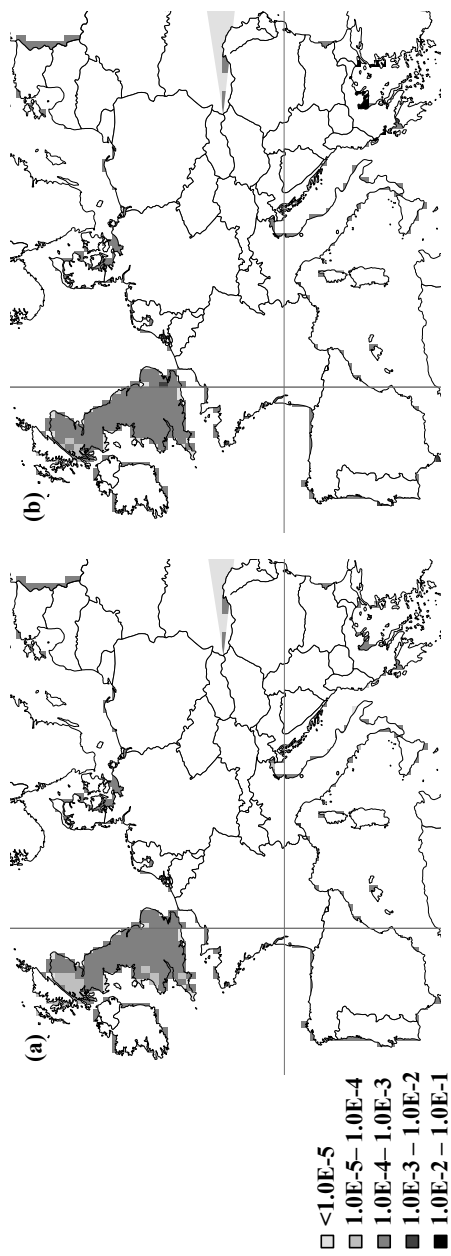


Figure S6.2.3 Concentrations of mean annual TP ($C_{w,p}$ unit: $\text{kg P}\cdot\text{m}^{-3}$), for (a) lakes and (b) streams in Europe.

Appendix S6.3 Statistical analysis results

Grid-specific CFs based on the three effect models are shown in Figure S6.3.1 (for lakes) and Figure S6.3.2 (for streams). River-basin specific CFs based on the three effect models are shown in Table S6.3.1 for lakes and in Table S6.3.2 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 Figure S6.3.3 and S6.3.4, respectively. The results of the ANOVA are shown in Table S6.3.3.

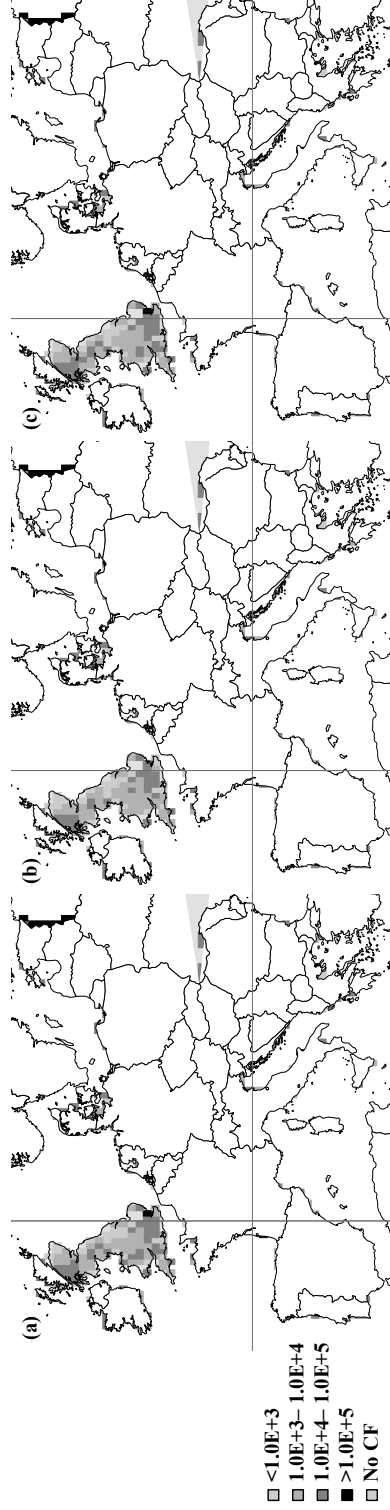


Figure S6.3.1 Grid CFs (unit: $\text{day}\cdot\text{kg P}^1\cdot\text{m}^3$) for lakes determined with (a) marginal effect factors, (b) linear effect factors, and (c) average effect factors.

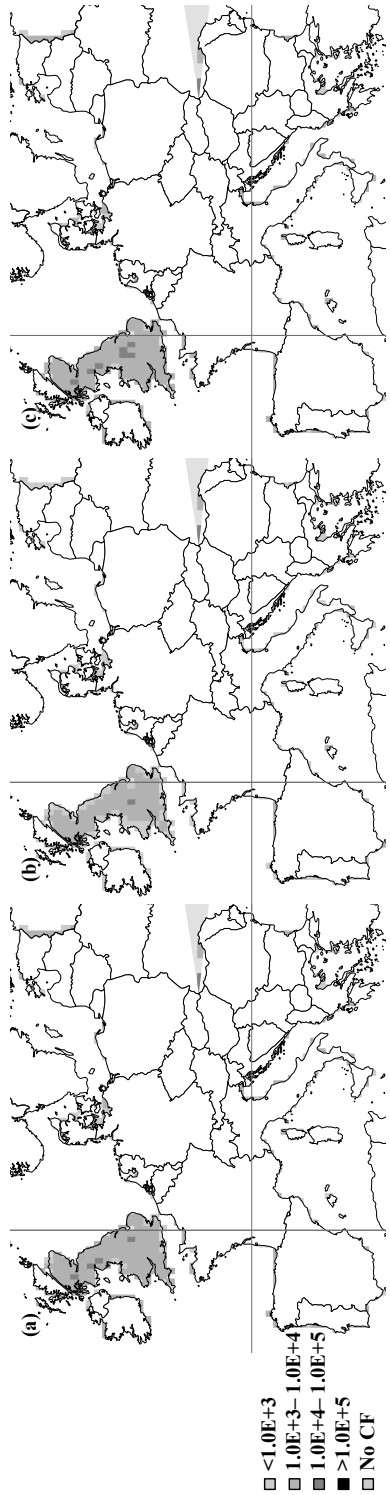


Figure S6.3.2 Grid CFs (unit: $\text{day}\cdot\text{kg P}^{-1}\cdot\text{m}^3$) for streams determined with (a) marginal effect factors, (b) linear effect factors, and (c) average effect factors.

Supporting information

Table S6.3.1 River-basin specific CF based on the three effect models (marginal – MEF, linear – LEF, and average – AEF) for (a) lakes and (b) streams. All units are reported as $\text{day}\cdot\text{kg P}^{-1}\cdot\text{m}^3$.

River Basin	CF _{MEF}	CF _{LEF}	CF _{AEF}	River Basin	CF _{MEF}	CF _{LEF}	CF _{AEF}
(a) Lakes				Jucar	62369.7	45018.51	59598.72
Adour	12084.37	8818.56	10910.6	Jutland	97951.88	76286.99	99090.98
Algarve	29926.6	21415.93	27142.06	Koiva	174683.6	126308.2	167831
Andalusia	34230.14	26948.19	30123.35	Lielupe	27931.63	20437.86	27057.53
Anglian	23724.54	17571.44	23032.07	Loire	8534.87	6739.51	8731.61
Black Sea	46081.95	55696.21	63273.45	Meuse	29748.49	27182.81	34098.45
Cantabrian	6181.93	4861.13	5977.29	Middle Appenines	99271.99	70749.01	92255.13
Catalan	35923.2	27135.41	34501.39	Minho	19146.42	16069.94	18335.91
Cavado	2565.54	1950.44	2278.46	Mosel	7286.35	7438.16	8156.63
Central Macedonia	2921.9	2166.69	2927.66	Neagh Bann	205231.3	172815.7	224487.9
Corsica	14364.4	10387.74	14038.38	Nemunas	25879.64	19022.83	24239.1
Cyprus	72105.15	52727.79	64602.98	North Adriatic	4137.53	3478.07	3618.52
Danube	26293.48	21445.01	26769.19	North Appenines	25072.62	18347.88	23849.15
Daugava	90016.35	65243.84	84673.75	Northumbria	5691.5	4086.45	5322.07
Douro	5976.2	4927.85	6246.38	Oder	48647.18	41942.85	50848.9
East	27492.49	20113.16	24596.89	Po	341890.5	249785.8	312877.8
East Aegean Isl.	34610.83	26535.35	35300.65	Pregolya	55881.34	39944.84	50925.88
East Alps	19458.29	14804.26	17533.57	Rhine	50332.93	81619.22	56727.85
East Estonia	209884.3	149242.7	194755.4	Rhone	227821.4	167250.4	207916.1
Ebro	10389.35	7651.07	9488.49	Sado	69124.67	49207.61	65474.47
Eider	16927.19	14441	18998.02	Sardinia	136509.2	98717.84	133410.9
NorthWest (IRL)	29635.62	21111.87	28040.66	Scheldt	57182.19	52025.47	66752.12
SouthEast (IRL)	17801.32	13044.88	15918.78	Schlei	99574.47	85891.29	110036.7
SouthWest (IRL)	25560.07	19687.9	22561.76	Scotland	16234.26	13092.9	14483.33
Elbe	14798.8	14634.21	14864.56	Segura	53072.39	40389.02	49078.75
Ems	11503.52	9077.94	12087.41	Seine	7304.05	5471.55	6808.58
Epirus	62972.73	44565.24	57802.38	Serchio	112073.4	89041.22	109417.7
Galician	7577.12	10076.31	11015.51	Severn	7395.3	6507.67	7843.29
Gauja	85097.2	62241.85	81829.82	Shannon	145082.6	108867.8	131141.1
Guadalete	108552.6	86845.82	95319.81	Sicily	30300.4	22493.97	29761.1
Guadalquivir	10354.97	8171.41	10310.79	Solway South	10647.91	7960.84	9868.28
Guadiana	30343.24	24200.97	29947.16	Appenines	51116.74	40234.28	48094.26
Humber	4200.71	4288.23	4791.47	Tagus	21327.75	17297.27	22329.12

Appendix S6.3

River Basin	CF _{MEF}	CF _{LEF}	CF _{AEF}	River Basin	CF _{MEF}	CF _{LEF}	CF _{AEF}
Tagus West	14239.61	11768.61	15429.66	Danube	19385.12	14798.3	22693.85
Thames	17163.26	13900.53	18400.34	Daugava	9239.01	5603.69	9834.79
Thessalia	61256.88	43359.92	56236.75	Douro	11935.65	8637.77	13762.93
Thrace	6428.48	4893.35	6591.86	East	2934.67	1742.05	3079.58
North West (UK)	37995.76	27511.53	35689.24	East Aegean Isl.	5154.11	5480.35	6281.03
South East (UK)	8248.33	6560.34	8724.28	East Alps	4666.51	2920.46	5026.5
South West (UK)	6209.73	4819.06	6340.26	East Estonia	2440.27	1405.71	2522.08
Venta	41660.18	29773.95	38963.36	East Sterea	1743.92	1241.77	2028.29
Vistula	25094.47	18848.07	23941.3	Ebro	9401.49	5747.17	10033.18
Vouga	17714.87	12745.69	17183.27	Eider NorthWest (IRL)	1751.22	1240.83	2030.46
Warnow	77766.29	60782.73	80799.21	SouthEast (IRL)	3641.08	2102.42	3768.98
Weser West Aegean Isl.	9343.23	6970.55	9290.44	SouthWest (IRL)	2874.8	1760.73	3072.93
Western Western Wales West Estonian West Macedonia	83681.68	63710.64	74354.74	Elbe	20997.42	14411.01	23894.87
West Sterea	8655.44	6378.17	8099.35	Ems	3857.94	3560.75	5087.23
Zealand	29431.2	23465.05	29570.41	Epirus	2526.84	3058.55	2668.34
(b) Streams	201875.2	149631.6	198417.3	Galician	1487.95	977.05	1651.41
Adour	8440.98	5315.4	9149.19	Gauja	3010.72	1822.47	3204.34
Aegean Isl.	389.99	1071.59	908.21	Guadalete	1390.68	883.24	1517.65
Algarve	1788.33	1018.12	1835.26	Guadalquivir	2748.31	2897.46	3775.33
Andalusia	653.09	839.98	847.07	Guadiana	3082.47	2418.58	3727.02
Anglian	1550.61	1124.92	1804.22	Humber	5007.17	4391.99	6235.13
Balearic Isl. Basque County	646.83	1058.24	1156.66	Jucar	173.34	135.98	203.01
Black Sea	1520.32	1052.99	1742.27	Jutland	1590.64	1038.52	1765.05
Cantabrian	10548.58	6292.03	10744.91	Koiva	2464.45	1464.31	2594.9
Catalan	1865.64	1166.37	2019.37	Lielupe	3184.86	2229.31	3647.98
Cavado Central Macedonia	1088.5	1094.27	1494.27	Loire	8652.48	6053.77	9918.74
Corsica	7217.81	4487.43	7748.62	Meuse Middle Appenines	3210.06	2336.09	3738.08
Cyprus	29.04	1692.31	280.37	Minho	2148.72	1627.46	2560.86
	1929.99	1176.61	2054.77	Minho Lima	8233	4908.95	8645.18
	1155.47	659.97	1185.37	Mosel	1699.76	950.77	1723.99
				Neagh Bann	6639.63	4748.83	7731.17
				Nemunus North Adriatic North Appenines	2334.46	1550.8	2606.88
					13919.56	9441.05	15578.94
					3509.38	1921.29	3494
					2590.4	1847.89	2984.27

Supporting information

River Basin	CF_{MEF}	CF_{LEF}	CF_{AEF}	River Basin	CF_{MEF}	CF_{LEF}	CF_{AEF}
North East North	663.32	787.33	1006.38	Western Wales	1426.63	850.4	1497.55
Peloponese	175.36	1208.66	651.17	West Estonian	2508.69	1455.23	2602.8
Northumbria	3288.18	2076.89	3571.6	West Macedonia	353.65	2752.17	861.59
Oder	8247.77	6463.69	10044.14	West Sterea	4821.28	2920.21	5038.43
Po	7073.66	5190.26	8263.8	Zealand	993.29	688.5	1138.78
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				

Appendix S6.3

Table S6.3.2 River-basin specific normalization score (NS, m^3) based on the three effect models (marginal – MEF, linear – LEF, and average – AEF) for (a) lakes and (b) streams.

River Basin	NS _{MEF}	NS _{LEF}	NS _{AEF}	River Basin	NS _{MEF}	NS _{LEF}	NS _{AEF}
(a) Lakes				Jutland	2.79E+14	2.17E+14	2.82E+14
Adour	7.76E+13	5.66E+13	7.01E+13	Koiva	3.80E+12	2.74E+12	3.65E+12
Algarve	3.40E+12	2.43E+12	3.09E+12	Lielupe	9.64E+12	7.05E+12	9.34E+12
Andalusia	1.51E+13	1.19E+13	1.33E+13	Loire	1.05E+14	8.27E+13	1.07E+14
Anglian	3.13E+13	2.32E+13	3.04E+13	Meuse	2.87E+14	2.62E+14	3.29E+14
BlackSea	5.40E+12	6.53E+12	7.42E+12	Middle Appeninnes	1.72E+14	1.23E+14	1.60E+14
Cantabrian	2.85E+12	2.24E+12	2.75E+12	Minho	1.39E+13	1.17E+13	1.33E+13
Catalan	3.45E+13	2.61E+13	3.31E+13	Mosel	5.52E+12	5.64E+12	6.18E+12
Cavado	4.78E+11	3.64E+11	4.25E+11	Neagh Bann	1.94E+14	1.63E+14	2.12E+14
Central Macedonia	1.63E+12	1.21E+12	1.64E+12	Nemunas	2.62E+13	1.93E+13	2.46E+13
Corsica	5.88E+12	4.25E+12	5.75E+12	North Adriatic	2.17E+11	1.82E+11	1.89E+11
Danube	4.51E+14	3.68E+14	4.59E+14	North Appeninnes	3.22E+13	2.36E+13	3.07E+13
Daugava	1.03E+14	7.50E+13	9.73E+13	Northumbria	4.15E+12	2.98E+12	3.88E+12
Douro	2.57E+13	2.12E+13	2.69E+13	Oder	2.61E+14	2.25E+14	2.73E+14
East	1.65E+13	1.21E+13	1.48E+13	Po	1.84E+15	1.35E+15	1.69E+15
East Aegean Isl.	1.17E+13	8.97E+12	1.19E+13	Pregolya	2.72E+13	1.95E+13	2.48E+13
East Alps	3.84E+13	2.92E+13	3.46E+13	Rhine	9.31E+14	1.51E+15	1.05E+15
East Estonia	1.91E+13	1.36E+13	1.77E+13	Rhone	2.17E+15	1.59E+15	1.98E+15
Ebro	3.55E+13	2.61E+13	3.24E+13	Sado	2.07E+13	1.47E+13	1.96E+13
Eider NorthWest (IRL)	8.14E+12	6.95E+12	9.14E+12	Sardinia	6.43E+13	4.65E+13	6.29E+13
SouthEast (IRL)	7.84E+12	5.59E+12	7.42E+12	Scheldt	7.65E+14	6.96E+14	8.93E+14
SouthWest (IRL)	2.36E+13	1.73E+13	2.11E+13	Schlei	6.87E+13	5.93E+13	7.59E+13
Elbe	1.14E+14	1.12E+14	1.14E+14	Scotland	4.26E+13	3.44E+13	3.80E+13
Ems	2.41E+13	1.90E+13	2.53E+13	Segura	2.19E+13	1.67E+13	2.03E+13
Epirus	1.83E+13	1.30E+13	1.68E+13	Seine	9.84E+13	7.37E+13	9.17E+13
Galician	1.90E+12	2.53E+12	2.77E+12	Serchio	6.14E+12	4.88E+12	6.00E+12
Gauja	1.70E+13	1.24E+13	1.63E+13	Severn	1.90E+13	1.67E+13	2.02E+13
Guadalete	1.45E+13	1.16E+13	1.27E+13	Shannon	2.23E+14	1.67E+14	2.01E+14
Guadalquivir	2.14E+13	1.69E+13	2.13E+13	Solway South Appeninnes	9.48E+12	7.09E+12	8.79E+12
Guadiana	6.32E+13	5.04E+13	6.24E+13	Tagus	1.31E+14	1.03E+14	1.23E+14
Humber	1.12E+13	1.14E+13	1.28E+13	TagusWest	3.92E+13	3.18E+13	4.10E+13
Jucar	4.33E+13	3.13E+13	4.14E+13	Thames	9.68E+12	8.00E+12	1.05E+13
					3.68E+13	2.98E+13	3.95E+13

Supporting information

River Basin	NS _{MEF}	NS _{LEF}	NS _{AEF}	River Basin	NS _{MEF}	NS _{LEF}	NS _{AEF}
Thessalia	2.19E+13	1.55E+13	2.01E+13	East Alps	9.21E+12	5.76E+12	9.92E+12
Thrace	1.60E+12	1.21E+12	1.64E+12	East Estonia	2.22E+11	1.28E+11	2.29E+11
NorthWest (UK)	7.62E+13	5.52E+13	7.16E+13	East Sterea	1.06E+11	7.52E+10	1.23E+11
SouthEast (UK)	3.44E+12	2.73E+12	3.64E+12	Ebro	3.21E+13	1.96E+13	3.43E+13
SouthWest (UK)	6.94E+12	5.38E+12	7.08E+12	Eider NorthWest (IRL)	8.43E+11	5.97E+11	9.77E+11
Venta	1.76E+13	1.26E+13	1.65E+13	SouthEast (IRL)	9.64E+11	5.57E+11	9.98E+11
Vistula	1.64E+14	1.23E+14	1.56E+14	SouthWest (IRL)	3.82E+12	2.34E+12	4.08E+12
Vouga	5.78E+12	4.16E+12	5.61E+12	Elbe	2.62E+12	1.50E+12	2.69E+12
Warnow	5.65E+13	4.42E+13	5.87E+13	Ems	1.61E+14	1.11E+14	1.84E+14
Weser West Aegean Isl.	2.40E+13	1.79E+13	2.38E+13	Epirus	8.09E+12	7.47E+12	1.07E+13
Western Western Wales West	1.03E+13	7.41E+12	9.95E+12	Galician	7.35E+11	8.90E+11	7.76E+11
Estonian West Macedonia	5.89E+13	4.48E+13	5.23E+13	Gauja	3.74E+11	2.45E+11	4.15E+11
West Sterea	7.56E+12	5.57E+12	7.07E+12	Guadalete	6.01E+11	3.64E+11	6.39E+11
Zealand	4.69E+12	3.74E+12	4.71E+12	Guadalquivir	1.85E+11	1.18E+11	2.02E+11
	7.86E+13	5.82E+13	7.72E+13	Guadiana	5.67E+12	5.98E+12	7.79E+12
	3.53E+13	2.59E+13	3.26E+13	Humber	6.42E+12	5.04E+12	7.77E+12
	6.15E+12	4.70E+12	6.35E+12	Jucar	1.34E+13	1.17E+13	1.66E+13
(b) Streams				Jutland	1.20E+11	9.45E+10	1.41E+11
Adour	5.42E+13	3.41E+13	5.88E+13	Koiva	4.53E+12	2.95E+12	5.02E+12
Aegean Isl.	1.14E+10	3.14E+10	2.67E+10	Lielupe	5.36E+10	3.18E+10	5.64E+10
Algarve	2.03E+11	1.16E+11	2.09E+11	Loire	1.10E+12	7.69E+11	1.26E+12
Andalusia	2.88E+11	3.71E+11	3.74E+11	Loire	1.06E+14	7.43E+13	1.22E+14
Anglian	2.05E+12	1.48E+12	2.38E+12	Meuse Middle Appenines	3.10E+13	2.25E+13	3.61E+13
BlackSea	1.24E+12	7.38E+11	1.26E+12	Minho	3.73E+12	2.83E+12	4.45E+12
Cantabrian	8.59E+11	5.37E+11	9.30E+11	MinhoLima	5.98E+12	3.57E+12	6.28E+12
Catalan	1.05E+12	1.05E+12	1.44E+12	Mosel	1.29E+11	7.24E+10	1.31E+11
Cavado Central Macedonia	1.35E+12	8.36E+11	1.44E+12	Neagh Bann	5.03E+12	3.60E+12	5.86E+12
Corsica	1.07E+10	9.45E+11	1.24E+11	Nemunas North Adriatic	2.21E+12	1.47E+12	2.47E+12
Danube	7.90E+11	4.82E+11	8.41E+11	North Appenines	1.41E+13	9.57E+12	1.58E+13
Daugava	3.32E+14	2.54E+14	3.89E+14	North East North Peloponnese	1.84E+11	1.01E+11	1.83E+11
Douro	1.06E+13	6.44E+12	1.13E+13	Northumbria	3.33E+12	2.38E+12	3.84E+12
East East Aegean Isl.	5.14E+13	3.72E+13	5.92E+13	Oder	5.11E+10	6.06E+10	7.75E+10
	1.76E+12	1.05E+12	1.85E+12	Po	1.15E+10	7.94E+10	4.28E+10
	1.74E+12	1.85E+12	2.12E+12		2.40E+12	1.52E+12	2.61E+12
					4.42E+13	3.47E+13	5.39E+13
					3.81E+13	2.80E+13	4.45E+13

Appendix S6.3

River Basin	NS _{MEF}	NS _{LEF}	NS _{AEF}	River Basin	NS _{MEF}	NS _{LEF}	NS _{AEF}
Pregolya	5.97E+12	4.22E+12	6.85E+12	Thessalia	4.09E+11	5.96E+11	6.59E+11
Rhine	2.47E+14	1.67E+14	2.78E+14	Thrace	1.15E+11	4.16E+11	2.40E+11
Rhone	7.33E+13	4.43E+13	7.76E+13	NorthWest (UK)	4.83E+12	4.03E+12	5.89E+12
Sado	6.13E+11	4.81E+11	7.41E+11	SouthEast (UK)	6.77E+11	6.60E+11	8.93E+11
Sardinia	4.21E+11	2.35E+11	4.26E+11	SouthWest (UK)	1.77E+12	1.20E+12	2.00E+12
Scheldt	2.23E+13	1.70E+13	2.66E+13	Venta	2.42E+12	1.48E+12	2.59E+12
Schlei	9.51E+11	6.52E+11	1.08E+12	Vistula	9.32E+13	6.72E+13	1.09E+14
Scotland	8.87E+12	5.03E+12	9.03E+12	Vouga	1.05E+12	7.49E+11	1.20E+12
Segura	1.24E+11	7.68E+10	1.30E+11	Warnow	1.10E+12	7.64E+11	1.26E+12
Seine	1.27E+14	8.34E+13	1.41E+14	Weser West	1.94E+13	1.42E+13	2.28E+13
Serchio	2.53E+11	2.19E+11	3.24E+11	Aegean Isl.	4.20E+10	8.49E+10	6.98E+10
Severn	9.49E+12	8.32E+12	1.18E+13	Western Western	1.29E+12	7.36E+11	1.33E+12
Shannon	4.97E+12	2.94E+12	5.21E+12	Wales West	1.25E+12	7.43E+11	1.31E+12
Solway South	5.96E+12	3.71E+12	6.41E+12	Estonian West	4.00E+11	2.32E+11	4.15E+11
Appeninnes	3.73E+12	2.93E+12	4.46E+12	Macedonia	1.38E+11	1.07E+12	3.35E+11
Tagus	1.64E+13	1.29E+13	1.97E+13	West Sterea	1.23E+12	7.48E+11	1.29E+12
TagusWest	2.85E+12	2.60E+12	3.64E+12	Zealand	2.65E+11	1.84E+11	3.04E+11
Thames	5.44E+12	7.25E+12	8.18E+12				

Supporting information

Table S6.3.4 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 $\frac{SS_{effect}}{SS_{total}}$. Kolmogorov-Smirnov normality test of residuals of the analysis of variance (ANOVA) showed a p value = 0.102 and the Levene test for homogeneity of variances showed a p values of 0.064 (homogeneity of freshwater type variances) and 0.407 (homogeneity of model type variances).

	Degrees of freedom	Sum of squares (SS)	Mean sum of squares	F value	P value	$\frac{SS_{effect}}{SS_{total}}$
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 S6.4

Appendix S6.4 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

$$CF_{w,i} = \sum_j FF_{i \rightarrow w,j} \quad (S6.4.1)$$

where $FF_{i \rightarrow w,j}$ 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 variability in fate factors as

$$CF_{w,i} = \overline{EF_{w,j}} \quad (S6.4.2)$$

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

Supporting information

Appendix S7.1. Maximum reported concentrations of NO₃ (Table S1) per invertebrate species in temperate lakes and streams. Maximum reported concentrations of total phosphorus are available in Table S5.2.2, chapter 5 of this thesis.

Table S7.1 Maximum reported concentrations of NO₃ (mg N·L⁻¹) per invertebrate species in temperate (a) lakes and (b) streams.

Species	Max NO ₃	Species	Max NO ₃
(a) Lake		<i>Sigara stagnalis</i>	0.06
<i>Argyroneta aquatica</i>	0.03	<i>Sphaeroma rugicauda</i>	0.06
<i>Athripsodes aterrimus</i>	0.03	<i>Arrenurus crassicaudatus</i>	0.1
<i>Dugesia lugubris</i>	0.03	<i>Caenis horaria</i>	0.1
<i>Haliplus immaculatus</i>	0.03	<i>Clinotanytus nervosus</i>	0.1
<i>Limnephilus lunatus</i>	0.03	<i>Cymatia coleoptrata</i>	0.1
<i>Sigara distincta</i>	0.03	<i>Dendrocoelum lacteum</i>	0.1
<i>Cyclops scutifer</i>	0.035	<i>Gammarus duebeni</i>	0.1
<i>Colurella adriatica</i>	0.036	<i>Glossiphonia complanata</i>	0.1
<i>Colurella tessellata</i>	0.036	<i>Glossiphonia heteroclita</i>	0.1
<i>Lecane clara</i>	0.036	<i>Laccobius minutus</i>	0.1
<i>Lecane ligona</i>	0.036	<i>Mystacides longicornis</i>	0.1
<i>Lecane lunaris</i>	0.036	<i>Neomysis integer</i>	0.1
<i>Lecane mylacris</i>	0.036	<i>Oecetis ochracea</i>	0.1
<i>Lecane signifera</i>	0.036	<i>Proasellus meridianus</i>	0.1
<i>Stephanoceros fimbriatus</i>	0.036	<i>Stagnicola palustris</i>	0.1
<i>Trichotria tetractis</i>	0.036	<i>Stylaria lacustris</i>	0.1
<i>Cyclops strenuus</i>	0.045	<i>Amnicola limosus</i>	0.101
<i>Heterocope appendiculata</i>	0.045	<i>Aplexa hypnorum</i>	0.101
<i>Camptocercus rectirostris</i>	0.05	<i>Cincinnatia cincinnatiensis</i>	0.101
<i>Chydorus piger</i>	0.05	<i>Fossaria dalli</i>	0.101
<i>Glyptotendipes barbipes</i>	0.05	<i>Fossaria decampi</i>	0.101
<i>Jaera ischiosetosa</i>	0.05	<i>Fossaria exigua</i>	0.101
<i>Limnephilus affinis</i>	0.05	<i>Fossaria modicella</i>	0.101
<i>Sida crystallina</i>	0.05	<i>Fossaria parva</i>	0.101
<i>Simocephalus serrulatus</i>	0.05	<i>Fusconaia flava</i>	0.101
<i>Corophium volutator</i>	0.06	<i>Gyraulus circumstriatus</i>	0.101
<i>Gammarus zaddachi</i>	0.06	<i>Gyraulus deflectus</i>	0.101
<i>Hydrobia ventrosa</i>	0.06	<i>Gyraulus parvus</i>	0.101
<i>Nereis diversicolor</i>	0.06	<i>Helisoma anceps</i>	0.101
<i>Palaemonetes varians</i>	0.06	<i>Helisoma campanulatum</i>	0.101

Appendix S7.1

Species	Max NO ₃	Species	Max NO ₃
<i>Helisoma trivolvis</i>	0.101	<i>Callicorixa praeusta</i>	0.15
<i>Lampsilis siliquoidea</i>	0.101	<i>Cloeon dipterum</i>	0.15
<i>Lampsilis ventricosa</i>	0.101	<i>Cloeon simile</i>	0.15
<i>Physa gyrina</i>	0.101	<i>Corixa panzeri</i>	0.15
<i>Physa integra</i>	0.101	<i>Corixa punctata</i>	0.15
<i>Physa jennessi</i>	0.101	<i>Haliplus apicalis</i>	0.15
<i>Physa winnipegensis</i>	0.101	<i>Haliplus confinis</i>	0.15
<i>Planorbula armigera</i>	0.101	<i>Helobdella stagnalis</i>	0.15
<i>Probythinella lacustris</i>	0.101	<i>Hesperocorixa linnaei</i>	0.15
<i>Proptera alata</i>	0.101	<i>Hesperocorixa sahlbergi</i>	0.15
<i>Sphaerium lacustre</i>	0.101	<i>Hydrodroma despiciens</i>	0.15
<i>Sphaerium nitidum</i>	0.101	<i>Hygrotus inaequalis</i>	0.15
<i>Sphaerium rhomboideum</i>	0.101	<i>Ischnura elegans</i>	0.15
<i>Sphaerium striatinum</i>	0.101	<i>Nepa cinerea</i>	0.15
<i>Stagnicola catascopium</i>	0.101	<i>Noterus clavicornis</i>	0.15
<i>Stagnicola elodes</i>	0.101	<i>Oecetis furva</i>	0.15
<i>Strophitus undulatus</i>	0.101	<i>Piona carnea</i>	0.15
<i>Valvata sincera</i>	0.101	<i>Polycelis tenuis</i>	0.15
<i>Valvata tricarinata</i>	0.101	<i>Rhantus frontalis</i>	0.15
<i>Lecane mira</i>	0.102	<i>Sigara falleni</i>	0.15
<i>Bosmina berolinensis</i>	0.105	<i>Sigara lateralis</i>	0.15
<i>Bosmina crassicornis</i>	0.105	<i>Sigara striata</i>	0.15
<i>Bosmina obtusirostris</i>	0.105	<i>Theromyzon tessulatum</i>	0.15
<i>Daphnia cristata</i>	0.105	<i>Phryganea striata</i>	0.153
<i>Daphnia longiremis</i>	0.105	<i>Eudiaptomus graciloides</i>	0.16
<i>Eurytemora lacustris</i>	0.105	<i>Holopedium gibberum</i>	0.16
<i>Mesocyclops oithonoides</i>	0.105	<i>Mesocyclops leukarti</i>	0.16
<i>Candona neglecta</i>	0.128	<i>Peracantha truncata</i>	0.16
<i>Ilyocypris decipiens</i>	0.128	<i>Polyphemus pediculus</i>	0.16
<i>Enallagma cyathigerum</i>	0.141	<i>Simocephalus vetulus</i>	0.16
<i>Lecane stichaea</i>	0.141	<i>Keratella hiemalis</i>	0.17
<i>Lestes sponsa</i>	0.141	<i>Alonella nana</i>	0.181
<i>Agrypnia pagetana</i>	0.15	<i>Ilyocryptus sordidus</i>	0.181
<i>Alona quadrangularis</i>	0.15	<i>Acroperus harpae</i>	0.215
<i>Arrenurus globator</i>	0.15	<i>Alona affinis</i>	0.215
<i>Caenis luctuosa</i>	0.15	<i>Arctodiaptomus alpinus</i>	0.215
<i>Caenis robusta</i>	0.15	<i>Cyclops abyssorum</i>	0.215

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Species	Max NO ₃	Species	Max NO ₃
<i>Alona azorica</i>	0.221	<i>Chaetocladius dentiforceps</i>	0.283
<i>Alonella excisa</i>	0.221	<i>Chironomus thummi</i>	0.283
<i>Attheyella trispinosa</i>	0.221	<i>Corynoneura arctica</i>	0.283
<i>Bradleycypris obliqua</i>	0.221	<i>Corynoneura lacustris</i>	0.283
<i>Cypridopsis hartwigi</i>	0.221	<i>Corynoneura lobata</i>	0.283
<i>Graptoleberis testudinaria</i>	0.221	<i>Corynoneura scutellata</i>	0.283
<i>Macrothrix groenlandica</i>	0.221	<i>Cricotopus laricomalis</i>	0.283
<i>Macrothrix rosea</i>	0.221	<i>Endochironomus dispar</i>	0.283
<i>Microcyclops rubellus</i>	0.221	<i>Erpobdella testacea</i>	0.283
<i>Scapholeberis rammneri</i>	0.221	<i>Helophorus glacialis</i>	0.283
<i>Arctodiptomus bacillifer</i>	0.231	<i>Hydroporus foveolatus</i>	0.283
<i>Alona nuragica</i>	0.239	<i>Hydroporus palustris</i>	0.283
<i>Canthocamptus staphylinus</i>	0.239	<i>Limnephilus coenosus</i>	0.283
<i>Diacyclops bicuspidatus</i>	0.239	<i>Melampophylax mucoreus</i>	0.283
<i>Diacyclops bisetosus</i>	0.239	<i>Odontocerum albicorne</i>	0.283
<i>Estatheroporus gauthieri</i>	0.239	<i>Paracladius alpicola</i>	0.283
<i>Eucypris virens</i>	0.239	<i>Paracladopelma camptolabis</i>	0.283
<i>Megacyclops gigas</i>	0.239	<i>Parakiefferiella coronata</i>	0.283
<i>Mixodiptomus liljeborgi</i>	0.239	<i>Parakiefferiella triquetra</i>	0.283
<i>Paralimnocythere psammophila</i>	0.239	<i>Paratanytarsus austriacus</i>	0.283
<i>Eudiptomus gracilis</i>	0.24	<i>Paratanytarsus laccophilus</i>	0.283
<i>Scapholeberis mucronata</i>	0.24	<i>Paratrichocladius nivalis</i>	0.283
<i>Alona costata</i>	0.26	<i>Paratrichocladius skirwithensis</i>	0.283
<i>Alona tenuicaudis</i>	0.26	<i>Parorthocladius nudipennis</i>	0.283
<i>Brachionus patulus</i>	0.26	<i>Pisidium oasertanum</i>	0.283
<i>Filinia opoliensis</i>	0.26	<i>Prodiamesa olivacea</i>	0.283
<i>Hexarthra mira</i>	0.26	<i>Protanytus caudatus</i>	0.283
<i>Keratella valga</i>	0.26	<i>Pseudodiamesa branickii</i>	0.283
<i>Lecane quadridentata</i>	0.26	<i>Pseudodiamesa nivosa</i>	0.283
<i>Agabus bipustulatus</i>	0.283	<i>Radix peregra</i>	0.283
<i>Agabus congener</i>	0.283	<i>Rheocricotopus effusus</i>	0.283
<i>Agabus solieri</i>	0.283	<i>Rhyacophila italica</i>	0.283
<i>Allogamus antennatus</i>	0.283	<i>Stictotarsus griseostriatus</i>	0.283
<i>Allogamus auricollis</i>	0.283	<i>Stilociadius montanus</i>	0.283
<i>Allogamus uncatus</i>	0.283	<i>Tanytarsus pallidicornis</i>	0.283
<i>Apsectrotanytus trifascipennis</i>	0.283	<i>Tvetenia calvescens</i>	0.283
<i>Arctocoris carinata</i>	0.283	<i>Acanthocyclops robustus</i>	0.339

Appendix S7.1

Species	Max NO ₃	Species	Max NO ₃
<i>Alona protzi</i>	0.339	<i>Lymnaea peregra</i>	0.4
<i>Alona rectangula</i>	0.339	<i>Lymnaea stagnalis</i>	0.4
<i>Alona weltneri</i>	0.339	<i>Neoplanorbis carinatus</i>	0.4
<i>Alonella exigua</i>	0.339	<i>Physa fontinalis</i>	0.4
<i>Anuraeopsis fissa</i>	0.339	<i>Physella acuta</i>	0.4
<i>Ascomorpha ecaudis</i>	0.339	<i>Planorbarius corneus</i>	0.4
<i>Brachionus bidentata</i>	0.339	<i>Planorbis planorbis</i>	0.4
<i>Brachionus falcatulus</i>	0.339	<i>Segmentina nitida</i>	0.4
<i>Ceriodaphnia pulchella</i>	0.339	<i>Valvata naticina</i>	0.4
<i>Asplanchna girodi</i>	0.386	<i>Valvata piscinalis</i>	0.4
<i>Asplanchna seiboldi</i>	0.386	<i>Viviparus contectus</i>	0.4
<i>Chydorus sphaericus</i>	0.386	<i>Aeschna juncea</i>	0.434
<i>Cyclops vicinus</i>	0.386	<i>Limnephilus griseus</i>	0.434
<i>Daphnia magna</i>	0.386	<i>Palaemon modestus</i>	0.513
<i>Daphnia pulex</i>	0.386	<i>Euchlanis dilatata</i>	0.61
<i>Disparalona rostrata</i>	0.386	<i>Notholca squamula</i>	0.61
<i>Filinia terminalis</i>	0.386	<i>Brachionus angularis</i>	0.655
<i>Notholca acuminata</i>	0.386	<i>Ploesoma hudsoni</i>	0.655
<i>Philodina megalotrocha</i>	0.386	<i>Ceriodaphnia quadrangula</i>	0.686
<i>Polyarthra dolichoptera</i>	0.386	<i>Mystacides azureus</i>	0.686
<i>Rotaria rotatoria</i>	0.386	<i>Polyarthra remata</i>	0.686
<i>Synchaeta littoralis</i>	0.386	<i>Asplanchna priodonta</i>	0.745
<i>Testudinella mucronata</i>	0.386	<i>Bosmina coregoni</i>	0.745
<i>Testudinella patina</i>	0.386	<i>Bosmina longirostris</i>	0.745
<i>Trichocerca elongata</i>	0.386	<i>Brachionus calyciflorus</i>	0.745
<i>Ancylus fluviatilis</i>	0.4	<i>Conochiloides natans</i>	0.745
<i>Anisus vortex</i>	0.4	<i>Conochilus hippocrepis</i>	0.745
<i>Anisus vorticulus</i>	0.4	<i>Conochilus unicornis</i>	0.745
<i>Bathymphalus contortus</i>	0.4	<i>Daphnia cucullata</i>	0.745
<i>Bithynia tentaculata</i>	0.4	<i>Daphnia longispina</i>	0.745
<i>Ferrissia clessiniana</i>	0.4	<i>Daphnia obtusa</i>	0.745
<i>Gyraululus albus</i>	0.4	<i>Diaphanosoma brachyurum</i>	0.745
<i>Gyraululus crista</i>	0.4	<i>Filinia longiseta</i>	0.745
<i>Hippeutis complanatus</i>	0.4	<i>Gastropus hyptopus</i>	0.745
<i>Lymnaea auricularia</i>	0.4	<i>Kellicottia longispina</i>	0.745
<i>Lymnaea corvus</i>	0.4	<i>Keratella cochlearis</i>	0.745
<i>Lymnaea palustris</i>	0.4	<i>Keratella quadrata</i>	0.745

Supporting information

Species	Max NO ₃	Species	Max NO ₃
<i>Leptodora kindtii</i>	0.745	<i>Microcodon clavus</i>	1.2
<i>Polyarthra major</i>	0.745	<i>Nemoura cinerea</i>	1.2
<i>Polyarthra vulgaris</i>	0.745	<i>Nemurella pictetii</i>	1.2
<i>Pompholyx sulcata</i>	0.745	<i>Oligotricha striata</i>	1.2
<i>Synchaeta pectinata</i>	0.745	<i>Oxyurella tenuicaudis</i>	1.2
<i>Trichocerca longiseta</i>	0.745	<i>Phryganea bipunctata</i>	1.2
<i>Trichocerca similis</i>	0.745	<i>Plectrocnemia conspersa</i>	1.2
<i>Tanytulus kraatzi</i>	0.762	<i>Polycentropus flavomaculatus</i>	1.2
<i>Cephalodella gibboides</i>	0.894	<i>Protonemura auberti</i>	1.2
<i>Cephalodella mus</i>	0.894	<i>Protonemura hrabei</i>	1.2
<i>Lecane bifurca</i>	0.894	<i>Pyrrhosoma nymphula</i>	1.2
<i>Lecane pyriformis</i>	0.894	<i>Sialis lutaria</i>	1.2
<i>Lepadella elliptica</i>	0.894	<i>Siphonurus lacustris</i>	1.2
<i>Leydigia acanthocercoides</i>	0.894	<i>Metacyclops mendocinus</i>	1.222
<i>Trichocerca vernalis</i>	0.894	<i>Moina micrura</i>	1.222
<i>Dicrotendipes nervosus</i>	1.139	<i>Notodiptomus incompositus</i>	1.222
<i>Procladius choreus</i>	1.199	<i>Tropocyclops meridionalis</i>	1.222
<i>Acanthocyclops bicuspidatus</i>	1.2	<i>Cryptochironomus tentans</i>	1.238
<i>Acanthocyclops languidus</i>	1.2	<i>Anodonta woodiana woodiana</i>	1.514
<i>Acanthocyclops vernalis</i>	1.2	<i>Lamprotula leai</i>	1.514
<i>Aeschna cyanea</i>	1.2	<i>Alona karelica</i>	1.75
<i>Ameletus inopinatus</i>	1.2	<i>Ceriodaphnia megops</i>	1.75
<i>Amphinemura triangularis</i>	1.2	<i>Chydorus gibbus</i>	1.75
<i>Brachionus urceolaris</i>	1.2	<i>Dunhevedia crassa</i>	1.75
<i>Cephalodella gigantea</i>	1.2	<i>Euchlanis triquetra</i>	1.75
<i>Codonella cratera</i>	1.2	<i>Notommata glyphura</i>	1.75
<i>Keratella serrulata</i>	1.2	<i>Pseudochydorus globosus</i>	1.75
<i>Lecane aculeata</i>	1.2	<i>Daphnia hyalina</i>	2.872
<i>Lecane inermis</i>	1.2	<i>Diptomus glacialis</i>	2.872
<i>Leptophlebia vespertina</i>	1.2	<i>Endochironomus tendens</i>	3.365
<i>Leuctra aurita</i>	1.2	<i>Cladotanytarsus mancus</i>	3.428
<i>Leuctra digitata</i>	1.2	<i>Cricotopus flavocinctus</i>	3.428
<i>Leuctra fusca</i>	1.2	<i>Cryptotendipes holsatus</i>	3.428
<i>Leuctra handlirschi</i>	1.2	<i>Dicrotendipes tritonus</i>	3.428
<i>Leuctra nigra</i>	1.2	<i>Polypedilum sordens</i>	3.428
<i>Limnephilus rhombicus</i>	1.2	<i>Psectrocladius limbatellus</i>	3.428
<i>Limnephilus stigma</i>	1.2	<i>Psectrocladius sordidellus</i>	3.428

Appendix S7.1

<u>Species</u>	<u>Max NO₃</u>
<i>Chironomus anthracinus</i>	5.382
<i>Cricotopus bicinctus</i>	5.382
<i>Tanytus punctipennis</i>	5.382
<i>Chironomus plumosus</i>	5.728
<i>Cricotopus sylvestris</i>	5.728
<i>Endochironomus albipennis</i>	5.728
<i>Nais communis</i>	5.728
<i>Nais variabilis</i>	5.728
<i>Parachironomus arcuatus</i>	5.728
<i>Paratanytarsus lauterborni</i>	5.728
<i>Polypedilum convictum</i>	5.728
<i>Chironomus aprilinus</i>	8.465
<i>Cryptochironomus defectus</i>	8.465
<i>Limnodrilus claparedianus</i>	8.465
<i>Limnodrilus hoffmeisteri</i>	8.465
<i>Limnodrilus profundicola</i>	8.465
<i>Polypedilum pedestre</i>	8.465
<i>Potamothenix hammoniensis</i>	8.465
<i>Psammoryctides albicola</i>	8.465
<i>Pseudosmittia forcipatus</i>	8.465
<i>Tubifex tubifex</i>	8.465
<i>Virgatanytarsus arduennensis</i>	8.465
<i>Asellus aquaticus</i>	16.83

Supporting information

Appendix S7.2 Summary statistics of environmental concentrations

Table S7.2.1 Average (α_c) and standard deviation (σ) of $^{10}\log$ concentrations of NO_3 and total phosphorus (TP) in lake and stream monitoring stations in river basins reported by the European Environment Agency, EEA (2013b). The average and, in parenthesis, the standard deviation and number of monitoring stations are shown first for NO_3 and then for TP (separated by a slash). Units are $\text{mg P}\cdot\text{L}^{-1}$ or $\text{mg N}\cdot\text{L}^{-1}$ and not available data are shown as n.a. The α_c and β_c (converted from the standard deviation σ as $\frac{\sigma\sqrt{3}}{\pi}$) were employed as described in equation 4 of the main text.

Basin	Year	Lake	Stream
Adour	1985	n.a. / n.a.	0.16 (0.37, 88) / -0.68 (0.47, 4)
Black Sea	1985	n.a. / -1.55 (0.42, 5)	n.a. / n.a.
Danube	1985	-0.32 (0.28, 3) / n.a.	n.a. / n.a.
Daugava	1985	n.a. / n.a.	n.a. / -0.4 (0.42, 11)
Elbe	1985	n.a. / n.a.	0.39 (0.27, 28) / n.a.
Gauja	1985	n.a. / n.a.	n.a. / -0.54 (0.38, 8)
Guadalquivir	1985	n.a. / n.a.	n.a. / -0.54 (0.33, 7)
Humber	1985	0.34 (0.21, 2) / n.a.	0.99 (0.07, 3) / n.a.
Loire	1985	n.a. / -0.85 (0.32, 2)	n.a. / n.a.
North West (UK)	1985	-0.43 (0.33, 5) / n.a.	0.31 (0.41, 15) / n.a.
Northumbria	1985	n.a. / n.a.	0.02 (0.35, 4) / n.a.
Oder	1985	n.a. / n.a.	0.52 (0.09, 5) / n.a.
Pregolya	1985	n.a. / n.a.	n.a. / -0.17 (0.1, 3)
Rhine	1985	-1 (1.19, 2) / -1.46 (0.05, 2)	0.59 (0.16, 11) / n.a.
Rhone	1985	n.a. / n.a.	-0.01 (0.26, 33) / -0.02 (0.45, 9)
Scheldt	1985	n.a. / n.a.	0.69 (0.11, 18) / -0.06 (0.14, 3)
Seine	1985	0.11 (0.3, 2) / n.a.	0.53 (0.19, 14) / -0.48 (0.23, 3)
South Appenines	1985	n.a. / -1.6 (0.1, 3)	n.a. / n.a.
South East (Irl.)	1985	n.a. / n.a.	n.a. / -0.6 (0.18, 12)
South West (UK)	1985	n.a. / n.a.	0.3 (0.37, 4) / n.a.
Warnow	1985	n.a. / n.a.	0.39 (0.08, 4) / n.a.
Weser	1985	n.a. / n.a.	0.7 (0.11, 3) / n.a.
Adour	1986	n.a. / n.a.	0.25 (0.36, 88) / n.a.
Black Sea	1986	n.a. / -1.57 (0.43, 5)	n.a. / n.a.
Cantabrian	1986	n.a. / n.a.	n.a. / -1.2 (0.7, 2)
Danube	1986	-0.31 (0.29, 3) / n.a.	0.28 (0.19, 2) / n.a.
Daugava	1986	n.a. / n.a.	n.a. / -0.34 (0.5, 9)
Elbe	1986	n.a. / n.a.	0.48 (0.27, 29) / -0.64 (0.35, 7)
Gauja	1986	n.a. / n.a.	n.a. / -0.43 (0.19, 7)
Guadalquivir	1986	n.a. / n.a.	n.a. / -0.62 (0.32, 9)
Humber	1986	0.53 (0.05, 2) / n.a.	1 (0.09, 3) / n.a.
Meuse	1986	n.a. / n.a.	n.a. / 0.02 (0.23, 3)
North West (UK)	1986	-0.28 (0.31, 5) / n.a.	0.3 (0.4, 15) / n.a.
Northumbria	1986	n.a. / n.a.	0.01 (0.39, 4) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Oder	1986	n.a. / n.a.	0.5 (0.17, 5) / n.a.
Po	1986	n.a. / -1.49 (0.02, 2)	n.a. / n.a.
Pregolya	1986	n.a. / n.a.	n.a. / 0.01 (0.49, 4)
Rhine	1986	-0.94 (1.1, 2) / n.a.	0.59 (0.18, 8) / n.a.
Rhone	1986	n.a. / n.a.	0.06 (0.23, 29) / -0.06 (0.44, 10)
Scheldt	1986	n.a. / n.a.	0.65 (0.12, 18) / n.a.
Seine	1986	0.41 (0.16, 2) / n.a.	0.48 (0.19, 12) / -0.38 (0.12, 3)
South Appenines	1986	n.a. / -1.49 (0.1, 2)	n.a. / n.a.
South East (Irl.)	1986	n.a. / n.a.	n.a. / -0.66 (0.18, 13)
South West (UK)	1986	n.a. / n.a.	0.32 (0.37, 4) / n.a.
Warnow	1986	n.a. / n.a.	0.25 (0.07, 4) / n.a.
Weser	1986	n.a. / n.a.	0.69 (0.07, 3) / n.a.
Adour	1987	n.a. / n.a.	0.19 (0.36, 98) / n.a.
Black Sea	1987	n.a. / -1.38 (0.41, 13)	n.a. / n.a.
Cantabrian	1987	n.a. / n.a.	n.a. / -0.46 (0.43, 58)
Danube	1987	-0.61 (0.46, 12) / n.a.	0.33 (0.25, 88) / n.a.
Daugava	1987	n.a. / n.a.	n.a. / -0.45 (0.26, 12)
Elbe	1987	n.a. / n.a.	0.53 (0.28, 30) / -0.79 (0.32, 24)
Gauja	1987	n.a. / n.a.	n.a. / -0.72 (0.2, 8)
Guadalquivir	1987	n.a. / n.a.	n.a. / -0.7 (0.37, 29)
Humber	1987	0.55 (0.04, 2) / n.a.	0.96 (0.08, 3) / n.a.
Middle Appenines	1987	n.a. / n.a.	n.a. / 0.02 (0.14, 3)
North West (UK)	1987	-0.42 (0.4, 4) / n.a.	0.3 (0.38, 14) / n.a.
Northumbria	1987	n.a. / n.a.	0.02 (0.32, 4) / n.a.
Oder	1987	n.a. / n.a.	0.5 (0.1, 4) / n.a.
Pregolya	1987	n.a. / n.a.	n.a. / -0.36 (0.08, 3)
Rhine	1987	-0.84 (1.05, 2) / -1.56 (0.09, 2)	0.59 (0.15, 13) / n.a.
Rhone	1987	n.a. / n.a.	0.01 (0.36, 50) / -0.29 (0.45, 15)
Scheldt	1987	n.a. / n.a.	0.62 (0.11, 18) / n.a.
Seine	1987	0.09 (0.31, 2) / n.a.	0.57 (0.2, 16) / -0.32 (0.17, 2)
Severn	1987	n.a. / n.a.	0.7 (0.68, 2) / n.a.
South Appenines	1987	n.a. / -1.5 (0.18, 2)	n.a. / n.a.
South West (Irl.)	1987	n.a. / n.a.	n.a. / -0.7 (0.15, 15)
South West (UK)	1987	n.a. / n.a.	0.31 (0.38, 4) / n.a.
Warnow	1987	n.a. / n.a.	0.35 (0.05, 4) / n.a.
Weser	1987	n.a. / n.a.	0.62 (0.1, 4) / n.a.
Adour	1988	n.a. / n.a.	0.23 (0.35, 99) / n.a.
Cantabrian	1988	n.a. / n.a.	n.a. / -0.49 (0.45, 62)
Cavado	1988	n.a. / -1.41 (0.38, 14)	n.a. / n.a.
Corsica	1988	n.a. / n.a.	-0.4 (0.2, 4) / n.a.
Danube	1988	-0.61 (0.34, 13) / n.a.	0.35 (0.25, 89) / n.a.
Douro	1988	n.a. / n.a.	n.a. / -0.43 (0.28, 17)
Elbe	1988	n.a. / n.a.	0.52 (0.24, 30) / -0.8 (0.3, 24)
Ems	1988	n.a. / n.a.	0.79 (0.17, 3) / -0.6 (0.07, 3)

Supporting information

Basin	Year	Lake	Stream
Gauja	1988	n.a. / n.a.	n.a. / -0.79 (0.22, 7)
Guadalquivir	1988	n.a. / n.a.	n.a. / -0.85 (0.37, 36)
Humber	1988	0.23 (0.75, 4) / n.a.	0.96 (0.11, 3) / n.a.
Jutland	1988	n.a. / -1.95 (0.49, 2)	n.a. / n.a.
Loire	1988	n.a. / n.a.	0.51 (0.34, 22) / n.a.
Meuse	1988	n.a. / n.a.	0.7 (0.27, 5) / -0.66 (0.57, 4)
Middle Appenines	1988	n.a. / n.a.	n.a. / -0.02 (0.23, 3)
North West (UK)	1988	-0.49 (0.35, 4) / n.a.	0.22 (0.37, 14) / n.a.
Northumbria	1988	n.a. / n.a.	-0.11 (0.41, 4) / n.a.
Oder	1988	n.a. / n.a.	0.51 (0.12, 5) / n.a.
Pregolya	1988	n.a. / n.a.	n.a. / -0.24 (0.28, 14)
Rhine	1988	-0.81 (0.95, 2) / -1.62 (0.02, 2)	0.63 (0.23, 41) / n.a.
Rhone	1988	n.a. / n.a.	-0.02 (0.36, 66) / -0.38 (0.38, 32)
Scheldt	1988	n.a. / n.a.	0.64 (0.15, 18) / n.a.
Seine	1988	0.28 (0.19, 2) / n.a.	0.62 (0.19, 15) / -0.29 (0.13, 4)
South West (Irl.)	1988	n.a. / n.a.	n.a. / -0.74 (0.15, 19)
South West (UK)	1988	n.a. / n.a.	0.32 (0.41, 4) / n.a.
Warnow	1988	n.a. / n.a.	0.39 (0.09, 4) / -0.4 (0.15, 3)
Weser	1988	n.a. / n.a.	0.71 (0.14, 14) / n.a.
Adour	1989	n.a. / n.a.	0.19 (0.39, 99) / n.a.
Cantabrian	1989	n.a. / n.a.	n.a. / -0.46 (0.5, 73)
Cavado	1989	n.a. / -1.36 (0.4, 13)	n.a. / n.a.
Corsica	1989	n.a. / n.a.	-0.4 (0.25, 7) / n.a.
Danube	1989	-0.77 (0.44, 12) / n.a.	0.32 (0.25, 90) / n.a.
Douro	1989	n.a. / n.a.	n.a. / -0.43 (0.35, 12)
East	1989	n.a. / n.a.	n.a. / -0.61 (0.25, 4)
Elbe	1989	n.a. / n.a.	0.48 (0.29, 29) / -0.63 (0.3, 24)
Ems	1989	n.a. / n.a.	0.59 (0.32, 4) / -0.46 (0.25, 26)
Gauja	1989	n.a. / n.a.	n.a. / -0.75 (0.33, 13)
Guadalquivir	1989	n.a. / n.a.	n.a. / -0.82 (0.5, 45)
Humber	1989	0.45 (0.44, 4) / n.a.	1.01 (0.09, 3) / -0.56 (0.3, 15)
Jutland	1989	-0.25 (0.56, 12) / -1.14 (0.38, 12)	n.a. / n.a.
Lielupe	1989	n.a. / n.a.	n.a. / -0.45 (0.39, 62)
Loire	1989	n.a. / n.a.	0.41 (0.28, 30) / n.a.
Meuse	1989	n.a. / n.a.	0.49 (0.25, 14) / n.a.
Middle Appenines	1989	n.a. / n.a.	n.a. / 0.18 (0.32, 8)
Neagh Bann	1989	n.a. / n.a.	-0.41 (0.28, 3) / n.a.
North East (UK)	1989	n.a. / n.a.	-0.2 (0.08, 3) / n.a.
North West (UK)	1989	-0.56 (0.37, 4) / n.a.	0.1 (0.49, 19) / n.a.
Northumbria	1989	n.a. / n.a.	0.04 (0.34, 4) / n.a.
Oder	1989	n.a. / n.a.	0.39 (0.27, 5) / -0.27 (0.31, 3)
Pregolya	1989	n.a. / n.a.	n.a. / -0.38 (0.2, 14)
Rhine	1989	-0.74 (0.81, 2) / -1.64 (0.05, 2)	0.54 (0.26, 69) / n.a.
Rhone	1989	n.a. / n.a.	-0.09 (0.36, 75) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Scheldt	1989	n.a. / n.a.	0.56 (0.26, 20) / n.a.
Seine	1989	0.35 (0.11, 2) / n.a.	0.61 (0.17, 15) / -0.14 (0.14, 4)
South West (Irl.)	1989	n.a. / n.a.	n.a. / -0.75 (0.19, 27)
South West (UK)	1989	n.a. / n.a.	0.32 (0.41, 4) / n.a.
Tagus West	1989	n.a. / -1.68 (0.09, 2)	n.a. / n.a.
Warnow	1989	n.a. / n.a.	0.04 (0.15, 4) / n.a.
Weser	1989	n.a. / n.a.	0.7 (0.11, 14) / n.a.
Adour	1990	n.a. / -1.63 (0.32, 4)	0.15 (0.35, 98) / n.a.
Cantabrian	1990	n.a. / n.a.	0 (0.42, 6) / -0.73 (0.54, 66)
Cavado	1990	n.a. / -1.37 (0.41, 13)	n.a. / n.a.
Corsica	1990	n.a. / n.a.	-0.51 (0.08, 7) / n.a.
Danube	1990	-0.77 (0.44, 13) / n.a.	0.24 (0.26, 105) / n.a.
Douro	1990	n.a. / n.a.	0.11 (0.36, 26) / -0.44 (0.34, 17)
East	1990	n.a. / n.a.	n.a. / -0.67 (0.37, 4)
Ebro	1990	n.a. / n.a.	0.02 (0.38, 53) / n.a.
Elbe	1990	n.a. / n.a.	0.53 (0.26, 31) / -0.62 (0.37, 33)
Ems	1990	n.a. / n.a.	0.69 (0.2, 4) / -0.54 (0.28, 33)
Gauja	1990	n.a. / n.a.	n.a. / -0.58 (0.37, 15)
Guadalquivir	1990	n.a. / n.a.	0.24 (0.56, 13) / -0.68 (0.53, 40)
Guadiana	1990	n.a. / n.a.	0.25 (0.31, 8) / n.a.
Humber	1990	n.a. / -1.15 (0.43, 12)	1.02 (0.09, 3) / -0.55 (0.35, 20)
Jucar	1990	n.a. / n.a.	0.25 (0.68, 8) / n.a.
Jutland	1990	-0.14 (0.65, 12) / n.a.	n.a. / n.a.
Lielupe	1990	n.a. / n.a.	n.a. / -0.48 (0.38, 68)
Loire	1990	n.a. / n.a.	0.33 (0.44, 34) / n.a.
Meuse	1990	n.a. / n.a.	0.45 (0.27, 15) / n.a.
Middle Appenines	1990	n.a. / n.a.	n.a. / 0.21 (0.47, 13)
Minho	1990	n.a. / n.a.	-0.29 (0.15, 3) / n.a.
Neagh Bann	1990	n.a. / n.a.	0.46 (0.26, 3) / n.a.
North Adriatic	1990	n.a. / n.a.	-0.15 (0.24, 7) / -1.56 (0.31, 7)
North East (UK)	1990	n.a. / n.a.	0.58 (0.13, 3) / n.a.
North West (UK)	1990	-0.47 (0.27, 3) / n.a.	0.3 (0.35, 19) / n.a.
Northumbria	1990	n.a. / n.a.	-0.1 (0.47, 4) / n.a.
Oder	1990	n.a. / n.a.	0.39 (0.22, 5) / -0.4 (0.3, 4)
Pregolya	1990	n.a. / n.a.	n.a. / -0.47 (0.16, 15)
Rhine	1990	-0.93 (1.12, 2) / -1.4 (0.4, 3)	0.51 (0.27, 72) / n.a.
Rhone	1990	-0.28 (0.07, 3) / n.a.	-0.11 (0.39, 71) / n.a.
Scheldt	1990	n.a. / n.a.	0.47 (0.37, 29) / n.a.
Schlei	1990	n.a. / n.a.	0.47 (0.35, 2) / -0.73 (0.05, 2)
Scotland	1990	-0.73 (0.64, 5) / -1.74 (1.07, 5)	-0.72 (0.52, 11) / -1.77 (0.65, 9)
Seine	1990	0.47 (0.14, 2) / n.a.	0.52 (0.16, 15) / -0.21 (0.06, 4)
Solway	1990	n.a. / n.a.	-0.23 (0.44, 2) / n.a.
South West (Irl.)	1990	n.a. / n.a.	n.a. / -0.82 (0.17, 27)
South West (UK)	1990	n.a. / n.a.	0.32 (0.38, 4) / n.a.

Supporting information

Basin	Year	Lake	Stream
Tagus	1990	n.a. / n.a.	0.13 (0.35, 28) / n.a.
Tagus West	1990	n.a. / -1.85 (0.04, 2)	n.a. / n.a.
Warnow	1990	n.a. / n.a.	0.27 (0.06, 4) / n.a.
Weser	1990	n.a. / n.a.	0.7 (0.1, 15) / n.a.
Adour	1991	n.a. / n.a.	0.2 (0.38, 98) / n.a.
Cantabrian	1991	n.a. / n.a.	0.02 (0.15, 6) / -0.69 (0.57, 74)
Corsica	1991	n.a. / n.a.	-0.38 (0.11, 7) / n.a.
Danube	1991	-0.65 (0.4, 17) / -1.46 (0.53, 18)	0.27 (0.26, 105) / n.a.
Douro	1991	n.a. / n.a.	0.11 (0.32, 26) / -0.45 (0.27, 29)
East	1991	n.a. / n.a.	n.a. / -0.69 (0.1, 4)
Ebro	1991	n.a. / n.a.	0.21 (0.38, 53) / n.a.
Elbe	1991	n.a. / n.a.	0.5 (0.27, 37) / -0.62 (0.28, 43)
Ems	1991	n.a. / n.a.	0.78 (0.19, 3) / -0.57 (0.23, 29)
Gauja	1991	n.a. / n.a.	n.a. / -0.64 (0.35, 15)
Guadalquivir	1991	n.a. / n.a.	0.2 (0.42, 13) / -0.83 (0.44, 52)
Guadiana	1991	n.a. / n.a.	0.18 (0.38, 8) / n.a.
Humber	1991	n.a. / -1.23 (0.39, 12)	1.03 (0.06, 3) / -0.54 (0.41, 24)
Jucar	1991	n.a. / n.a.	0.3 (0.36, 16) / n.a.
Jutland	1991	-0.16 (0.63, 12) / n.a.	n.a. / n.a.
Lielupe	1991	n.a. / n.a.	n.a. / -0.54 (0.35, 84)
Loire	1991	n.a. / -1.74 (0.48, 2)	0.43 (0.32, 29) / -1.65 (0.34, 7)
Meuse	1991	n.a. / n.a.	0.44 (0.28, 19) / n.a.
Middle Appenines	1991	n.a. / n.a.	n.a. / 0.14 (0.3, 23)
Minho	1991	n.a. / n.a.	-0.19 (0.2, 3) / -0.73 (0, 2)
Mosel	1991	n.a. / n.a.	0.73 (0.01, 2) / -0.19 (0.3, 2)
Neagh Bann	1991	n.a. / n.a.	0.4 (0.25, 3) / n.a.
North Adriatic	1991	n.a. / n.a.	-0.15 (0.18, 7) / n.a.
North East (UK)	1991	n.a. / n.a.	0.5 (0.11, 3) / n.a.
North West (UK)	1991	-0.58 (0.36, 3) / n.a.	0.3 (0.36, 20) / n.a.
Northumbria	1991	n.a. / n.a.	0 (0.39, 4) / n.a.
Oder	1991	n.a. / n.a.	0.44 (0.17, 5) / -0.52 (0.26, 4)
Pregolya	1991	n.a. / n.a.	n.a. / -0.54 (0.19, 15)
Rhine	1991	-0.72 (0.9, 2) / -1.5 (0.36, 3)	0.49 (0.28, 83) / n.a.
Rhone	1991	n.a. / n.a.	-0.01 (0.36, 69) / n.a.
Scheldt	1991	n.a. / n.a.	0.56 (0.26, 29) / n.a.
Schlei	1991	n.a. / -1.73 (0.91, 5)	0.4 (0.38, 2) / n.a.
Scotland	1991	-0.68 (0.6, 5) / n.a.	-0.67 (0.53, 11) / n.a.
Seine	1991	0.42 (0.12, 2) / n.a.	0.59 (0.15, 15) / -0.36 (0.12, 4)
Solway	1991	n.a. / n.a.	-0.15 (0.43, 2) / n.a.
South West (Irl.)	1991	n.a. / n.a.	n.a. / -0.83 (0.18, 27)
South West (UK)	1991	n.a. / n.a.	0.39 (0.4, 4) / n.a.
Tagus	1991	n.a. / n.a.	-0.06 (0.72, 28) / n.a.
Tagus West	1991	n.a. / -1.68 (0.28, 3)	n.a. / n.a.
Warnow	1991	n.a. / n.a.	0.3 (0.07, 4) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Weser	1991	n.a. / n.a.	0.66 (0.13, 15) / n.a.
Adour	1992	n.a. / n.a.	0.26 (0.35, 101) / n.a.
Black Sea	1992	n.a. / n.a.	0.41 (0.38, 4) / n.a.
Cantabrian	1992	n.a. / n.a.	0.05 (0.18, 6) / -0.7 (0.48, 124)
Corsica	1992	n.a. / n.a.	-0.66 (0.17, 7) / n.a.
Danube	1992	-0.67 (0.38, 18) / -1.53 (0.62, 18)	0.25 (0.33, 286) / n.a.
Daugava	1992	-0.06 (0.16, 5) / -1.2 (0.06, 5)	0.05 (0.15, 16) / -1.1 (0.26, 15)
Douro	1992	n.a. / n.a.	-0.07 (0.29, 26) / -0.67 (0.32, 69)
East	1992	n.a. / n.a.	n.a. / -0.73 (0.09, 4)
East Aegean Islands	1992	0.65 (0.59, 2) / n.a.	0.47 (0.39, 31) / n.a.
East Estonia	1992	-1.35 (0.7, 7) / -1.46 (0.32, 7)	-0.01 (0.4, 31) / -1.14 (0.31, 31)
Ebro	1992	n.a. / n.a.	0.27 (0.33, 52) / n.a.
Elbe	1992	n.a. / n.a.	0.55 (0.24, 71) / -0.66 (0.22, 52)
Ems	1992	n.a. / n.a.	0.78 (0.13, 3) / -0.51 (0.3, 38)
Gauja	1992	n.a. / n.a.	0 (0.04, 14) / -1.39 (0.16, 7)
Guadalquivir	1992	n.a. / n.a.	0.06 (0.37, 14) / -0.93 (0.48, 66)
Guadiana	1992	n.a. / n.a.	0.09 (0.31, 8) / n.a.
Humber	1992	-0.4 (0.28, 2) / -1.21 (0.33, 12)	1 (0.07, 3) / -0.57 (0.42, 24)
Jucar	1992	n.a. / n.a.	0.11 (0.51, 19) / n.a.
Jutland	1992	-0.14 (0.65, 12) / n.a.	n.a. / n.a.
Lielupe	1992	n.a. / n.a.	0.39 (0.18, 30) / -0.66 (0.57, 21)
Loire	1992	n.a. / n.a.	0.32 (0.38, 38) / -1.71 (0.3, 7)
Meuse	1992	n.a. / n.a.	0.5 (0.26, 19) / n.a.
Middle Appenines	1992	n.a. / n.a.	n.a. / 0.08 (0.26, 23)
Minho	1992	n.a. / n.a.	-0.16 (0.08, 3) / -0.79 (0.01, 2)
Mosel	1992	n.a. / n.a.	0.67 (0, 2) / -1.84 (0.63, 12)
Neagh Bann	1992	n.a. / n.a.	0.33 (0.28, 3) / n.a.
Nemunas	1992	n.a. / n.a.	0.02 (0.32, 42) / -0.86 (0.32, 38)
North Adriatic	1992	n.a. / n.a.	-0.19 (0.22, 7) / n.a.
North East (UK)	1992	n.a. / n.a.	0.42 (0.15, 3) / n.a.
North West (UK)	1992	-0.11 (0.28, 2) / n.a.	0.19 (0.5, 27) / n.a.
Northumbria	1992	n.a. / n.a.	0.03 (0.52, 4) / n.a.
Oder	1992	n.a. / n.a.	0.33 (0.29, 59) / -0.46 (0.11, 4)
Pregolya	1992	n.a. / n.a.	0.12 (0.16, 3) / -0.42 (0.07, 2)
Rhine	1992	n.a. / -1.42 (0.38, 2)	0.44 (0.3, 93) / n.a.
Rhone	1992	n.a. / n.a.	-0.06 (0.38, 77) / n.a.
Scheldt	1992	n.a. / n.a.	0.6 (0.21, 28) / n.a.
Schlei	1992	n.a. / n.a.	0.39 (0.43, 2) / n.a.
Scotland	1992	-0.73 (0.56, 6) / -1.72 (0.86, 6)	-0.69 (0.5, 12) / n.a.
Seine	1992	0.5 (0.12, 2) / n.a.	0.58 (0.14, 15) / -0.36 (0.42, 53)
Solway	1992	n.a. / n.a.	-0.27 (0.4, 2) / n.a.
South West (Irl.)	1992	n.a. / n.a.	n.a. / -0.93 (0.13, 27)
South West (UK)	1992	n.a. / n.a.	0.34 (0.4, 4) / n.a.
Tagus	1992	n.a. / n.a.	-0.05 (0.44, 26) / n.a.

Supporting information

Basin	Year	Lake	Stream
Venta	1992	n.a. / n.a.	0.11 (0.16, 16) / -1.15 (0.32, 12)
Vistula	1992	n.a. / n.a.	0.11 (0.26, 50) / -0.47 (0.45, 40)
Warnow	1992	n.a. / n.a.	0.35 (0.1, 4) / n.a.
Weser	1992	n.a. / n.a.	0.7 (0.11, 15) / n.a.
West Aegean	1992	n.a. / n.a.	0.81 (0.17, 5) / n.a.
West Estonian	1992	n.a. / n.a.	0.09 (0.3, 17) / -1.13 (0.22, 17)
Adour	1993	n.a. / n.a.	0.22 (0.35, 104) / -0.12 (0.01, 2)
Black Sea	1993	-0.41 (0.29, 2) / n.a.	0.16 (0.29, 5) / n.a.
Cantabrian	1993	n.a. / n.a.	-0.28 (0.38, 6) / -0.86 (0.55, 197)
Cavado	1993	n.a. / n.a.	n.a. / -1.21 (0.24, 16)
Corsica	1993	n.a. / n.a.	-0.44 (0.11, 7) / n.a.
Danube	1993	-0.66 (0.42, 18) / -1.59 (0.43, 17)	0.16 (0.33, 339) / -1.16 (0.3, 32)
Daugava	1993	0.12 (0.18, 5) / n.a.	0.09 (0.25, 16) / n.a.
Douro	1993	n.a. / n.a.	0.04 (0.18, 26) / -0.72 (0.28, 75)
East Aegean Islands	1993	n.a. / n.a.	0.03 (0.24, 35) / -0.7 (0.08, 3)
East Alps	1993	n.a. / -1.44 (0.19, 8)	n.a. / -1.47 (0.22, 14)
East Estonia	1993	-0.64 (0.34, 4) / n.a.	0.01 (0.34, 32) / n.a.
Ebro	1993	n.a. / n.a.	0.21 (0.32, 57) / n.a.
Elbe	1993	n.a. / n.a.	0.54 (0.24, 76) / -0.67 (0.2, 68)
Ems	1993	n.a. / n.a.	0.77 (0.08, 3) / n.a.
Epirus	1993	n.a. / n.a.	n.a. / -0.57 (0.36, 35)
Gauja	1993	n.a. / n.a.	-0.07 (0.07, 14) / -0.65 (0.31, 16)
Guadalquivir	1993	n.a. / n.a.	0 (0.33, 13) / n.a.
Guadiana	1993	n.a. / n.a.	0.19 (0.23, 7) / -0.76 (0.41, 58)
Humber	1993	-0.18 (0.06, 2) / -1.23 (0.35, 12)	1 (0.09, 3) / -0.57 (0.42, 24)
Jucar	1993	n.a. / n.a.	-1.23 (0.78, 8) / n.a.
Jutland	1993	-0.14 (0.7, 12) / n.a.	n.a. / n.a.
Lielupe	1993	n.a. / n.a.	0.33 (0.21, 31) / -0.75 (0.49, 100)
Loire	1993	n.a. / -1.93 (0.32, 2)	0.47 (0.36, 35) / -1.74 (0.19, 7)
Meuse	1993	n.a. / n.a.	0.48 (0.23, 20) / n.a.
Middle Appenines	1993	n.a. / n.a.	n.a. / 0.03 (0.32, 22)
Minho	1993	n.a. / n.a.	-0.22 (0.16, 3) / -0.87 (0.04, 2)
Mosel	1993	n.a. / n.a.	0.7 (0.09, 2) / -1.84 (0.77, 12)
Neagh Bann	1993	n.a. / n.a.	0.2 (0.24, 3) / n.a.
Nemunas	1993	-0.25 (0.61, 2) / -1.55 (0.21, 2)	0 (0.28, 43) / n.a.
North Adriatic	1993	n.a. / n.a.	-0.21 (0.23, 7) / n.a.
North East (UK)	1993	n.a. / n.a.	0.31 (0.1, 5) / n.a.
North West (UK)	1993	-0.29 (0.08, 3) / n.a.	0.13 (0.5, 27) / n.a.
Northumbria	1993	n.a. / n.a.	0.03 (0.36, 4) / -1.22 (0.26, 16)
Oder	1993	n.a. / n.a.	0.3 (0.26, 61) / -0.72 (0.13, 4)
Po	1993	-0.4 (0.67, 2) / -0.89 (0.24, 2)	n.a. / n.a.
Pregolya	1993	n.a. / n.a.	0.13 (0.18, 3) / -0.64 (0.17, 16)
Rhine	1993	-0.08 (0.54, 22) / -1.36 (0.38, 22)	0.4 (0.31, 98) / n.a.
Rhone	1993	n.a. / n.a.	-0.03 (0.37, 75) / -0.51 (0.06, 3)

Appendix S7.2

Basin	Year	Lake	Stream
Scheldt	1993	n.a. / n.a.	0.6 (0.19, 30) / n.a.
Schlei	1993	n.a. / n.a.	0.46 (0.38, 2) / n.a.
Scotland	1993	-0.73 (0.55, 6) / -1.73 (0.82, 6)	-0.66 (0.53, 12) / n.a.
Seine	1993	0.42 (0.18, 2) / n.a.	0.62 (0.15, 16) / -0.39 (0.44, 56)
Solway	1993	n.a. / n.a.	-0.32 (0.53, 2) / n.a.
South West (Irl.)	1993	n.a. / n.a.	n.a. / -0.92 (0.15, 30)
South West (UK)	1993	n.a. / n.a.	0.35 (0.42, 4) / n.a.
Tagus	1993	n.a. / n.a.	-0.1 (0.46, 27) / n.a.
Tagus West	1993	n.a. / -1.59 (0.13, 2)	n.a. / n.a.
Venta	1993	-0.63 (0.1, 2) / -1.49 (0.44, 2)	0.04 (0.26, 16) / n.a.
Vistula	1993	n.a. / n.a.	0.15 (0.23, 53) / n.a.
Warnow	1993	n.a. / n.a.	0.43 (0.09, 4) / n.a.
Weser	1993	n.a. / n.a.	0.7 (0.11, 16) / n.a.
West Aegean	1993	n.a. / n.a.	0.22 (0.45, 12) / n.a.
West Estonian	1993	n.a. / n.a.	0.03 (0.3, 18) / n.a.
Adour	1994	n.a. / n.a.	0.21 (0.36, 103) / -0.28 (0.13, 2)
Andalusia	1994	n.a. / n.a.	0.04 (0.38, 14) / n.a.
Black Sea	1994	-0.12 (0.17, 2) / n.a.	0.15 (0.16, 6) / n.a.
Cantabrian	1994	n.a. / n.a.	-0.34 (0.57, 17) / -0.89 (0.56, 260)
Catalan	1994	n.a. / n.a.	0.24 (0.29, 58) / n.a.
Central Macedonia	1994	n.a. / n.a.	n.a. / -1.18 (0.24, 16)
Corsica	1994	n.a. / n.a.	-0.32 (0.12, 7) / n.a.
Danube	1994	-0.58 (0.31, 18) / -1.44 (0.64, 20)	0.19 (0.36, 352) / -1.22 (0.29, 34)
Daugava	1994	-0.03 (0.23, 5) / n.a.	-0.03 (0.27, 16) / n.a.
Douro	1994	n.a. / n.a.	-0.04 (0.34, 45) / -0.97 (0.52, 20)
East Aegean Islands	1994	n.a. / n.a.	-0.06 (0.28, 33) / -0.72 (0.14, 4)
East Alps	1994	n.a. / -1.5 (0.32, 8)	n.a. / -1.42 (0.14, 15)
East Estonia	1994	-1.62 (1.03, 8) / n.a.	-0.05 (0.3, 34) / n.a.
Ebro	1994	n.a. / n.a.	0.17 (0.33, 92) / -0.83 (0.34, 7)
Elbe	1994	n.a. / n.a.	0.58 (0.25, 76) / -0.84 (0.19, 30)
Ems	1994	n.a. / n.a.	0.7 (0.12, 3) / n.a.
Epirus	1994	n.a. / n.a.	n.a. / -0.62 (0.3, 36)
Galician	1994	n.a. / n.a.	-0.16 (0.2, 4) / n.a.
Gauja	1994	n.a. / n.a.	-0.15 (0.23, 15) / -0.77 (0.24, 17)
Guadalquivir	1994	n.a. / n.a.	-0.09 (0.35, 33) / n.a.
Guadiana	1994	n.a. / n.a.	0.03 (0.35, 49) / -0.88 (0.42, 55)
Humber	1994	n.a. / -1.26 (0.35, 12)	0.97 (0.07, 3) / -0.52 (0.45, 32)
Jucar	1994	n.a. / n.a.	-0.46 (0.38, 53) / -1.07 (0.48, 14)
Jutland	1994	-0.17 (0.7, 12) / -0.65 (0.5, 2)	n.a. / n.a.
Lielupe	1994	n.a. / -1.58 (0.19, 3)	0.24 (0.18, 31) / -0.81 (0.48, 100)
Loire	1994	0.99 (0.57, 4) / -1.97 (0.39, 2)	0.54 (0.34, 36) / -1.82 (0.25, 7)
Meuse	1994	n.a. / n.a.	0.52 (0.21, 29) / -1.02 (0.2, 2)
Middle Appenines	1994	n.a. / n.a.	n.a. / -0.07 (0.31, 28)
Minho	1994	n.a. / n.a.	-0.8 (0.69, 7) / -0.8 (0.08, 2)

Supporting information

Basin	Year	Lake	Stream
Mosel	1994	n.a. / n.a.	0.73 (0.03, 2) / -1.76 (0.6, 12)
Neagh Bann	1994	n.a. / n.a.	0.14 (0.27, 3) / n.a.
Nemunas	1994	-0.76 (0.35, 3) / n.a.	-0.03 (0.28, 45) / n.a.
North Adriatic	1994	n.a. / n.a.	-0.16 (0.22, 7) / n.a.
North East (UK)	1994	n.a. / -0.92 (0.25, 2)	0.24 (0.14, 5) / n.a.
North West (UK)	1994	-0.28 (0.03, 3) / -1.54 (0.36, 2)	0.13 (0.5, 27) / n.a.
Northumbria	1994	n.a. / n.a.	-0.03 (0.4, 4) / -1.31 (0.39, 18)
Oder	1994	n.a. / n.a.	0.4 (0.22, 60) / -0.65 (0.46, 50)
Po	1994	-0.39 (0.64, 2) / n.a.	n.a. / n.a.
Pregolya	1994	n.a. / n.a.	0.12 (0.1, 4) / n.a.
Rhine	1994	-0.07 (0.41, 20) / -1.44 (0.48, 21)	0.39 (0.31, 101) / -0.59 (0.2, 15)
Rhone	1994	0.04 (0.67, 3) / n.a.	0.03 (0.41, 70) / -0.61 (0.15, 4)
Scheldt	1994	n.a. / n.a.	0.64 (0.17, 35) / n.a.
Schlei	1994	n.a. / n.a.	0.43 (0.45, 2) / n.a.
Scotland	1994	-0.61 (0.53, 5) / -1.74 (0.83, 7)	-0.7 (0.51, 12) / n.a.
Segura	1994	n.a. / n.a.	-0.13 (0.12, 6) / n.a.
Seine	1994	0.62 (0.76, 6) / n.a.	0.67 (0.17, 16) / -0.49 (0.44, 57)
Solway	1994	n.a. / n.a.	-0.33 (0.46, 2) / n.a.
South West (UK)	1994	n.a. / n.a.	0.35 (0.43, 4) / n.a.
Tagus	1994	n.a. / n.a.	-0.47 (0.46, 76) / n.a.
Tagus West	1994	n.a. / -1.55 (0.19, 3)	n.a. / n.a.
Venta	1994	-0.61 (0.25, 2) / n.a.	-0.07 (0.43, 18) / n.a.
Vistula	1994	n.a. / n.a.	0.11 (0.26, 53) / n.a.
Warnow	1994	n.a. / n.a.	0.55 (0.11, 4) / n.a.
Weser	1994	n.a. / n.a.	0.7 (0.11, 16) / n.a.
West Aegean	1994	n.a. / n.a.	0.74 (0.27, 6) / n.a.
West Estonian	1994	n.a. / n.a.	-0.02 (0.25, 18) / n.a.
Adour	1995	n.a. / n.a.	0.14 (0.38, 103) / -0.06 (0.14, 2)
Andalusia	1995	n.a. / n.a.	0.08 (0.43, 14) / n.a.
Black Sea	1995	-0.14 (0.43, 2) / n.a.	0.23 (0.31, 6) / n.a.
Cantabrian	1995	n.a. / n.a.	-0.32 (0.28, 4) / -0.52 (0.45, 7)
Catalan	1995	n.a. / n.a.	0.25 (0.28, 58) / n.a.
Central Macedonia	1995	n.a. / n.a.	n.a. / -1.27 (0.24, 16)
Corsica	1995	n.a. / n.a.	-0.55 (0.21, 7) / -0.84 (0.09, 2)
Danube	1995	-0.64 (0.32, 18) / -1.52 (0.54, 20)	0.21 (0.36, 368) / -1.27 (0.27, 34)
Daugava	1995	-0.08 (0.21, 5) / n.a.	-0.08 (0.22, 16) / -0.76 (0.36, 7)
Douro	1995	n.a. / n.a.	-0.03 (0.33, 45) / -0.83 (0.24, 78)
East Aegean Islands	1995	n.a. / n.a.	0.01 (0.29, 33) / -0.84 (0.07, 4)
East Alps	1995	n.a. / -1.36 (0.38, 8)	n.a. / n.a.
East Estonia	1995	-1.01 (0.53, 8) / n.a.	-0.05 (0.32, 34) / -1.59 (0.15, 15)
Ebro	1995	n.a. / n.a.	0.18 (0.38, 95) / -0.46 (0.91, 16)
Elbe	1995	-1.07 (0.46, 2) / -1.08 (0.18, 2)	0.57 (0.25, 78) / -0.92 (0.14, 30)
Ems	1995	n.a. / n.a.	0.66 (0.15, 3) / n.a.
Epirus	1995	n.a. / n.a.	n.a. / -0.66 (0.29, 37)

Appendix S7.2

Basin	Year	Lake	Stream
Galician	1995	n.a. / n.a.	n.a. / -1.88 (0.15, 4)
Gauja	1995	n.a. / n.a.	-0.04 (0.24, 15) / -0.75 (0.24, 30)
Guadalquivir	1995	n.a. / n.a.	-0.38 (0.39, 31) / n.a.
Guadiana	1995	n.a. / n.a.	0.05 (0.38, 48) / -0.89 (0.39, 63)
Humber	1995	n.a. / -1.29 (0.35, 12)	1 (0.08, 3) / -0.81 (0.49, 31)
Jucar	1995	n.a. / n.a.	-0.41 (0.44, 63) / n.a.
Jutland	1995	-0.25 (0.75, 12) / -0.62 (0.14, 2)	n.a. / n.a.
Lielupe	1995	n.a. / -1.74 (0.46, 3)	0.3 (0.12, 31) / -0.81 (0.44, 107)
Loire	1995	n.a. / -1.39 (0.7, 3)	0.52 (0.36, 35) / -1.68 (0.33, 7)
Meuse	1995	n.a. / n.a.	0.51 (0.19, 31) / -1.06 (0.11, 2)
Middle Appenines	1995	n.a. / n.a.	n.a. / -0.13 (0.37, 29)
Minho	1995	n.a. / n.a.	-0.76 (0.47, 4) / -1.5 (0.72, 4)
Mosel	1995	n.a. / n.a.	0.67 (0.06, 2) / -1.79 (0.65, 12)
Neagh Bann	1995	n.a. / n.a.	0.22 (0.26, 3) / n.a.
Nemunas	1995	-0.68 (0.37, 3) / n.a.	0 (0.27, 45) / n.a.
North Adriatic	1995	n.a. / n.a.	-0.16 (0.19, 7) / n.a.
North East (UK)	1995	n.a. / n.a.	0.35 (0.15, 5) / n.a.
North West (UK)	1995	-0.2 (0.12, 3) / -1.77 (0.08, 2)	0.09 (0.48, 28) / n.a.
Northumbria	1995	n.a. / n.a.	-0.05 (0.35, 4) / -1.42 (0.31, 19)
Oder	1995	n.a. / -0.93 (0.29, 2)	0.38 (0.23, 60) / -0.77 (0.43, 52)
Po	1995	-0.42 (0.68, 2) / n.a.	n.a. / n.a.
Pregolya	1995	n.a. / n.a.	0.19 (0.15, 4) / n.a.
Rhine	1995	-0.05 (0.38, 22) / -1.43 (0.46, 23)	0.4 (0.31, 108) / -0.71 (0.13, 16)
Rhone	1995	n.a. / n.a.	-0.08 (0.35, 75) / -0.66 (0.11, 4)
Scheldt	1995	n.a. / n.a.	0.64 (0.17, 36) / n.a.
Schlei	1995	n.a. / n.a.	0.36 (0.36, 2) / n.a.
Scotland	1995	-0.53 (0.48, 5) / -1.71 (0.88, 7)	-0.69 (0.53, 12) / n.a.
Segura	1995	n.a. / n.a.	-0.23 (0.44, 6) / n.a.
Seine	1995	0.46 (0.08, 2) / n.a.	0.66 (0.17, 29) / -0.55 (0.42, 56)
Solway	1995	n.a. / n.a.	-0.23 (0.47, 2) / n.a.
South West (UK)	1995	n.a. / n.a.	0.36 (0.43, 4) / n.a.
Tagus	1995	n.a. / n.a.	-0.69 (0.35, 37) / n.a.
Venta	1995	-0.65 (0.14, 2) / n.a.	-0.12 (0.38, 19) / n.a.
Vistula	1995	n.a. / n.a.	0.17 (0.23, 53) / n.a.
Warnow	1995	n.a. / n.a.	0.38 (0.07, 4) / n.a.
Weser	1995	n.a. / n.a.	0.67 (0.12, 16) / n.a.
West Aegean	1995	n.a. / n.a.	0.29 (0.44, 12) / n.a.
West Estonian	1995	n.a. / n.a.	-0.02 (0.28, 18) / n.a.
Adour	1996	n.a. / n.a.	0.15 (0.37, 103) / -0.13 (0.06, 2)
Andalusia	1996	n.a. / n.a.	0.33 (0.17, 14) / n.a.
Basque County	1996	n.a. / n.a.	n.a. / -0.63 (0.29, 10)
Black Sea	1996	0.24 (0.39, 2) / n.a.	0.33 (0.39, 6) / -1.17 (0.23, 5)
Cantabrian	1996	n.a. / n.a.	-0.1 (0.34, 23) / -0.98 (0.49, 332)
Catalan	1996	n.a. / n.a.	0.23 (0.39, 57) / n.a.

Supporting information

Basin	Year	Lake	Stream
Central Macedonia	1996	n.a. / n.a.	n.a. / -1.19 (0.28, 15)
Corsica	1996	n.a. / n.a.	-0.54 (0.18, 7) / -1 (0.39, 19)
Danube	1996	-0.57 (0.39, 18) / -1.59 (0.71, 20)	0.24 (0.38, 366) / -1.24 (0.34, 34)
Daugava	1996	-0.08 (0.22, 5) / n.a.	0 (0.11, 15) / -0.52 (0.3, 4)
Douro	1996	n.a. / n.a.	0.08 (0.34, 65) / -0.79 (0.26, 62)
East Aegean Islands	1996	n.a. / n.a.	0.19 (0.27, 32) / -0.82 (0.08, 4)
East Alps	1996	n.a. / -1.43 (0.26, 8)	n.a. / n.a.
East Estonia	1996	-1.03 (0.49, 8) / n.a.	0.03 (0.31, 34) / -1.57 (0.18, 15)
Ebro	1996	n.a. / n.a.	0.23 (0.36, 98) / n.a.
Eider	1996	n.a. / n.a.	n.a. / -1.28 (0.35, 22)
Elbe	1996	-1.13 (0.52, 4) / -1.28 (0.33, 4)	0.52 (0.27, 78) / -0.93 (0.19, 30)
Ems	1996	n.a. / n.a.	0.68 (0.19, 3) / n.a.
Epirus	1996	n.a. / n.a.	n.a. / -0.68 (0.27, 32)
Galician	1996	n.a. / n.a.	-0.05 (0.12, 4) / n.a.
Gauja	1996	n.a. / n.a.	0.04 (0.23, 15) / n.a.
Guadalete	1996	n.a. / n.a.	n.a. / -0.71 (0.29, 33)
Guadalquivir	1996	n.a. / n.a.	0.35 (0.42, 51) / n.a.
Guadiana	1996	n.a. / n.a.	0.35 (0.37, 56) / -0.7 (0.48, 63)
Humber	1996	-0.06 (0.12, 2) / -1.26 (0.25, 12)	1.06 (0.05, 3) / -0.67 (0.54, 31)
Jucar	1996	n.a. / n.a.	0.09 (0.5, 51) / -1.21 (0.23, 3)
Jutland	1996	-0.32 (0.59, 12) / n.a.	n.a. / n.a.
Lielupe	1996	n.a. / n.a.	0.19 (0.17, 31) / -0.81 (0.51, 109)
Loire	1996	n.a. / n.a.	0.44 (0.35, 32) / -1.62 (0.57, 7)
Meuse	1996	n.a. / -1.66 (0.18, 3)	0.45 (0.25, 33) / -1.05 (0.07, 2)
Middle Appenines	1996	n.a. / n.a.	n.a. / -0.11 (0.32, 29)
Minho	1996	n.a. / n.a.	-0.37 (0.21, 18) / n.a.
Minho Lima	1996	n.a. / n.a.	n.a. / -0.76 (0.1, 2)
Mosel	1996	n.a. / n.a.	0.65 (0.04, 2) / -1.72 (0.57, 12)
Neagh Bann	1996	n.a. / n.a.	0.35 (0.26, 3) / n.a.
Nemunas	1996	-1.2 (0.4, 3) / n.a.	-0.08 (0.26, 45) / n.a.
North Adriatic	1996	n.a. / n.a.	-0.17 (0.21, 7) / n.a.
North East (UK)	1996	n.a. / n.a.	0.51 (0.07, 5) / n.a.
North West (UK)	1996	0.03 (0.29, 4) / -1.59 (0.3, 2)	0.3 (0.46, 28) / n.a.
Northumbria	1996	n.a. / n.a.	0.06 (0.28, 4) / -1.33 (0.34, 19)
Oder	1996	n.a. / n.a.	0.36 (0.26, 68) / -0.66 (0.34, 61)
Po	1996	-0.41 (0.66, 2) / -0.94 (0.32, 2)	n.a. / -0.86 (0.07, 4)
Pregolya	1996	n.a. / n.a.	0.06 (0.11, 4) / n.a.
Rhine	1996	-0.16 (0.53, 22) / -1.49 (0.46, 23)	0.41 (0.3, 109) / -0.65 (0.14, 16)
Rhone	1996	n.a. / n.a.	-0.01 (0.42, 74) / -0.68 (0.19, 4)
Scheldt	1996	n.a. / n.a.	0.65 (0.21, 35) / n.a.
Schlei	1996	n.a. / n.a.	0.27 (0.41, 2) / n.a.
Scotland	1996	-0.41 (0.41, 5) / -1.77 (0.78, 7)	-0.6 (0.59, 12) / n.a.
Seine	1996	0.41 (0.12, 2) / n.a.	0.63 (0.18, 32) / -0.52 (0.35, 68)
Solway	1996	n.a. / n.a.	-0.09 (0.4, 2) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
South West (UK)	1996	n.a. / n.a.	0.42 (0.37, 4) / n.a.
Tagus	1996	n.a. / n.a.	-0.6 (0.33, 40) / n.a.
Thames	1996	n.a. / n.a.	n.a. / -0.45 (0.84, 2)
Venta	1996	-0.52 (0.01, 2) / n.a.	-0.06 (0.35, 19) / n.a.
Vistula	1996	n.a. / n.a.	0.13 (0.23, 62) / n.a.
Warnow	1996	n.a. / n.a.	0.16 (0.06, 4) / n.a.
Weser	1996	n.a. / n.a.	0.65 (0.11, 16) / n.a.
West Aegean	1996	n.a. / n.a.	0.46 (0.49, 13) / n.a.
West Estonian	1996	n.a. / n.a.	0.03 (0.22, 18) / n.a.
Adour	1997	n.a. / n.a.	0.12 (0.39, 110) / -0.32 (0.21, 2)
Basque County	1997	n.a. / n.a.	-0.25 (0.42, 2) / n.a.
Black Sea	1997	n.a. / n.a.	0.49 (0.46, 4) / -1.16 (0.32, 7)
Cantabrian	1997	n.a. / n.a.	-0.28 (0.33, 22) / -1.01 (0.52, 335)
Central Macedonia	1997	n.a. / n.a.	n.a. / -1.19 (0.21, 15)
Corsica	1997	n.a. / n.a.	-0.66 (0.24, 7) / n.a.
Cyprus	1997	n.a. / n.a.	0.1 (0.67, 8) / -0.76 (1.6, 2)
Danube	1997	-0.69 (0.46, 18) / -1.55 (0.59, 20)	0.21 (0.36, 368) / -1.29 (0.32, 34)
Daugava	1997	n.a. / n.a.	0.06 (0.11, 15) / n.a.
Douro	1997	n.a. / n.a.	-0.06 (0.55, 48) / -0.8 (0.25, 78)
East	1997	n.a. / n.a.	0.17 (0.7, 4) / n.a.
East Aegean Islands	1997	n.a. / n.a.	0.08 (0.29, 34) / -0.89 (0.12, 4)
East Estonia	1997	-1.2 (0.77, 8) / -1.45 (0.45, 8)	0.04 (0.33, 34) / -1.61 (0.09, 15)
Ebro	1997	n.a. / n.a.	0.14 (0.53, 69) / n.a.
Elbe	1997	-0.92 (0.44, 8) / -1.3 (0.48, 8)	0.5 (0.27, 78) / -0.97 (0.15, 30)
Ems	1997	n.a. / n.a.	0.66 (0.12, 3) / -0.77 (0.37, 62)
Galician	1997	n.a. / n.a.	n.a. / -0.73 (0.37, 38)
Gauja	1997	n.a. / n.a.	0.01 (0.29, 15) / n.a.
Guadalete	1997	n.a. / n.a.	n.a. / -0.74 (0.3, 44)
Guadalquivir	1997	n.a. / n.a.	0.4 (0.6, 34) / n.a.
Guadiana	1997	n.a. / n.a.	0.09 (0.49, 11) / -0.84 (0.42, 102)
Humber	1997	-0.08 (0.06, 2) / -1.3 (0.3, 12)	1.03 (0.09, 3) / -0.82 (0.5, 31)
Jucar	1997	n.a. / n.a.	0.3 (0.53, 22) / n.a.
Jutland	1997	-0.32 (0.67, 12) / -0.51 (0.34, 2)	n.a. / n.a.
Lielupe	1997	n.a. / n.a.	0.28 (0.2, 31) / -0.82 (0.46, 114)
Loire	1997	n.a. / n.a.	0.46 (0.34, 38) / -1.93 (0.25, 6)
Meuse	1997	n.a. / -1.68 (0.15, 3)	0.5 (0.23, 34) / -1.04 (0.13, 2)
Middle Appenines	1997	n.a. / n.a.	n.a. / -0.09 (0.3, 28)
Minho	1997	n.a. / n.a.	-0.3 (0.17, 12) / n.a.
Minho Lima	1997	n.a. / n.a.	n.a. / -0.77 (0.02, 2)
Mosel	1997	n.a. / n.a.	0.77 (0.04, 2) / -1.76 (0.63, 12)
Neagh Bann	1997	n.a. / n.a.	0.41 (0.25, 4) / n.a.
Nemunas	1997	-1.01 (0.35, 3) / n.a.	-0.01 (0.32, 45) / n.a.
North Adriatic	1997	n.a. / n.a.	-0.27 (0.36, 6) / n.a.
North East (UK)	1997	n.a. / n.a.	0.5 (0.09, 5) / n.a.

Supporting information

Basin	Year	Lake	Stream
North West (Irl.)	1997	n.a. / n.a.	-0.89 (0.37, 3) / n.a.
North West (UK)	1997	-0.17 (0.2, 3) / n.a.	0.24 (0.5, 28) / -1.05 (0.15, 4)
Northumbria	1997	n.a. / n.a.	0.09 (0.33, 4) / -1.4 (0.36, 19)
Oder	1997	n.a. / n.a.	0.31 (0.25, 74) / -0.7 (0.37, 63)
Po	1997	-0.42 (0.65, 2) / -0.92 (0.33, 2)	n.a. / -0.87 (0.1, 4)
Pregolya	1997	n.a. / n.a.	0.15 (0.16, 4) / n.a.
Rhine	1997	-0.18 (0.47, 23) / -1.46 (0.41, 24)	0.4 (0.31, 113) / -0.68 (0.08, 16)
Rhone	1997	n.a. / n.a.	-0.02 (0.41, 110) / -0.74 (0.2, 4)
Scheldt	1997	n.a. / n.a.	0.62 (0.19, 37) / n.a.
Schlei	1997	n.a. / n.a.	0.32 (0.43, 2) / n.a.
Scotland	1997	-0.5 (0.37, 5) / -1.71 (0.74, 7)	-0.62 (0.54, 12) / n.a.
Seine	1997	n.a. / n.a.	0.64 (0.16, 43) / -0.48 (0.44, 72)
Shannon	1997	n.a. / n.a.	0.06 (0.29, 14) / n.a.
Solway	1997	n.a. / n.a.	-0.16 (0.53, 2) / n.a.
South East (Irl.)	1997	n.a. / n.a.	0.6 (0.18, 5) / n.a.
South West (Irl.)	1997	n.a. / n.a.	0.19 (0.46, 14) / n.a.
South West (UK)	1997	n.a. / n.a.	0.39 (0.39, 4) / n.a.
Tagus	1997	n.a. / n.a.	-0.32 (0.62, 70) / n.a.
Venta	1997	n.a. / n.a.	-0.1 (0.34, 19) / n.a.
Vistula	1997	n.a. / n.a.	0.12 (0.2, 64) / n.a.
Warnow	1997	n.a. / n.a.	0.15 (0.09, 4) / n.a.
Weser	1997	n.a. / n.a.	0.65 (0.1, 16) / n.a.
West Aegean	1997	n.a. / n.a.	-0.3 (1.12, 12) / n.a.
West Estonian	1997	n.a. / n.a.	0.07 (0.25, 18) / n.a.
Adour	1998	n.a. / n.a.	0.13 (0.43, 109) / -0.22 (0.09, 2)
Basque County	1998	n.a. / n.a.	-0.15 (0.23, 2) / n.a.
Black Sea	1998	n.a. / n.a.	0.34 (0.24, 8) / -0.96 (0.25, 7)
Cantabrian	1998	n.a. / n.a.	-0.4 (0.65, 17) / -0.98 (0.5, 335)
Corsica	1998	n.a. / n.a.	-0.67 (0.33, 7) / -1.22 (0.11, 16)
Cyprus	1998	n.a. / n.a.	-0.07 (0.74, 9) / n.a.
Danube	1998	-0.6 (0.34, 18) / -1.84 (0.54, 34)	0.19 (0.34, 378) / -1.27 (0.3, 34)
Daugava	1998	-0.35 (0.36, 5) / n.a.	-0.25 (0.09, 16) / n.a.
Douro	1998	n.a. / n.a.	-0.02 (0.47, 48) / -0.76 (0.26, 78)
East Aegean Islands	1998	n.a. / n.a.	0.05 (0.32, 43) / -0.74 (0.08, 3)
East Estonia	1998	-0.97 (0.44, 8) / -1.42 (0.27, 8)	0 (0.34, 34) / -1.38 (0.14, 15)
Ebro	1998	n.a. / n.a.	0.2 (0.45, 39) / n.a.
Elbe	1998	-0.96 (0.46, 9) / -1.02 (0.54, 9)	0.49 (0.26, 77) / -0.91 (0.17, 30)
Ems	1998	n.a. / n.a.	0.69 (0.14, 4) / -0.75 (0.3, 57)
Galician	1998	n.a. / n.a.	n.a. / -0.73 (0.33, 37)
Gauja	1998	n.a. / n.a.	-0.17 (0.27, 15) / n.a.
Guadalete	1998	n.a. / n.a.	n.a. / -0.8 (0.27, 51)
Guadalquivir	1998	n.a. / n.a.	0.38 (0.38, 35) / n.a.
Guadiana	1998	n.a. / n.a.	-0.08 (0.52, 10) / -0.87 (0.4, 109)
Humber	1998	0.46 (0.55, 3) / -1.28 (0.29, 12)	0.88 (0.26, 16) / -0.93 (0.4, 31)

Appendix S7.2

Basin	Year	Lake	Stream
Jucar	1998	n.a. / n.a.	0.3 (0.36, 33) / n.a.
Jutland	1998	-0.15 (0.68, 12) / -1.05 (0.63, 3)	n.a. / n.a.
Lielupe	1998	n.a. / n.a.	0.37 (0.24, 31) / -0.85 (0.44, 112)
Loire	1998	n.a. / n.a.	0.5 (0.34, 38) / -1.85 (0.44, 6)
Meuse	1998	n.a. / n.a.	0.55 (0.26, 40) / -1.04 (0.17, 2)
Middle Appenines	1998	n.a. / -1.66 (0.11, 3)	n.a. / n.a.
Minho	1998	n.a. / n.a.	-0.24 (0.26, 12) / -0.29 (0.39, 35)
Minho Lima	1998	n.a. / n.a.	n.a. / -0.84 (0.17, 2)
Mosel	1998	n.a. / n.a.	0.72 (0.06, 2) / -1.75 (0.57, 12)
Neagh Bann	1998	n.a. / n.a.	0.38 (0.32, 3) / n.a.
Nemunas	1998	-0.85 (0.37, 3) / n.a.	0.09 (0.32, 46) / n.a.
North Adriatic	1998	n.a. / n.a.	-0.15 (0.21, 6) / n.a.
North East (UK)	1998	n.a. / n.a.	0.41 (0.1, 5) / -1.07 (0.26, 4)
North West (UK)	1998	0.41 (0.81, 4) / -1.47 (0.22, 2)	0.22 (0.53, 28) / n.a.
Northumbria	1998	n.a. / n.a.	0.11 (0.3, 4) / -1.3 (0.26, 19)
Oder	1998	n.a. / n.a.	0.38 (0.25, 73) / -0.72 (0.39, 64)
Po	1998	-0.44 (0.65, 2) / -0.97 (0.38, 2)	n.a. / -0.88 (0.06, 4)
Pregolya	1998	n.a. / n.a.	0.25 (0.18, 4) / n.a.
Rhine	1998	-0.19 (0.49, 23) / -1.5 (0.45, 23)	0.4 (0.32, 115) / -0.7 (0.12, 16)
Rhone	1998	n.a. / n.a.	0 (0.38, 123) / -0.81 (0.18, 4)
Scheldt	1998	n.a. / n.a.	0.69 (0.17, 35) / n.a.
Schlei	1998	n.a. / n.a.	0.46 (0.36, 2) / n.a.
Scotland	1998	-0.61 (0.33, 8) / -1.77 (0.69, 8)	-0.47 (0.51, 12) / n.a.
Seine	1998	n.a. / n.a.	0.66 (0.16, 51) / -0.58 (0.35, 73)
Shannon	1998	n.a. / n.a.	n.a. / -1.01 (0.25, 2)
Solway	1998	n.a. / n.a.	-0.05 (0.35, 2) / n.a.
South West (UK)	1998	n.a. / n.a.	0.36 (0.42, 4) / n.a.
Tagus	1998	n.a. / n.a.	-0.54 (0.5, 69) / n.a.
Venta	1998	-0.75 (0.32, 2) / n.a.	-0.21 (0.53, 19) / n.a.
Vistula	1998	n.a. / n.a.	0.19 (0.24, 65) / n.a.
Warnow	1998	n.a. / n.a.	0.46 (0.08, 4) / n.a.
Weser	1998	n.a. / n.a.	0.66 (0.1, 16) / n.a.
West Aegean	1998	n.a. / n.a.	-0.44 (0.45, 18) / n.a.
West Estonian	1998	n.a. / n.a.	0.13 (0.27, 18) / n.a.
Adour	1999	n.a. / n.a.	0.19 (0.41, 108) / -0.76 (0.18, 2)
Basque County	1999	n.a. / n.a.	-0.04 (0.21, 2) / n.a.
Black Sea	1999	0.1 (0.22, 4) / n.a.	0.26 (0.43, 8) / -0.72 (0.16, 5)
Cantabrian	1999	n.a. / n.a.	-0.17 (0.29, 15) / -1.49 (0.8, 8)
Catalan	1999	n.a. / n.a.	n.a. / -0.95 (0.46, 338)
Corsica	1999	n.a. / n.a.	-0.56 (0.21, 8) / -1.21 (0.17, 16)
Cyprus	1999	n.a. / n.a.	0.22 (0.78, 10) / n.a.
Danube	1999	-0.59 (0.31, 20) / -1.74 (0.52, 31)	0.2 (0.34, 380) / -1.24 (0.31, 34)
Daugava	1999	-0.42 (0.38, 5) / n.a.	-0.23 (0.12, 16) / n.a.
Douro	1999	n.a. / n.a.	0.04 (0.36, 47) / -0.81 (0.24, 78)

Supporting information

Basin	Year	Lake	Stream
East	1999	n.a. / n.a.	-0.35 (0.87, 4) / n.a.
East Aegean Islands	1999	-0.14 (0.41, 7) / n.a.	-0.02 (0.29, 43) / -0.81 (0.04, 3)
East Estonia	1999	-1.54 (0.81, 8) / -1.43 (0.3, 8)	-0.03 (0.31, 34) / -1.3 (0.09, 14)
Ebro	1999	n.a. / n.a.	0.09 (0.42, 70) / n.a.
Elbe	1999	-1.02 (0.39, 10) / -1.01 (0.47, 10)	0.5 (0.26, 78) / -0.9 (0.14, 30)
Ems	1999	n.a. / n.a.	0.61 (0.1, 3) / -0.69 (0.31, 61)
Galician	1999	n.a. / n.a.	n.a. / -0.76 (0.3, 37)
Gauja	1999	n.a. / n.a.	-0.28 (0.06, 14) / n.a.
Guadalquivir	1999	n.a. / n.a.	0.22 (0.41, 33) / -0.83 (0.25, 51)
Guadiana	1999	n.a. / n.a.	0.13 (0.34, 8) / -0.91 (0.4, 112)
Humber	1999	0.59 (0.67, 3) / -1.26 (0.36, 12)	0.89 (0.22, 19) / -0.2 (0.45, 2)
Jucar	1999	n.a. / n.a.	0.36 (0.33, 26) / n.a.
Jutland	1999	-0.23 (0.69, 12) / -1.09 (0.32, 7)	n.a. / n.a.
Lielupe	1999	n.a. / n.a.	0.26 (0.24, 31) / -0.84 (0.36, 122)
Loire	1999	n.a. / n.a.	0.53 (0.34, 38) / -1.85 (0.28, 6)
Meuse	1999	n.a. / n.a.	0.45 (0.22, 34) / -1.21 (0.35, 4)
Middle Appenines	1999	n.a. / -1.45 (0.15, 5)	n.a. / n.a.
Minho	1999	n.a. / n.a.	-0.16 (0.24, 10) / -0.35 (0.36, 34)
Minho Lima	1999	n.a. / n.a.	n.a. / -0.78 (0.01, 2)
Mosel	1999	n.a. / n.a.	0.72 (0.08, 2) / -1.65 (0.59, 12)
Neagh Bann	1999	n.a. / n.a.	0.2 (0.25, 4) / n.a.
Nemunas	1999	-1.51 (0.72, 4) / n.a.	-0.05 (0.28, 46) / -0.86 (0.28, 2)
North Adriatic	1999	n.a. / n.a.	-0.16 (0.3, 6) / n.a.
North East (UK)	1999	n.a. / n.a.	0.34 (0.15, 5) / -2.02 (1.47, 6)
North West (Irl.)	1999	n.a. / n.a.	-0.99 (0.92, 3) / n.a.
North West (UK)	1999	-0.39 (0.01, 3) / n.a.	0.16 (0.52, 28) / n.a.
Northumbria	1999	n.a. / n.a.	0 (0.38, 4) / -1.21 (0.15, 18)
Oder	1999	n.a. / -1.38 (0.23, 3)	0.38 (0.23, 74) / -0.72 (0.39, 61)
Po	1999	-0.4 (0.61, 2) / -0.99 (0.4, 2)	n.a. / -0.93 (0.04, 4)
Pregolya	1999	n.a. / n.a.	0.15 (0.2, 4) / n.a.
Rhine	1999	-0.1 (0.39, 23) / -1.55 (0.45, 22)	0.34 (0.31, 119) / -0.75 (0.1, 16)
Rhone	1999	n.a. / n.a.	-0.09 (0.41, 130) / -0.78 (0.21, 4)
Scheldt	1999	n.a. / n.a.	0.69 (0.15, 35) / n.a.
Schlei	1999	-0.58 (0.29, 2) / -1.15 (0.04, 2)	0.33 (0.45, 2) / n.a.
Scotland	1999	-0.63 (0.38, 8) / -1.77 (0.62, 8)	-0.53 (0.4, 12) / n.a.
Seine	1999	n.a. / -1.18 (0.32, 2)	0.65 (0.19, 51) / -0.64 (0.4, 71)
Severn	1999	n.a. / n.a.	0.3 (0.12, 2) / n.a.
Shannon	1999	n.a. / n.a.	-0.07 (0.42, 2) / n.a.
Solway	1999	n.a. / n.a.	-0.15 (0.45, 2) / -1.52 (0.39, 2)
South East (Irl.)	1999	n.a. / n.a.	0.51 (0.2, 12) / n.a.
South West (Irl.)	1999	n.a. / n.a.	0.49 (0.13, 6) / n.a.
South West (UK)	1999	n.a. / -1.17 (0.56, 4)	0.26 (0.4, 4) / n.a.
Tagus	1999	n.a. / n.a.	-0.52 (0.43, 61) / n.a.
Thames	1999	n.a. / -1.69 (0.19, 6)	n.a. / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Venta	1999	-0.51 (0.43, 4) / n.a.	-0.04 (0.24, 18) / n.a.
Vistula	1999	n.a. / -1.27 (0.19, 5)	0.1 (0.24, 65) / n.a.
Warnow	1999	n.a. / n.a.	0.4 (0.08, 4) / n.a.
Weser	1999	n.a. / n.a.	0.62 (0.11, 16) / n.a.
West Aegean	1999	n.a. / n.a.	-0.03 (0.34, 18) / n.a.
West Estonian	1999	n.a. / n.a.	0.02 (0.29, 18) / n.a.
Adour	2000	n.a. / n.a.	0.2 (0.38, 108) / -0.49 (0.05, 2)
Andalusia	2000	n.a. / n.a.	-0.27 (0.64, 9) / n.a.
Basque County	2000	n.a. / n.a.	-0.19 (0.07, 2) / n.a.
Black Sea	2000	-0.28 (0.31, 4) / n.a.	0.09 (0.5, 8) / n.a.
Cantabrian	2000	n.a. / n.a.	-0.17 (0.24, 36) / n.a.
Catalan	2000	n.a. / n.a.	n.a. / -0.98 (0.48, 338)
Central Macedonia	2000	n.a. / n.a.	0.09 (0.18, 6) / n.a.
Corsica	2000	n.a. / n.a.	-0.5 (0.14, 7) / -1.16 (0.16, 16)
Cyprus	2000	n.a. / n.a.	-0.05 (0.69, 10) / n.a.
Danube	2000	-0.55 (0.33, 20) / -1.75 (0.56, 31)	0.18 (0.35, 380) / -1.29 (0.25, 34)
Daugava	2000	-0.32 (0.51, 5) / n.a.	-0.09 (0.13, 16) / n.a.
Douro	2000	n.a. / n.a.	-0.04 (0.38, 67) / -0.79 (0.26, 78)
East	2000	n.a. / n.a.	-0.26 (0.84, 5) / n.a.
East Aegean Islands	2000	-0.4 (0.55, 7) / n.a.	0.09 (0.35, 44) / -0.79 (0.09, 3)
East Alps	2000	n.a. / n.a.	0.12 (0.25, 49) / -1.29 (0.29, 42)
East Estonia	2000	-1.26 (0.62, 7) / -1.38 (0.31, 8)	-0.03 (0.36, 34) / -1.35 (0.13, 14)
East Sterea	2000	n.a. / n.a.	0.31 (0.26, 5) / n.a.
Ebro	2000	n.a. / n.a.	0.16 (0.43, 96) / 0.71 (0.81, 2)
Elbe	2000	-0.94 (0.3, 10) / -1.12 (0.49, 10)	0.47 (0.26, 78) / -0.92 (0.16, 31)
Ems	2000	n.a. / n.a.	0.6 (0.09, 3) / -0.98 (0.31, 102)
Epirus	2000	n.a. / n.a.	-0.47 (0.22, 7) / -0.95 (0.26, 7)
Galician	2000	n.a. / n.a.	-0.02 (0.16, 4) / -0.82 (0.27, 92)
Gauja	2000	n.a. / n.a.	-0.12 (0.12, 14) / n.a.
Guadalquivir	2000	n.a. / n.a.	0.14 (0.47, 63) / -0.84 (0.22, 50)
Guadiana	2000	n.a. / n.a.	0.1 (0.45, 56) / -0.98 (0.39, 65)
Humber	2000	0.42 (0.69, 3) / -1.21 (0.27, 12)	0.88 (0.25, 15) / -0.81 (0.54, 31)
Jucar	2000	n.a. / n.a.	0.22 (0.37, 52) / n.a.
Jutland	2000	-0.27 (0.63, 12) / -1.09 (0.23, 4)	n.a. / n.a.
Lielupe	2000	n.a. / n.a.	0.35 (0.19, 31) / -0.89 (0.38, 125)
Loire	2000	n.a. / n.a.	0.54 (0.39, 97) / -1.79 (0.45, 7)
Meuse	2000	n.a. / n.a.	0.49 (0.23, 42) / -0.98 (0.09, 3)
Middle Appenines	2000	n.a. / -1.61 (0.21, 5)	0.27 (0.17, 9) / -0.97 (0.23, 9)
Minho	2000	n.a. / n.a.	-0.31 (0.24, 18) / -0.29 (0.34, 33)
Mosel	2000	n.a. / n.a.	0.68 (0.06, 2) / -0.83 (0.04, 2)
Neagh Bann	2000	n.a. / n.a.	-0.32 (0.36, 4) / -1.63 (0.49, 12)
Nemunas	2000	-1.82 (0.34, 4) / n.a.	-0.03 (0.33, 46) / -1.02 (0.29, 2)
North Adriatic	2000	n.a. / -1.26 (0.3, 3)	-0.18 (0.25, 7) / n.a.
North Appenines	2000	n.a. / n.a.	0.13 (0.15, 9) / -1.08 (0.84, 9)

Supporting information

Basin	Year	Lake	Stream
North East (UK)	2000	n.a. / n.a.	-0.3 (0.13, 5) / -0.68 (0.3, 2)
North Peloponese	2000	n.a. / n.a.	-0.03 (0.22, 5) / n.a.
North West (Irl.)	2000	n.a. / n.a.	-0.94 (0.77, 3) / n.a.
North West (UK)	2000	-0.28 (0.06, 5) / n.a.	-0.05 (0.71, 28) / n.a.
Northumbria	2000	n.a. / n.a.	n.a. / -1.22 (0.16, 18)
Oder	2000	n.a. / n.a.	0.32 (0.25, 74) / -0.73 (0.39, 62)
Po	2000	-0.37 (0.59, 2) / -0.99 (0.38, 2)	n.a. / -0.89 (0.09, 4)
Pregolya	2000	n.a. / n.a.	0.15 (0.2, 4) / n.a.
Rhine	2000	-0.16 (0.48, 24) / -1.57 (0.39, 24)	0.31 (0.31, 124) / -0.78 (0.1, 16)
Rhone	2000	n.a. / n.a.	0.03 (0.38, 135) / -0.71 (0.3, 4)
Scheldt	2000	-0.96 (1.39, 2) / -0.84 (0.28, 3)	0.71 (0.16, 38) / n.a.
Schlei	2000	-0.66 (0.32, 2) / -1.23 (0.02, 2)	0.26 (0.45, 2) / n.a.
Scotland	2000	-0.65 (0.41, 7) / -1.75 (0.67, 7)	-0.42 (0.3, 12) / n.a.
Segura	2000	n.a. / n.a.	-0.13 (0.44, 7) / n.a.
Seine	2000	n.a. / -1.37 (0.1, 2)	0.66 (0.17, 52) / -0.65 (0.33, 72)
Shannon	2000	n.a. / n.a.	-0.16 (0.31, 4) / n.a.
Solway	2000	n.a. / n.a.	-0.12 (0.4, 2) / n.a.
South East (Irl.)	2000	n.a. / n.a.	0.52 (0.19, 12) / n.a.
South West (Irl.)	2000	n.a. / n.a.	0.36 (0.18, 5) / n.a.
South West (UK)	2000	n.a. / -1.21 (0.54, 3)	0.32 (0.42, 4) / n.a.
Tagus	2000	n.a. / n.a.	0.08 (0.43, 78) / n.a.
Thessalia	2000	n.a. / n.a.	0.27 (0.17, 11) / n.a.
Thrace	2000	n.a. / n.a.	0.82 (0.33, 8) / n.a.
Venta	2000	-0.7 (0.55, 3) / -1.36 (0.16, 5)	-0.02 (0.19, 18) / n.a.
Vistula	2000	n.a. / n.a.	0.12 (0.24, 65) / n.a.
Warnow	2000	n.a. / n.a.	0.34 (0.06, 4) / n.a.
Weser	2000	n.a. / n.a.	0.6 (0.1, 16) / n.a.
West Aegean	2000	n.a. / n.a.	-0.01 (0.41, 19) / n.a.
West Estonian	2000	n.a. / n.a.	0.08 (0.28, 18) / n.a.
West Macedonia	2000	n.a. / n.a.	0.4 (0.2, 5) / n.a.
West Sterea	2000	n.a. / n.a.	-0.73 (0.22, 2) / n.a.
Adour	2001	n.a. / n.a.	0.2 (0.39, 109) / -0.67 (0.1, 2)
Andalusia	2001	n.a. / n.a.	0.03 (0.42, 14) / -0.95 (0.27, 7)
Basque County	2001	n.a. / n.a.	-0.19 (0.21, 2) / n.a.
Black Sea	2001	-0.75 (0.19, 2) / n.a.	0.01 (0.49, 8) / -1.56 (0.28, 5)
Cantabrian	2001	n.a. / n.a.	-0.1 (0.36, 29) / n.a.
Catalan	2001	n.a. / n.a.	0.08 (0.53, 58) / -1.03 (0.54, 302)
Central Macedonia	2001	n.a. / n.a.	0.18 (0.23, 7) / n.a.
Corsica	2001	n.a. / n.a.	-0.38 (0.1, 6) / -1.12 (0.19, 16)
Cyprus	2001	n.a. / n.a.	0.36 (0.03, 2) / -1.29 (0.42, 57)
Danube	2001	-0.6 (0.36, 20) / -1.88 (0.54, 41)	0.12 (0.34, 461) / -1.26 (0.28, 34)
Daugava	2001	-0.26 (0.22, 5) / n.a.	-0.13 (0.09, 16) / n.a.
Douro	2001	n.a. / n.a.	0 (0.45, 68) / -0.82 (0.26, 78)
East	2001	n.a. / n.a.	0.37 (0.17, 3) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
East Aegean Islands	2001	-0.45 (0.29, 7) / n.a.	-0.01 (0.3, 44) / -0.78 (0.04, 3)
East Alps	2001	n.a. / n.a.	-0.61 (0.32, 65) / n.a.
East Estonia	2001	-0.91 (0.31, 5) / -1.35 (0.11, 5)	-0.01 (0.38, 34) / -1.32 (0.13, 17)
East Sterea	2001	n.a. / n.a.	0.11 (0.61, 6) / n.a.
Ebro	2001	n.a. / n.a.	0.22 (0.38, 97) / -0.28 (0.39, 2)
Eider	2001	n.a. / n.a.	n.a. / 0.01 (0.38, 7)
Elbe	2001	-1.09 (0.31, 10) / -1.17 (0.51, 10)	0.46 (0.27, 78) / -0.94 (0.14, 31)
Ems	2001	n.a. / n.a.	0.7 (0.06, 3) / -0.97 (0.28, 109)
Epirus	2001	n.a. / n.a.	0.15 (0.08, 7) / n.a.
Galician	2001	n.a. / n.a.	0.05 (0.22, 4) / -0.79 (0.24, 78)
Gauja	2001	n.a. / n.a.	-0.22 (0.22, 17) / n.a.
Guadalquivir	2001	n.a. / n.a.	0.37 (0.4, 64) / -0.82 (0.23, 48)
Guadiana	2001	n.a. / n.a.	0.06 (0.44, 56) / -1.1 (0.38, 95)
Humber	2001	0.54 (0.82, 3) / -1.23 (0.3, 12)	0.88 (0.24, 14) / -0.83 (0.48, 31)
Jucar	2001	n.a. / n.a.	0.22 (0.37, 52) / -1.3 (0.55, 19)
Jutland	2001	-0.32 (0.66, 12) / n.a.	n.a. / n.a.
Lielupe	2001	n.a. / n.a.	0.39 (0.23, 31) / -0.94 (0.38, 125)
Loire	2001	n.a. / n.a.	0.46 (0.39, 85) / -1.99 (0.35, 7)
Meuse	2001	n.a. / n.a.	0.47 (0.22, 41) / -1.15 (0.23, 4)
Middle Appenines	2001	n.a. / -1.67 (0.21, 5)	-0.76 (0.4, 22) / n.a.
Minho	2001	n.a. / n.a.	-0.26 (0.21, 18) / -0.38 (0.29, 36)
Mosel	2001	n.a. / n.a.	0.67 (0.01, 2) / -0.8 (0.12, 2)
Neagh Bann	2001	n.a. / n.a.	-0.52 (0.34, 3) / -1.66 (0.53, 12)
Nemunas	2001	-1.35 (0.25, 4) / n.a.	0.01 (0.32, 46) / -1.71 (0.49, 2)
North Adriatic	2001	n.a. / -1.36 (0.2, 3)	-0.22 (0.21, 7) / n.a.
North Appenines	2001	n.a. / n.a.	-1.15 (0.85, 24) / n.a.
North East (UK)	2001	n.a. / n.a.	-0.34 (0.18, 5) / -0.68 (0.3, 2)
North Peloponese	2001	n.a. / n.a.	0.07 (0.42, 8) / n.a.
North West (Irl.)	2001	n.a. / n.a.	-0.77 (0.3, 5) / n.a.
North West (UK)	2001	-0.3 (0, 4) / n.a.	-0.03 (0.7, 28) / n.a.
Northumbria	2001	n.a. / n.a.	0.14 (0.22, 4) / -1.24 (0.25, 21)
Oder	2001	n.a. / n.a.	0.35 (0.24, 74) / -0.71 (0.39, 63)
Po	2001	-0.06 (0.58, 10) / -1.45 (0.35, 10)	-0.18 (0.77, 16) / -0.95 (0.17, 16)
Pregolya	2001	n.a. / n.a.	0.2 (0.15, 4) / n.a.
Rhine	2001	-0.12 (0.37, 24) / -1.63 (0.46, 23)	0.31 (0.3, 121) / -0.7 (0.15, 15)
Rhone	2001	n.a. / n.a.	-0.04 (0.34, 126) / -0.63 (0.32, 4)
Scheldt	2001	-0.15 (0.23, 3) / -0.6 (0.2, 3)	0.71 (0.16, 39) / n.a.
Schlei	2001	-0.87 (0.35, 2) / -1.19 (0.03, 2)	0.3 (0.4, 2) / n.a.
Scotland	2001	-0.73 (0.23, 7) / -1.74 (0.7, 7)	-0.58 (0.45, 12) / n.a.
Segura	2001	n.a. / n.a.	-0.35 (0.63, 7) / n.a.
Seine	2001	n.a. / n.a.	0.64 (0.19, 52) / -0.67 (0.29, 74)
Shannon	2001	n.a. / n.a.	-0.07 (0.25, 7) / n.a.
Solway	2001	n.a. / n.a.	-0.25 (0.46, 2) / n.a.
South Appenines	2001	n.a. / n.a.	-0.53 (0.44, 12) / -1.04 (0.84, 7)

Supporting information

Basin	Year	Lake	Stream
South East (Irl.)	2001	n.a. / n.a.	0.52 (0.2, 12) / n.a.
South West (Irl.)	2001	n.a. / n.a.	0.33 (0.41, 8) / n.a.
South West (UK)	2001	n.a. / n.a.	0.33 (0.43, 4) / n.a.
Tagus	2001	n.a. / n.a.	-0.01 (0.58, 99) / n.a.
Thessalia	2001	n.a. / n.a.	0.2 (0.39, 12) / n.a.
Thrace	2001	n.a. / n.a.	-0.13 (0.23, 8) / n.a.
Venta	2001	-0.46 (0.7, 4) / -1.36 (0.33, 4)	-0.09 (0.31, 21) / n.a.
Vistula	2001	n.a. / n.a.	0.07 (0.27, 63) / n.a.
Warnow	2001	n.a. / n.a.	0.34 (0.09, 4) / n.a.
Weser	2001	n.a. / n.a.	0.61 (0.1, 16) / n.a.
West Aegean	2001	n.a. / n.a.	-0.14 (0.36, 18) / n.a.
West Estonian	2001	n.a. / n.a.	0.11 (0.27, 18) / n.a.
West Macedonia	2001	n.a. / n.a.	0.1 (0.17, 6) / n.a.
West Sterea	2001	n.a. / n.a.	-0.65 (0.36, 5) / n.a.
Adour	2002	n.a. / n.a.	0.14 (0.38, 109) / -0.56 (0.02, 2)
Andalusia	2002	n.a. / n.a.	-0.02 (0.5, 14) / -0.79 (0.3, 8)
Anglian	2002	n.a. / n.a.	n.a. / -0.71 (0.11, 2)
Basque County	2002	n.a. / n.a.	-0.12 (0.04, 2) / n.a.
Black Sea	2002	-0.4 (0.26, 4) / n.a.	0.23 (0.37, 8) / -1.41 (0.25, 8)
Cantabrian	2002	n.a. / n.a.	-0.14 (0.28, 25) / n.a.
Catalan	2002	n.a. / n.a.	0.2 (0.37, 60) / -0.43 (0.44, 47)
Central Macedonia	2002	n.a. / n.a.	0.38 (0.1, 6) / n.a.
Corsica	2002	n.a. / n.a.	-0.37 (0.15, 7) / -1.12 (0.23, 16)
Cyprus	2002	n.a. / n.a.	0.27 (0.53, 11) / -1.33 (0.39, 59)
Danube	2002	-0.65 (0.31, 21) / -1.84 (0.52, 43)	0.12 (0.34, 501) / -1.29 (0.29, 34)
Daugava	2002	-0.6 (0.46, 5) / -1.32 (0.23, 5)	-0.09 (0.14, 16) / n.a.
Douro	2002	n.a. / n.a.	-0.01 (0.4, 65) / -0.88 (0.25, 80)
East	2002	n.a. / n.a.	0.48 (0.13, 3) / n.a.
East Aegean Islands	2002	-0.71 (0.46, 7) / n.a.	-0.04 (0.31, 44) / -0.75 (0.08, 4)
East Alps	2002	n.a. / -1.81 (0.37, 18)	0.09 (0.33, 65) / n.a.
East Estonia	2002	-1 (0.4, 5) / -1.36 (0.08, 5)	-0.02 (0.38, 34) / -1.28 (0.14, 16)
East Sterea	2002	n.a. / n.a.	0.58 (0.25, 3) / -1.18 (0.66, 3)
Ebro	2002	n.a. / n.a.	0.17 (0.39, 114) / -0.08 (0.35, 4)
Elbe	2002	-0.91 (0.41, 10) / -1.16 (0.47, 10)	0.49 (0.27, 80) / -0.94 (0.13, 31)
Ems	2002	n.a. / n.a.	0.51 (0.27, 4) / -0.93 (0.35, 97)
Epirus	2002	n.a. / n.a.	0.19 (0.15, 7) / n.a.
Galician	2002	n.a. / n.a.	-0.19 (0.21, 4) / -0.81 (0.26, 40)
Gauja	2002	n.a. / n.a.	-0.15 (0.21, 16) / n.a.
Guadalquivir	2002	n.a. / n.a.	0.25 (0.42, 49) / -0.9 (0.22, 47)
Guadiana	2002	n.a. / n.a.	-0.16 (0.53, 56) / -0.91 (0.43, 113)
Humber	2002	-0.21 (0.3, 2) / -1.23 (0.35, 12)	0.68 (0.33, 29) / -0.8 (0.48, 31)
Jucar	2002	n.a. / n.a.	0.37 (0.38, 67) / -1.2 (0.51, 24)
Jutland	2002	-0.37 (0.69, 12) / -1.17 (0.51, 3)	n.a. / n.a.
Lielupe	2002	n.a. / n.a.	0.31 (0.2, 31) / -0.93 (0.42, 124)

Appendix S7.2

Basin	Year	Lake	Stream
Loire	2002	0.52 (0.48, 3) / n.a.	0.49 (0.32, 41) / -1.99 (0.46, 7)
Meuse	2002	n.a. / n.a.	0.44 (0.21, 41) / -1.06 (0.2, 4)
Middle Appenines	2002	n.a. / -1.12 (0.49, 9)	0 (0.32, 24) / n.a.
Minho	2002	n.a. / n.a.	-0.32 (0.3, 17) / -0.42 (0.35, 34)
Mosel	2002	n.a. / n.a.	0.73 (0.03, 2) / -0.83 (0.06, 2)
Neagh Bann	2002	n.a. / n.a.	-0.41 (0.3, 3) / -1.73 (0.49, 12)
Nemunas	2002	-1 (0.54, 4) / n.a.	0 (0.26, 46) / -1.6 (0.32, 2)
North Adriatic	2002	n.a. / n.a.	-0.2 (0.29, 7) / -0.84 (0.74, 28)
North Appenines	2002	n.a. / -1.29 (0.57, 12)	0.03 (0.31, 23) / n.a.
North East (UK)	2002	n.a. / n.a.	-0.23 (0.09, 5) / -0.68 (0.34, 2)
North Peloponese	2002	n.a. / n.a.	0.09 (0.46, 7) / -0.49 (0.54, 3)
North West (Irl.)	2002	n.a. / n.a.	-0.73 (0.4, 5) / n.a.
North West (UK)	2002	-0.46 (0.1, 3) / n.a.	0.01 (0.73, 28) / n.a.
Northumbria	2002	n.a. / n.a.	-0.09 (0.47, 11) / -0.97 (0.41, 4)
Oder	2002	n.a. / n.a.	0.34 (0.23, 74) / -0.75 (0.45, 63)
Po	2002	-0.43 (0.65, 2) / -1.56 (0.48, 47)	0.36 (0.04, 17) / -0.99 (0.03, 4)
Pregolya	2002	n.a. / n.a.	0.2 (0.2, 4) / n.a.
Rhine	2002	-0.22 (0.48, 20) / -1.61 (0.36, 19)	0.31 (0.3, 124) / -0.73 (0.09, 17)
Rhone	2002	n.a. / n.a.	0 (0.35, 130) / -0.9 (0.27, 17)
Scheldt	2002	-0.03 (0.11, 2) / -0.52 (0.09, 2)	0.68 (0.16, 40) / n.a.
Schlei	2002	-0.53 (0.35, 2) / -1.13 (0.01, 2)	0.34 (0.36, 2) / n.a.
Scotland	2002	-0.63 (0.48, 7) / -1.62 (0.86, 7)	-0.66 (0.54, 12) / n.a.
Segura	2002	n.a. / n.a.	-0.21 (0.43, 7) / n.a.
Seine	2002	n.a. / n.a.	0.66 (0.2, 50) / -0.72 (0.29, 72)
Severn	2002	n.a. / n.a.	0.41 (0.5, 9) / n.a.
Shannon	2002	n.a. / n.a.	-0.14 (0.3, 7) / n.a.
Sicily	2002	n.a. / -1.57 (0.35, 7)	n.a. / n.a.
Solway	2002	n.a. / n.a.	0.05 (0.52, 3) / n.a.
South Appenines	2002	n.a. / -3.02 (1.35, 3)	0.18 (0.63, 28) / n.a.
South East (Irl.)	2002	n.a. / n.a.	0.54 (0.17, 12) / n.a.
South East (UK)	2002	n.a. / n.a.	0.64 (0.28, 6) / n.a.
South West (Irl.)	2002	n.a. / n.a.	0.23 (0.42, 8) / n.a.
South West (UK)	2002	-0.17 (0.6, 7) / n.a.	0.58 (0.27, 24) / -0.69 (0.24, 4)
Tagus	2002	n.a. / n.a.	0.03 (0.54, 92) / -0.69 (0.63, 96)
Thames	2002	0.42 (0.73, 2) / n.a.	0.76 (0.1, 4) / n.a.
Thessalia	2002	n.a. / n.a.	0.31 (0.25, 13) / -0.37 (0.37, 13)
Thrace	2002	n.a. / n.a.	0.09 (0.33, 8) / -1.18 (0.44, 8)
Venta	2002	-0.94 (0.29, 4) / -1.37 (0.29, 4)	-0.06 (0.21, 22) / n.a.
Vistula	2002	n.a. / n.a.	0.11 (0.23, 65) / n.a.
Warnow	2002	n.a. / n.a.	0.46 (0.07, 4) / n.a.
Weser	2002	n.a. / n.a.	0.65 (0.12, 17) / n.a.
West Aegean	2002	n.a. / n.a.	-0.11 (0.29, 19) / n.a.
West Estonian	2002	n.a. / n.a.	0.03 (0.31, 18) / n.a.
West Macedonia	2002	n.a. / n.a.	0.16 (0.12, 6) / -1.03 (0.27, 6)

Supporting information

Basin	Year	Lake	Stream
West Sterea	2002	n.a. / n.a.	-0.5 (0.35, 4) / n.a.
Western Wales	2002	-0.87 (0.24, 2) / n.a.	0.18 (0.34, 12) / n.a.
Adour	2003	n.a. / n.a.	0.13 (0.38, 101) / -0.96 (0.23, 46)
Andalusia	2003	n.a. / n.a.	0.09 (0.35, 13) / -1.03 (0.47, 7)
Anglian	2003	-1.51 (0.21, 8) / -1.18 (0.3, 9)	0.87 (0.13, 17) / n.a.
Basque County	2003	n.a. / n.a.	-0.26 (0.19, 2) / -0.81 (0.7, 46)
Black Sea	2003	-0.06 (0.35, 4) / -0.55 (0.1, 2)	0.03 (0.46, 8) / -1.01 (0.76, 6)
Cantabrian	2003	n.a. / n.a.	-0.14 (0.28, 24) / n.a.
Catalan	2003	n.a. / n.a.	0.31 (0.35, 46) / -0.97 (0.56, 374)
Corsica	2003	n.a. / n.a.	-0.37 (0.28, 7) / -1.04 (0.21, 18)
Cyprus	2003	n.a. / n.a.	0.04 (0.65, 9) / -1.32 (0.42, 61)
Danube	2003	-0.46 (0.64, 40) / -1.64 (0.58, 62)	0.12 (0.36, 509) / -1.24 (0.28, 34)
Daugava	2003	-0.22 (0.26, 5) / -1.18 (0.19, 5)	-0.13 (0.15, 18) / n.a.
Douro	2003	n.a. / n.a.	0.04 (0.46, 79) / -0.84 (0.25, 80)
East Aegean Islands	2003	-0.6 (0.3, 7) / -1 (0.32, 2)	-0.05 (0.31, 44) / -0.32 (0.51, 23)
East Alps	2003	-0.68 (0.58, 12) / n.a.	0.12 (0.29, 73) / n.a.
East Estonia	2003	-1.04 (0.43, 5) / -1.35 (0.13, 5)	0 (0.36, 34) / -1.14 (0.14, 15)
Ebro	2003	n.a. / n.a.	0.13 (0.45, 108) / -0.17 (0.32, 3)
Elbe	2003	-1.24 (0.33, 10) / -1.2 (0.46, 10)	0.43 (0.3, 80) / -0.99 (0.16, 31)
Ems	2003	n.a. / n.a.	0.55 (0.06, 3) / -1.01 (0.41, 101)
Galician	2003	n.a. / n.a.	0.04 (0.17, 4) / -0.88 (0.28, 38)
Gauja	2003	n.a. / n.a.	-0.18 (0.24, 15) / n.a.
Guadalquivir	2003	n.a. / n.a.	0.25 (0.48, 51) / -0.98 (0.28, 51)
Guadiana	2003	n.a. / n.a.	0 (0.69, 54) / -0.99 (0.44, 86)
Humber	2003	-1.86 (0.57, 6) / -1.23 (0.35, 12)	0.71 (0.32, 36) / -0.74 (0.44, 31)
Jucar	2003	n.a. / n.a.	0.34 (0.38, 68) / -0.83 (0.29, 37)
Jutland	2003	-0.43 (0.67, 12) / n.a.	n.a. / n.a.
Lielupe	2003	n.a. / n.a.	0.29 (0.21, 31) / -0.96 (0.43, 128)
Loire	2003	n.a. / n.a.	0.48 (0.3, 38) / -1.75 (0.46, 8)
Meuse	2003	n.a. / n.a.	0.38 (0.23, 35) / -1.09 (0.34, 4)
Middle Appenines	2003	0.12 (1.12, 12) / n.a.	0.08 (0.2, 37) / n.a.
Minho	2003	n.a. / n.a.	-0.24 (0.26, 18) / -0.48 (0.48, 40)
Mosel	2003	n.a. / n.a.	n.a. / -0.77 (0.04, 2)
Neagh Bann	2003	n.a. / -1.73 (0.29, 5)	-0.53 (0.38, 3) / -1.67 (0.57, 12)
Nemunas	2003	-1.19 (0.13, 4) / -1.44 (0.37, 6)	-0.07 (0.28, 46) / n.a.
North Adriatic	2003	-0.32 (0.18, 2) / -1.82 (0.19, 2)	-0.12 (0.21, 8) / -1.63 (0.35, 2)
North Appenines	2003	-0.33 (0.34, 7) / -1.16 (0.12, 3)	0.05 (0.29, 92) / n.a.
North East (UK)	2003	n.a. / n.a.	-0.34 (0.14, 5) / -1.11 (0.33, 8)
North Peloponese	2003	n.a. / n.a.	n.a. / -0.79 (0.72, 3)
North West (UK)	2003	-1.48 (0.63, 11) / -1.82 (0, 2)	0.01 (0.75, 26) / n.a.
Northumbria	2003	n.a. / n.a.	-0.22 (0.56, 8) / -0.53 (0.36, 3)
Oder	2003	n.a. / n.a.	0.3 (0.25, 74) / -0.76 (0.39, 65)
Po	2003	-0.35 (0.39, 59) / -1.58 (0.49, 60)	0.35 (0.18, 34) / -0.99 (0.13, 4)
Pregolya	2003	n.a. / n.a.	0.18 (0.13, 4) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Rhine	2003	-0.23 (0.4, 24) / -1.64 (0.5, 23)	0.3 (0.3, 120) / -0.8 (0.11, 17)
Rhone	2003	n.a. / n.a.	-0.07 (0.35, 106) / -0.96 (0.25, 34)
Scheldt	2003	0.13 (0.19, 3) / -0.58 (0.22, 3)	0.63 (0.23, 40) / n.a.
Schlei	2003	-0.8 (0.28, 2) / -1.2 (0.02, 2)	0.17 (0.42, 2) / n.a.
Scotland	2003	-0.62 (0.3, 8) / -1.8 (0.63, 8)	-0.67 (0.46, 12) / n.a.
Segura	2003	n.a. / n.a.	-0.34 (0.67, 7) / n.a.
Seine	2003	n.a. / -1.25 (0.36, 12)	0.64 (0.18, 51) / -0.71 (0.32, 74)
Serchio	2003	n.a. / n.a.	-0.25 (0.24, 11) / -1.32 (0.16, 11)
Severn	2003	n.a. / n.a.	0.52 (0.43, 15) / n.a.
Sicily	2003	0.3 (0.55, 14) / n.a.	n.a. / n.a.
Solway	2003	n.a. / n.a.	0.17 (0.56, 4) / n.a.
South Appenines	2003	n.a. / n.a.	0.37 (0.56, 38) / n.a.
South East (UK)	2003	n.a. / n.a.	0.73 (0.23, 7) / n.a.
South West (UK)	2003	-2.07 (0.37, 8) / n.a.	0.56 (0.29, 21) / n.a.
Tagus	2003	n.a. / n.a.	0.05 (0.45, 92) / n.a.
Thames	2003	-1.58 (0.55, 3) / -1.52 (0.26, 2)	0.76 (0.25, 15) / n.a.
Thrace	2003	n.a. / n.a.	0.43 (0.18, 8) / n.a.
Venta	2003	-1.04 (0.62, 4) / -1.29 (0.36, 4)	-0.17 (0.29, 23) / n.a.
Vistula	2003	n.a. / n.a.	0.08 (0.23, 65) / n.a.
Warnow	2003	n.a. / n.a.	0.04 (0.06, 4) / n.a.
Weser	2003	n.a. / n.a.	0.58 (0.12, 17) / n.a.
West Aegean	2003	n.a. / n.a.	-0.17 (0.27, 19) / -0.81 (0.47, 12)
West Estonian	2003	n.a. / n.a.	0.02 (0.28, 18) / n.a.
Western Wales	2003	-2 (0.27, 2) / n.a.	0.21 (0.33, 12) / n.a.
Adour	2004	n.a. / n.a.	0.21 (0.38, 105) / -0.5 (0.04, 2)
Andalusia	2004	n.a. / n.a.	0.18 (0.3, 14) / 1.31 (0.16, 7)
Anglian	2004	n.a. / n.a.	0.94 (0.1, 17) / -0.27 (0.2, 3)
Basque County	2004	n.a. / n.a.	-0.18 (0.04, 2) / -0.85 (0.68, 43)
Black Sea	2004	-0.22 (0.39, 4) / -1.09 (0.65, 4)	0.14 (0.25, 8) / -1.58 (0.16, 5)
Cantabrian	2004	n.a. / n.a.	-0.07 (0.29, 25) / n.a.
Catalan	2004	n.a. / n.a.	0.38 (0.37, 46) / -1.15 (0.61, 514)
Corsica	2004	n.a. / n.a.	-0.34 (0.16, 5) / -1.08 (0.27, 19)
Cyprus	2004	n.a. / n.a.	n.a. / -0.71 (0.65, 31)
Danube	2004	-0.61 (0.5, 36) / -1.71 (0.57, 60)	0.09 (0.37, 643) / -1.3 (0.25, 34)
Daugava	2004	-0.88 (0.48, 12) / -1.51 (0.3, 12)	-0.18 (0.12, 19) / n.a.
Douro	2004	n.a. / n.a.	-0.08 (0.52, 86) / -0.84 (0.24, 76)
East	2004	n.a. / -1.4 (0.41, 3)	n.a. / n.a.
East Aegean Islands	2004	-0.1 (0.25, 7) / -2.1 (0.65, 16)	0.11 (0.3, 44) / -0.86 (0.04, 3)
East Alps	2004	n.a. / n.a.	0.15 (0.3, 72) / n.a.
East Estonia	2004	-1.81 (1.17, 10) / -1.48 (0.26, 11)	0.01 (0.39, 34) / -1.17 (0.13, 11)
Ebro	2004	n.a. / n.a.	0.23 (0.43, 107) / -0.57 (0.55, 4)
Elbe	2004	-1.12 (0.31, 10) / -1.21 (0.46, 10)	0.43 (0.29, 81) / -0.94 (0.14, 31)
Ems	2004	n.a. / n.a.	0.62 (0.06, 3) / -1.17 (0.38, 105)
Galician	2004	n.a. / n.a.	0.05 (0.2, 4) / -0.96 (0.25, 38)

Supporting information

Basin	Year	Lake	Stream
Gauja	2004	-0.77 (0.43, 5) / -1.51 (0.21, 5)	-0.15 (0.17, 11) / n.a.
Guadalquivir	2004	n.a. / n.a.	0.21 (0.51, 54) / -0.97 (0.59, 56)
Guadiana	2004	n.a. / n.a.	0.02 (0.55, 57) / -1.23 (0.47, 110)
Humber	2004	n.a. / -1.22 (0.33, 12)	0.74 (0.33, 36) / -0.83 (0.4, 31)
Jucar	2004	n.a. / n.a.	0.3 (0.36, 52) / -0.96 (0.37, 39)
Jutland	2004	-0.27 (0.61, 12) / n.a.	n.a. / n.a.
Lielupe	2004	-0.95 (0.02, 3) / -1.49 (0.21, 3)	0.44 (0.25, 31) / -1.03 (0.46, 131)
Loire	2004	n.a. / n.a.	0.48 (0.3, 38) / -1.84 (0.3, 8)
Meuse	2004	n.a. / n.a.	0.46 (0.19, 39) / -1.03 (0.21, 3)
Middle Appenines	2004	n.a. / n.a.	0.07 (0.3, 39) / n.a.
Minho	2004	n.a. / n.a.	-0.26 (0.25, 20) / -0.49 (0.49, 39)
Mosel	2004	n.a. / n.a.	0.72 (0, 2) / -0.86 (0.06, 2)
Neagh Bann	2004	n.a. / -1.72 (0.3, 4)	0.16 (0.3, 3) / -1.12 (0.39, 2)
Nemunas	2004	-1.03 (0.43, 4) / -3.12 (1.1, 8)	0.08 (0.28, 46) / n.a.
North Adriatic	2004	n.a. / n.a.	-0.05 (0.21, 8) / -1.43 (0.31, 2)
North Appenines	2004	n.a. / -1.35 (0.23, 3)	0.05 (0.31, 94) / n.a.
North East (UK)	2004	n.a. / n.a.	0.34 (0.12, 5) / -1.14 (0.47, 4)
North Peloponese	2004	n.a. / n.a.	n.a. / -0.74 (0.6, 3)
North West (Irl.)	2004	n.a. / -1.54 (0.39, 4)	n.a. / n.a.
North West (UK)	2004	-0.32 (0.11, 6) / -1.55 (0.2, 7)	0.16 (0.56, 26) / n.a.
Northumbria	2004	n.a. / n.a.	-0.29 (0.61, 8) / -0.6 (0.37, 3)
Oder	2004	n.a. / n.a.	0.32 (0.26, 67) / -0.78 (0.39, 65)
Po	2004	n.a. / -1.53 (0.52, 46)	0.4 (0.2, 34) / -1.01 (0.05, 4)
Rhine	2004	-0.18 (0.56, 25) / -1.65 (0.42, 24)	0.33 (0.32, 131) / -0.81 (0.12, 17)
Rhone	2004	n.a. / n.a.	0.03 (0.38, 110) / -0.7 (0.33, 72)
Scheldt	2004	0.01 (0.42, 3) / -0.58 (0.11, 3)	0.65 (0.17, 40) / n.a.
Schlei	2004	-0.78 (0.32, 2) / -1.24 (0, 2)	0.33 (0.36, 2) / n.a.
Scotland	2004	-0.57 (0.62, 2) / -1.77 (0.55, 8)	-0.62 (0.47, 12) / n.a.
Segura	2004	n.a. / n.a.	-0.37 (0.86, 7) / n.a.
Seine	2004	n.a. / -1.95 (0.8, 9)	0.67 (0.17, 51) / n.a.
Serchio	2004	n.a. / n.a.	-0.17 (0.34, 11) / n.a.
Severn	2004	n.a. / n.a.	0.57 (0.44, 15) / -0.8 (0.44, 3)
Solway	2004	n.a. / n.a.	0.16 (0.57, 4) / n.a.
South Appenines	2004	n.a. / n.a.	0.36 (0.61, 54) / n.a.
South East (Irl.)	2004	n.a. / n.a.	0.52 (0.21, 12) / n.a.
South East (UK)	2004	n.a. / n.a.	0.72 (0.18, 7) / n.a.
South West (UK)	2004	n.a. / n.a.	0.58 (0.29, 21) / n.a.
Tagus	2004	n.a. / n.a.	0.08 (0.49, 96) / n.a.
Thames	2004	n.a. / n.a.	0.78 (0.22, 15) / n.a.
Thrace	2004	n.a. / n.a.	0.21 (0.25, 8) / n.a.
Venta	2004	-0.82 (0.26, 6) / -1.52 (0.26, 6)	-0.02 (0.23, 19) / n.a.
Vistula	2004	n.a. / n.a.	0.1 (0.25, 52) / n.a.
Warnow	2004	n.a. / n.a.	0.2 (0.09, 4) / n.a.
Weser	2004	n.a. / n.a.	0.59 (0.12, 17) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
West Aegean	2004	n.a. / n.a.	-0.13 (0.29, 18) / n.a.
West Estonian	2004	n.a. / n.a.	0.13 (0.28, 18) / n.a.
Western	2004	n.a. / n.a.	-0.12 (0.29, 3) / n.a.
Western Wales	2004	n.a. / n.a.	0.24 (0.36, 12) / n.a.
Adour	2005	n.a. / n.a.	0.15 (0.39, 112) / -0.5 (0.11, 2)
Andalusia	2005	n.a. / n.a.	n.a. / -0.8 (0.42, 5)
Anglian	2005	n.a. / n.a.	0.83 (0.13, 17) / -0.76 (0.38, 7)
Basque County	2005	n.a. / n.a.	-0.01 (0.07, 2) / n.a.
Black Sea	2005	-0.31 (0.19, 2) / -1.76 (0.34, 2)	0.15 (0.31, 8) / -1.76 (0.26, 6)
Cantabrian	2005	n.a. / n.a.	-0.1 (0.27, 23) / n.a.
Catalan	2005	n.a. / n.a.	n.a. / -1.09 (0.73, 519)
Corsica	2005	n.a. / n.a.	-0.28 (0.2, 6) / -1.03 (0.22, 20)
Cyprus	2005	n.a. / n.a.	0.21 (0.34, 4) / -0.8 (0.5, 31)
Danube	2005	-0.56 (0.56, 36) / -1.65 (0.58, 60)	0.08 (0.36, 643) / -1.29 (0.28, 34)
Daugava	2005	-0.88 (0.61, 12) / -1.41 (0.3, 12)	-0.11 (0.08, 20) / n.a.
Douro	2005	n.a. / n.a.	-0.04 (0.48, 87) / -0.58 (1.16, 81)
East Aegean Islands	2005	-0.14 (0.26, 6) / -1.12 (0.43, 6)	0.03 (0.3, 43) / -0.83 (0.05, 3)
East Alps	2005	-0.57 (0.51, 19) / n.a.	0.12 (0.37, 74) / n.a.
East Estonia	2005	-1.52 (0.84, 11) / -1.38 (0.31, 11)	-0.04 (0.43, 34) / -1.18 (0.12, 11)
East Sterea	2005	n.a. / n.a.	n.a. / -0.8 (0.63, 55)
Ebro	2005	n.a. / n.a.	0.21 (0.38, 109) / -0.58 (0.78, 9)
Eider	2005	n.a. / n.a.	n.a. / -0.51 (0.58, 43)
Elbe	2005	-1.11 (0.28, 9) / -1.2 (0.39, 9)	0.42 (0.3, 81) / -0.99 (0.12, 31)
Ems	2005	n.a. / n.a.	0.58 (0.09, 3) / -1.12 (0.4, 112)
Galician	2005	n.a. / n.a.	0.06 (0.18, 4) / -0.97 (0.34, 96)
Gauja	2005	-0.64 (0.61, 5) / -1.55 (0.2, 5)	-0.15 (0.19, 11) / n.a.
Guadalquivir	2005	n.a. / n.a.	0.05 (0.54, 54) / -1.24 (0.33, 51)
Guadiana	2005	n.a. / n.a.	-0.06 (0.64, 56) / -1.41 (0.56, 92)
Humber	2005	n.a. / -1.34 (0.29, 12)	0.71 (0.34, 38) / -0.95 (0.3, 24)
Jucar	2005	n.a. / n.a.	0.29 (0.5, 81) / -1.18 (0.43, 36)
Jutland	2005	-0.37 (0.62, 12) / n.a.	n.a. / n.a.
Lielupe	2005	-1.08 (0.12, 2) / n.a.	0.34 (0.24, 24) / -1.04 (0.44, 132)
Loire	2005	n.a. / n.a.	0.44 (0.38, 96) / -1.74 (0.49, 8)
Meuse	2005	n.a. / n.a.	0.35 (0.27, 39) / -1.1 (0.17, 3)
Middle Appenines	2005	-0.46 (0.51, 13) / n.a.	0.14 (0.37, 36) / n.a.
Minho	2005	n.a. / n.a.	-0.23 (0.17, 21) / -0.43 (0.31, 39)
Mosel	2005	n.a. / n.a.	0.68 (0.03, 2) / -0.88 (0.02, 2)
Neagh Bann	2005	n.a. / n.a.	0.18 (0.31, 3) / -1.75 (0.64, 12)
Nemunas	2005	-1.03 (0.65, 6) / -1.62 (0.2, 7)	0.04 (0.26, 44) / -0.89 (0.55, 3)
North Adriatic	2005	-2.07 (0.13, 2) / n.a.	-0.13 (0.19, 8) / -1.47 (0.61, 2)
North Appenines	2005	-1.65 (0.91, 13) / -1.53 (0.13, 3)	0.07 (0.31, 93) / -0.68 (0.66, 95)
North East (UK)	2005	n.a. / n.a.	0.39 (0.11, 5) / -0.65 (1, 4)
North Peloponese	2005	n.a. / n.a.	n.a. / -0.96 (0.5, 8)
North West (UK)	2005	-0.3 (0.1, 6) / -1.52 (0.25, 7)	0.21 (0.5, 28) / n.a.

Supporting information

Basin	Year	Lake	Stream
Northumbria	2005	n.a. / n.a.	-0.14 (0.45, 12) / -0.94 (0.47, 9)
Oder	2005	n.a. / n.a.	0.32 (0.24, 73) / -0.78 (0.36, 70)
Po	2005	-0.34 (0.38, 59) / -1.6 (0.67, 59)	0.34 (0.17, 34) / n.a.
Pregolya	2005	n.a. / n.a.	0.2 (0.17, 4) / -1.01 (0.05, 4)
Rhine	2005	-0.17 (0.32, 19) / -1.65 (0.4, 18)	0.3 (0.33, 132) / -0.79 (0.1, 17)
Rhone	2005	n.a. / n.a.	0.02 (0.39, 92) / -0.44 (1.05, 73)
Scheldt	2005	-0.26 (0.56, 4) / -0.75 (0.14, 4)	0.66 (0.17, 39) / n.a.
Schlei	2005	-0.84 (0.35, 2) / -1.26 (0.03, 2)	0.26 (0.39, 2) / n.a.
Scotland	2005	-0.74 (0.45, 8) / -1.82 (0.62, 8)	-0.57 (0.4, 12) / n.a.
Segura	2005	n.a. / n.a.	-0.35 (0.53, 7) / n.a.
Seine	2005	n.a. / -1.47 (0.12, 3)	0.65 (0.18, 51) / -1.21 (0.5, 88)
Serchio	2005	n.a. / n.a.	-0.27 (0.3, 10) / n.a.
Severn	2005	n.a. / n.a.	0.56 (0.43, 15) / n.a.
Sicily	2005	-0.23 (0.93, 16) / n.a.	n.a. / n.a.
Solway	2005	n.a. / n.a.	0.17 (0.53, 4) / n.a.
South Appenines	2005	-0.48 (0.58, 6) / n.a.	0.24 (0.5, 54) / n.a.
South East (Irl.)	2005	n.a. / n.a.	0.56 (0.2, 12) / n.a.
South East (UK)	2005	n.a. / n.a.	0.78 (0.15, 5) / n.a.
South West (UK)	2005	n.a. / n.a.	0.58 (0.27, 24) / n.a.
Tagus	2005	n.a. / n.a.	0.06 (0.5, 101) / n.a.
Thames	2005	n.a. / n.a.	0.66 (0.27, 13) / n.a.
Venta	2005	-1.01 (0.48, 7) / -1.57 (0.18, 7)	-0.03 (0.21, 21) / n.a.
Vistula	2005	n.a. / n.a.	0.09 (0.27, 69) / n.a.
Warnow	2005	n.a. / n.a.	0.35 (0.11, 4) / n.a.
Weser	2005	n.a. / n.a.	0.52 (0.11, 17) / n.a.
West Aegean	2005	n.a. / n.a.	-0.04 (0.27, 18) / n.a.
West Estonian	2005	n.a. / n.a.	0 (0.32, 18) / n.a.
Western	2005	n.a. / n.a.	-0.03 (0.26, 3) / n.a.
Western Wales	2005	n.a. / n.a.	0.22 (0.36, 12) / -1.25 (0.47, 7)
Adour	2006	n.a. / n.a.	0.23 (0.36, 178) / -0.71 (0.22, 3)
Algarve	2006	0.58 (0.17, 3) / -1.25 (0.21, 3)	-0.26 (0.27, 5) / -1.4 (0.17, 5)
Andalusia	2006	n.a. / n.a.	n.a. / -0.83 (0.33, 4)
Anglian	2006	n.a. / n.a.	0.86 (0.17, 17) / n.a.
Basque County	2006	n.a. / n.a.	-0.21 (0.18, 2) / -1.31 (0.45, 31)
Black Sea	2006	-0.35 (0.14, 2) / n.a.	-0.15 (0.51, 8) / -0.76 (0.15, 8)
Cantabrian	2006	n.a. / n.a.	-0.04 (0.23, 16) / n.a.
Catalan	2006	n.a. / n.a.	n.a. / -1.25 (0.55, 451)
Cavado	2006	0.3 (0, 3) / -1.47 (0.05, 3)	0.19 (0.2, 5) / -1.07 (0.49, 5)
Corsica	2006	n.a. / n.a.	-0.46 (0.12, 8) / -1.1 (0.23, 10)
Cyprus	2006	n.a. / n.a.	-0.08 (0.68, 5) / -1.32 (0.37, 56)
Danube	2006	-0.62 (0.52, 27) / -1.73 (0.53, 52)	0.11 (0.36, 611) / -1.29 (0.3, 33)
Daugava	2006	-0.55 (0.51, 6) / -1.23 (0.21, 6)	-0.24 (0.07, 10) / -1.5 (0.09, 2)
Douro	2006	0.55 (0.2, 3) / -1.2 (0.3, 3)	0 (0.46, 68) / -0.93 (0.21, 81)
East Aegean Islands	2006	-0.77 (0.67, 7) / -1.18 (0.55, 4)	-0.17 (0.5, 43) / -0.85 (0.08, 3)

Appendix S7.2

Basin	Year	Lake	Stream
East Alps	2006	-0.43 (0.28, 5) / n.a.	n.a. / n.a.
East Estonia	2006	-1.22 (0.47, 10) / -1.43 (0.38, 11)	-0.02 (0.37, 33) / -1.09 (0.2, 8)
East Sterea	2006	n.a. / n.a.	n.a. / -0.82 (0.6, 44)
Ebro	2006	n.a. / n.a.	0.19 (0.41, 92) / -0.67 (0.82, 9)
Elbe	2006	-0.17 (0.37, 8) / n.a.	0.42 (0.28, 81) / -1 (0.18, 31)
Ems	2006	n.a. / n.a.	0.6 (0.06, 3) / -1.21 (0.3, 178)
Galician	2006	n.a. / n.a.	n.a. / -1.19 (0.32, 216)
Gauja	2006	-0.74 (0.44, 3) / 1.04 (0.37, 7)	-0.16 (0.16, 8) / n.a.
Guadalquivir	2006	n.a. / n.a.	0.16 (0.42, 33) / -1.19 (0.37, 150)
Guadiana	2006	0.2 (0.14, 5) / -1.41 (0.29, 3)	-0.05 (0.39, 13) / -1.2 (0.47, 3)
Humber	2006	n.a. / -1.35 (0.34, 12)	0.7 (0.34, 38) / -0.87 (0.39, 18)
Jucar	2006	n.a. / n.a.	n.a. / -1.45 (0.12, 5)
Jutland	2006	-0.45 (0.72, 12) / n.a.	n.a. / n.a.
Lielupe	2006	n.a. / n.a.	0.25 (0.26, 18) / -1.01 (0.51, 127)
Loire	2006	n.a. / n.a.	0.53 (0.36, 216) / -1.58 (0.21, 6)
Meuse	2006	n.a. / n.a.	0.49 (0.19, 49) / -1.28 (0.22, 3)
Middle Appenines	2006	-0.54 (0.56, 11) / n.a.	-0.18 (0.13, 5) / n.a.
Minho	2006	n.a. / n.a.	-0.11 (0.23, 17) / -0.55 (0.4, 73)
Minho Lima	2006	n.a. / n.a.	0.05 (0.2, 5) / -1.1 (0.29, 5)
Mosel	2006	n.a. / n.a.	0.68 (0.23, 3) / -0.86 (0.03, 2)
Neagh Bann	2006	n.a. / n.a.	n.a. / -1.59 (0.53, 84)
Nemunas	2006	-0.94 (0.67, 12) / -1.36 (0.41, 12)	-0.04 (0.25, 38) / -0.98 (0.39, 4)
North Adriatic	2006	n.a. / n.a.	-0.06 (0.2, 6) / -1.55 (0.2, 11)
North Appenines	2006	-0.08 (0.61, 8) / n.a.	-0.02 (0.34, 69) / -0.8 (0.67, 79)
North East (UK)	2006	n.a. / n.a.	n.a. / -0.92 (0.61, 3)
North West (UK)	2006	n.a. / -1.45 (0.25, 13)	0.38 (0.4, 23) / n.a.
Northumbria	2006	n.a. / n.a.	-0.1 (0.45, 12) / -1.03 (0.59, 7)
Oder	2006	n.a. / n.a.	0.32 (0.25, 75) / -0.79 (0.34, 70)
Po	2006	-0.34 (0.51, 31) / -1.38 (0.41, 31)	n.a. / n.a.
Pregolya	2006	n.a. / n.a.	0.2 (0.18, 4) / -0.86 (0.05, 4)
Rhine	2006	-0.17 (0.57, 18) / -1.46 (0.86, 17)	0.33 (0.31, 142) / -0.77 (0.14, 17)
Rhone	2006	n.a. / n.a.	0.13 (0.34, 140) / -0.72 (0.32, 75)
Sado	2006	0.16 (0.2, 4) / -1.09 (0.1, 4)	n.a. / n.a.
Scheldt	2006	-0.4 (0.53, 4) / -0.82 (0.26, 4)	0.65 (0.2, 73) / n.a.
Schlei	2006	1.61 (0.01, 2) / 1.05 (0.01, 2)	0.34 (0.38, 2) / n.a.
Scotland	2006	n.a. / n.a.	-0.31 (0.7, 199) / n.a.
Seine	2006	n.a. / -1.68 (0.98, 12)	0.69 (0.19, 150) / -1.27 (0.48, 57)
Serchio	2006	n.a. / n.a.	-0.25 (0.28, 11) / n.a.
Severn	2006	n.a. / n.a.	0.57 (0.42, 15) / n.a.
Sicily	2006	-0.33 (0.2, 4) / n.a.	n.a. / n.a.
Solway	2006	n.a. / n.a.	0.02 (0.51, 39) / n.a.
South Appenines	2006	-0.03 (0.91, 5) / n.a.	n.a. / n.a.
South East (UK)	2006	n.a. / n.a.	0.79 (0.19, 5) / n.a.
South West (UK)	2006	n.a. / n.a.	0.59 (0.27, 24) / n.a.

Supporting information

Basin	Year	Lake	Stream
Tagus	2006	n.a. / n.a.	0.13 (0.49, 81) / n.a.
Tagus West	2006	0.34 (0.21, 7) / -0.95 (0.43, 5)	0.12 (0.35, 15) / -0.6 (0.43, 12)
Thames	2006	n.a. / n.a.	0.72 (0.23, 13) / n.a.
Venta	2006	-0.85 (0.58, 6) / -1.32 (0.34, 6)	0.08 (0.21, 19) / n.a.
Vistula	2006	n.a. / n.a.	0.08 (0.25, 69) / n.a.
Vouga	2006	n.a. / n.a.	0.07 (0.4, 10) / -1.37 (0.06, 2)
Warnow	2006	n.a. / n.a.	0.22 (0.04, 4) / n.a.
Weser	2006	n.a. / n.a.	0.57 (0.12, 17) / n.a.
West Aegean	2006	n.a. / n.a.	-0.06 (0.25, 15) / n.a.
West Estonian	2006	n.a. / n.a.	-0.01 (0.26, 18) / n.a.
Western Wales	2006	n.a. / n.a.	0.23 (0.37, 13) / n.a.
Adour	2007	n.a. / n.a.	0.24 (0.35, 178) / -0.56 (0.45, 4)
Aegean Islands	2007	n.a. / n.a.	0.15 (0.38, 2) / 0.01 (0.26, 2)
Algarve	2007	0.32 (0.1, 3) / -1.63 (0.2, 3)	-0.26 (0.28, 4) / -1.37 (0.15, 3)
Anglian	2007	n.a. / n.a.	0.92 (0.11, 17) / -1.11 (0.59, 4)
Basque County	2007	n.a. / n.a.	0.13 (0.18, 18) / -1.01 (0.52, 18)
Black Sea	2007	-0.2 (0.21, 4) / -1.9 (0, 3)	-0.25 (0.36, 8) / -0.99 (0.11, 4)
Cantabrian	2007	n.a. / n.a.	-0.35 (0.7, 18) / -1.38 (0.43, 22)
Catalan	2007	n.a. / n.a.	n.a. / -0.67 (0.92, 244)
Cavado	2007	0 (0, 2) / n.a.	0.31 (0.28, 7) / n.a.
Central Macedonia	2007	n.a. / n.a.	0.7 (0.18, 8) / -0.33 (0.47, 8)
Corsica	2007	n.a. / n.a.	-0.39 (0.2, 22) / -1.18 (0.17, 19)
Cyprus	2007	n.a. / n.a.	0.02 (0.48, 21) / -0.57 (0.49, 45)
Danube	2007	-0.23 (0.45, 39) / -1.56 (0.8, 38)	0.1 (0.38, 306) / -1.42 (0.25, 37)
Daugava	2007	-0.95 (0.46, 7) / -1.58 (0.27, 7)	-0.17 (0.21, 19) / -1.47 (0.43, 231)
Douro	2007	0.61 (0.32, 5) / n.a.	-0.08 (0.64, 71) / -1.01 (0.26, 39)
East	2007	n.a. / n.a.	-0.05 (0.17, 2) / n.a.
East Aegean Islands	2007	-0.72 (0.49, 7) / -1.26 (0.99, 2)	-0.2 (0.49, 45) / n.a.
East Alps	2007	-0.51 (0.43, 13) / n.a.	0.01 (0.32, 65) / -0.8 (0.45, 14)
East Estonia	2007	-0.88 (0.46, 10) / -1.39 (0.22, 14)	0.11 (0.39, 37) / -1.04 (0.14, 7)
East Sterea	2007	n.a. / n.a.	0.67 (0.14, 12) / -0.88 (0.75, 67)
Ebro	2007	n.a. / n.a.	0.01 (0.57, 232) / -1.25 (0.38, 3)
Elbe	2007	n.a. / n.a.	0.38 (0.25, 39) / -1.01 (0.13, 31)
Ems	2007	n.a. / n.a.	n.a. / -1.14 (0.33, 178)
Epirus	2007	n.a. / n.a.	0.41 (0.28, 14) / n.a.
Galician	2007	n.a. / n.a.	-0.01 (0.2, 26) / -1.09 (0.28, 419)
Gauja	2007	-0.33 (0.32, 6) / n.a.	-0.06 (0.23, 7) / n.a.
Guadalquivir	2007	n.a. / n.a.	0.15 (0.65, 68) / -1.2 (0.38, 217)
Guadiana	2007	0.31 (0.13, 5) / -1.18 (0.46, 6)	-0.24 (0.59, 14) / -1.43 (0.49, 382)
Humber	2007	n.a. / -1.34 (0.3, 5)	0.75 (0.32, 37) / -1.09 (0.26, 26)
Jucar	2007	n.a. / n.a.	0.29 (0.51, 62) / -0.96 (0.59, 264)
Lielupe	2007	-0.14 (0.48, 4) / n.a.	0.74 (0.28, 26) / -0.96 (0.41, 110)
Loire	2007	n.a. / n.a.	0.5 (0.38, 419) / -2.12 (0.52, 7)
Meuse	2007	n.a. / n.a.	0.45 (0.18, 52) / -1.15 (0.36, 4)

Appendix S7.2

Basin	Year	Lake	Stream
Middle Appenines	2007	-0.58 (0.75, 24) / n.a.	0.02 (0.44, 256) / n.a.
Minho	2007	n.a. / n.a.	-0.1 (0.28, 16) / -0.48 (0.38, 77)
Minho Lima	2007	n.a. / n.a.	0.08 (0.22, 5) / n.a.
Mosel	2007	n.a. / n.a.	0.6 (0.18, 4) / n.a.
Neagh Bann	2007	n.a. / n.a.	n.a. / -1.56 (0.48, 201)
Nemunas	2007	-0.9 (0.4, 14) / -1.67 (0.24, 14)	0.04 (0.44, 38) / -0.77 (0.26, 2)
North Adriatic	2007	n.a. / n.a.	-0.14 (0.21, 7) / -1.41 (0.29, 44)
North Appenines	2007	-0.42 (0.43, 15) / n.a.	0.05 (0.36, 169) / -0.78 (0.52, 81)
North East (UK)	2007	n.a. / n.a.	n.a. / -0.96 (0.64, 2)
North Peloponese	2007	n.a. / n.a.	0.45 (0.39, 9) / n.a.
North West (Irl.)	2007	n.a. / n.a.	-0.25 (0.28, 5) / -1.09 (0.69, 62)
North West (UK)	2007	n.a. / -1.6 (0.3, 16)	0.43 (0.37, 18) / n.a.
Northumbria	2007	n.a. / n.a.	-0.01 (0.48, 6) / -0.9 (0.64, 6)
Oder	2007	n.a. / n.a.	0.35 (0.26, 63) / -0.82 (0.34, 68)
Po	2007	-0.41 (0.42, 40) / -1.64 (0.49, 100)	-0.06 (0.45, 88) / n.a.
Pregolya	2007	n.a. / n.a.	0.27 (0.14, 4) / n.a.
Rhine	2007	-0.06 (0.3, 16) / -1.64 (0.46, 16)	0.26 (0.31, 110) / -0.35 (0.36, 16)
Rhone	2007	n.a. / n.a.	-0.02 (0.43, 382) / -0.8 (0.3, 63)
Sado	2007	0.21 (0.19, 4) / -1.2 (0.24, 4)	n.a. / n.a.
Scheldt	2007	-0.14 (0.33, 4) / -0.98 (0.11, 4)	0.66 (0.18, 77) / -0.7 (0.37, 7)
Scotland	2007	n.a. / n.a.	-0.36 (0.71, 205) / n.a.
Segura	2007	n.a. / n.a.	0.06 (0.03, 2) / n.a.
Seine	2007	n.a. / -1.17 (0.28, 4)	0.68 (0.21, 217) / -1.19 (0.7, 210)
Serchio	2007	n.a. / n.a.	-0.24 (0.32, 16) / n.a.
Severn	2007	n.a. / n.a.	0.54 (0.49, 14) / n.a.
Shannon	2007	n.a. / n.a.	-0.11 (0.82, 14) / n.a.
Sicily	2007	n.a. / n.a.	0.5 (0.35, 31) / -1.09 (0.65, 32)
Solway	2007	n.a. / n.a.	-0.06 (0.59, 44) / n.a.
South Appenines	2007	-0.43 (0.53, 16) / n.a.	0.08 (0.44, 206) / n.a.
South East (Irl.)	2007	n.a. / n.a.	0.51 (0.18, 30) / n.a.
South East (UK)	2007	n.a. / n.a.	0.69 (0.18, 5) / n.a.
South West (Irl.)	2007	n.a. / -1.59 (0.39, 5)	0.33 (0.39, 18) / -1.93 (0.16, 2)
South West (UK)	2007	n.a. / n.a.	0.58 (0.29, 18) / n.a.
Tagus	2007	n.a. / n.a.	0.05 (0.57, 83) / n.a.
Tagus West	2007	0.41 (0.29, 8) / n.a.	0.14 (0.3, 15) / n.a.
Thames	2007	n.a. / n.a.	0.71 (0.2, 13) / n.a.
Thrace	2007	n.a. / n.a.	0.67 (0.25, 15) / n.a.
Venta	2007	-0.65 (0.51, 8) / -1.33 (0.36, 8)	0.09 (0.23, 14) / n.a.
Vistula	2007	n.a. / n.a.	0.12 (0.26, 68) / n.a.
Vouga	2007	n.a. / n.a.	0.14 (0.25, 11) / n.a.
West Aegean	2007	n.a. / n.a.	-0.13 (0.33, 16) / n.a.
West Estonian	2007	n.a. / n.a.	0.28 (0.31, 22) / n.a.
West Macedonia	2007	n.a. / n.a.	0.5 (0.4, 7) / n.a.
West Sterea	2007	n.a. / n.a.	-0.08 (0.55, 6) / -0.96 (0.14, 2)

Supporting information

Basin	Year	Lake	Stream
Western	2007	n.a. / n.a.	n.a. / -1.51 (0.22, 5)
Western Wales	2007	n.a. / n.a.	0.18 (0.43, 13) / n.a.
Adour	2008	n.a. / n.a.	0.23 (0.42, 312) / -0.63 (0.35, 4)
Aegean Islands	2008	n.a. / n.a.	n.a. / 0.89 (1.75, 2)
Algarve	2008	-0.5 (0.1, 3) / -1.65 (0.17, 3)	-0.51 (0.34, 5) / -1.72 (0.25, 5)
Andalusia	2008	n.a. / n.a.	0.11 (0.53, 25) / -1.08 (0.82, 25)
Anglian	2008	n.a. / n.a.	0.86 (0.12, 15) / -1.96 (0.49, 4)
Basque County	2008	n.a. / n.a.	0.02 (0.26, 37) / -1.4 (0.47, 39)
Black Sea	2008	-0.11 (0.3, 4) / -1.3 (0, 3)	-0.18 (0.5, 5) / 1.45 (1.27, 7)
Cantabrian	2008	n.a. / n.a.	-0.31 (0.43, 24) / -1.39 (0.63, 18)
Catalan	2008	n.a. / n.a.	0.15 (0.5, 175) / -1.07 (0.46, 320)
Cavado	2008	n.a. / n.a.	0.3 (0.31, 7) / n.a.
Corsica	2008	n.a. / n.a.	-0.45 (0.18, 22) / -1.15 (0.2, 15)
Cyprus	2008	n.a. / n.a.	-0.25 (0.57, 18) / n.a.
Danube	2008	-0.42 (0.33, 43) / -1.87 (0.54, 40)	0.1 (0.32, 360) / -1.25 (0.34, 69)
Daugava	2008	-0.82 (0.48, 3) / -1.42 (0.3, 3)	-0.18 (0.19, 15) / -1.8 (0.59, 264)
Douro	2008	-0.28 (0.44, 5) / -1.78 (0.38, 6)	-0.12 (0.65, 82) / -0.94 (0.25, 80)
East Aegean Islands	2008	-0.46 (0.36, 7) / -0.44 (0.05, 3)	-0.15 (0.39, 41) / -0.68 (0.17, 9)
East Alps	2008	-0.6 (0.37, 15) / n.a.	0.03 (0.28, 66) / 0.1 (1.42, 14)
East Estonia	2008	-0.95 (0.49, 8) / -1.44 (0.25, 14)	0.16 (0.4, 37) / -1.14 (0.13, 7)
East Sterea	2008	n.a. / n.a.	n.a. / -0.93 (0.77, 114)
Ebro	2008	n.a. / n.a.	-0.04 (0.56, 264) / -1.49 (0.61, 3)
Eider	2008	n.a. / n.a.	0.39 (0.05, 2) / n.a.
Elbe	2008	-0.31 (0.68, 18) / -1.94 (0.3, 7)	0.4 (0.29, 91) / -0.99 (0.12, 30)
Ems	2008	n.a. / n.a.	0.46 (0.19, 9) / -1.32 (0.34, 312)
Galician	2008	n.a. / n.a.	-0.06 (0.25, 37) / -1.11 (0.27, 419)
Gauja	2008	-0.41 (0.47, 3) / -1.26 (0.43, 18)	-0.08 (0.18, 7) / n.a.
Guadalete	2008	n.a. / n.a.	0.32 (0.47, 19) / -0.82 (0.51, 19)
Guadalquivir	2008	n.a. / n.a.	0.13 (0.68, 127) / -1.22 (0.36, 217)
Guadiana	2008	-0.36 (0.14, 5) / -1.32 (0.27, 3)	-0.44 (0.47, 6) / -1.46 (0.46, 392)
Humber	2008	n.a. / -1.23 (0.39, 5)	0.67 (0.33, 33) / -1.04 (0.33, 18)
Jucar	2008	n.a. / n.a.	0.22 (0.6, 89) / -0.98 (0.59, 159)
Lielupe	2008	n.a. / n.a.	0.41 (0.5, 18) / n.a.
Loire	2008	n.a. / n.a.	0.5 (0.36, 419) / -1.65 (0.31, 7)
Meuse	2008	0.34 (0.26, 2) / -1.44 (0.49, 2)	0.45 (0.19, 57) / -0.94 (0.38, 175)
Middle Appenines	2008	-0.58 (0.55, 16) / n.a.	0.13 (0.35, 89) / n.a.
Minho	2008	n.a. / n.a.	n.a. / -0.49 (0.38, 80)
Minho Lima	2008	n.a. / n.a.	0.01 (0.38, 4) / n.a.
Mosel	2008	n.a. / n.a.	0.64 (0.18, 4) / n.a.
Neagh Bann	2008	n.a. / n.a.	n.a. / -1.5 (0.46, 197)
Nemunas	2008	-0.9 (0.39, 9) / -1.66 (0.28, 9)	-0.04 (0.22, 37) / -1.3 (0.21, 17)
North Adriatic	2008	n.a. / n.a.	-0.17 (0.3, 7) / -1.42 (0.27, 46)
North Appenines	2008	-0.47 (0.61, 17) / n.a.	0.01 (0.4, 219) / -0.95 (0.7, 237)
North East (UK)	2008	n.a. / n.a.	n.a. / -0.88 (0.52, 2)

Appendix S7.2

Basin	Year	Lake	Stream
North West (Irl.)	2008	n.a. / n.a.	n.a. / -1.18 (0.76, 89)
North West (UK)	2008	n.a. / -1.79 (0.23, 17)	0.38 (0.4, 17) / n.a.
Northumbria	2008	n.a. / n.a.	-0.02 (0.48, 6) / -0.95 (0.61, 6)
Oder	2008	n.a. / n.a.	0.3 (0.25, 65) / -0.89 (0.38, 62)
Po	2008	-0.56 (0.5, 100) / -1.87 (0.85, 100)	0.04 (0.35, 302) / n.a.
Pregolya	2008	n.a. / n.a.	0.2 (0.13, 4) / n.a.
Rhine	2008	-0.11 (0.29, 15) / -1.77 (0.38, 14)	0.37 (0.29, 182) / -0.84 (0.13, 39)
Rhone	2008	n.a. / n.a.	-0.04 (0.42, 392) / -0.77 (0.31, 67)
Sado	2008	-0.6 (0.1, 4) / -1.29 (0.1, 4)	n.a. / n.a.
Scheldt	2008	-0.22 (0.4, 3) / -0.95 (0.18, 3)	0.67 (0.18, 80) / 1.12 (0.29, 6)
Schlei	2008	-0.78 (0.15, 4) / -1.64 (0.14, 3)	0.53 (0.22, 9) / n.a.
Scotland	2008	n.a. / n.a.	-0.4 (0.72, 205) / n.a.
Segura	2008	n.a. / n.a.	-0.1 (0.38, 8) / -0.9 (0.66, 6)
Seine	2008	n.a. / -1.51 (0.33, 24)	0.65 (0.22, 217) / -1.21 (0.56, 214)
Serchio	2008	n.a. / n.a.	-0.36 (0.22, 17) / n.a.
Severn	2008	n.a. / n.a.	0.47 (0.48, 13) / n.a.
Solway	2008	n.a. / n.a.	-0.05 (0.54, 46) / n.a.
South Appenines	2008	0.07 (0.62, 6) / n.a.	0.35 (0.57, 17) / n.a.
South East (UK)	2008	n.a. / n.a.	0.66 (0.2, 5) / n.a.
South West (UK)	2008	n.a. / n.a.	0.58 (0.29, 18) / n.a.
Tagus	2008	n.a. / n.a.	-0.2 (0.63, 253) / n.a.
Tagus West	2008	-0.44 (0.36, 7) / n.a.	-0.19 (0.36, 10) / n.a.
Thames	2008	n.a. / n.a.	0.69 (0.19, 10) / n.a.
Venta	2008	-0.97 (0.2, 3) / -1.17 (0.42, 3)	-0.05 (0.23, 17) / n.a.
Vistula	2008	n.a. / n.a.	0.1 (0.28, 56) / n.a.
Vouga	2008	n.a. / n.a.	0.05 (0.32, 11) / n.a.
Warnow	2008	n.a. / n.a.	0.24 (0.24, 7) / n.a.
Weser	2008	n.a. / n.a.	0.55 (0.16, 44) / n.a.
West Aegean	2008	n.a. / n.a.	-0.15 (0.39, 14) / n.a.
West Estonian	2008	n.a. / n.a.	0.27 (0.31, 22) / n.a.
Western Wales	2008	n.a. / n.a.	0.15 (0.4, 13) / n.a.
Adour	2009	n.a. / n.a.	0.26 (0.42, 231) / -1.38 (0.21, 3)
Algarve	2009	-0.8 (0.14, 3) / -1.7 (0.13, 3)	-0.54 (0.39, 5) / -1.72 (0.19, 4)
Andalusia	2009	n.a. / n.a.	0.3 (0.41, 25) / -0.95 (0.74, 23)
Anglian	2009	n.a. / n.a.	0.82 (0.12, 13) / -1.6 (0.76, 4)
Basque County	2009	n.a. / n.a.	-0.02 (0.33, 42) / -0.18 (0.03, 2)
Black Sea	2009	-0.57 (0.05, 2) / n.a.	-0.18 (0.42, 5) / -1.28 (0.46, 4)
Cantabrian	2009	n.a. / n.a.	-0.51 (0.45, 32) / -1.76 (0.57, 23)
Catalan	2009	n.a. / n.a.	0.29 (0.52, 231) / n.a.
Cavado	2009	-0.61 (0.05, 2) / n.a.	0.19 (0.21, 5) / -1.07 (0.44, 286)
Corsica	2009	n.a. / n.a.	-0.46 (0.14, 22) / -1.19 (0.1, 12)
Cyprus	2009	n.a. / n.a.	-0.68 (0.93, 23) / -0.73 (0.28, 19)
Danube	2009	-0.33 (0.33, 38) / -1.74 (0.62, 35)	0.09 (0.34, 297) / -1.31 (0.38, 33)
Daugava	2009	-0.81 (0.69, 10) / -1.38 (0.26, 10)	-0.02 (0.22, 12) / -1.87 (0.53, 262)

Supporting information

Basin	Year	Lake	Stream
Douro	2009	-0.22 (0.36, 7) / -1.93 (0.32, 6)	-0.04 (0.52, 82) / n.a.
East	2009	n.a. / n.a.	n.a. / -0.84 (0.18, 43)
East Aegean Islands	2009	-0.59 (0.4, 7) / -1.1 (0.11, 5)	-0.21 (0.42, 34) / -0.71 (0.17, 9)
East Alps	2009	-0.48 (0.29, 10) / -1.97 (0.29, 10)	0.22 (0.26, 33) / -1.26 (0.46, 37)
East Estonia	2009	n.a. / n.a.	0.07 (0.39, 37) / -1.13 (0.14, 6)
Ebro	2009	n.a. / n.a.	-0.07 (0.62, 263) / -0.91 (0.65, 103)
Eider	2009	n.a. / n.a.	0.29 (0.1, 2) / -0.73 (0.1, 2)
Elbe	2009	-0.4 (0.67, 20) / n.a.	0.33 (0.37, 43) / -1.02 (0.12, 30)
Ems	2009	n.a. / n.a.	0.44 (0.22, 9) / -1.27 (0.36, 226)
Galician	2009	n.a. / n.a.	-0.05 (0.26, 37) / n.a.
Gauja	2009	-0.56 (0.47, 3) / -1.11 (0.34, 24)	-0.05 (0.18, 6) / -1.09 (0.29, 415)
Guadalete	2009	n.a. / n.a.	0.53 (0.45, 21) / n.a.
Guadalquivir	2009	n.a. / n.a.	0.29 (0.65, 130) / -1.22 (0.35, 216)
Guadiana	2009	-0.59 (0.23, 5) / -1.29 (0.29, 3)	-0.56 (0.48, 4) / -1.51 (0.44, 301)
Humber	2009	n.a. / -1.06 (0.66, 5)	0.64 (0.37, 26) / -1.13 (0.37, 15)
Jucar	2009	n.a. / n.a.	0.27 (0.47, 80) / -1.04 (0.4, 55)
Jutland	2009	n.a. / -1.21 (0.53, 10)	n.a. / n.a.
Lielupe	2009	n.a. / n.a.	0.26 (0.5, 15) / n.a.
Loire	2009	-0.65 (0.25, 10) / n.a.	0.45 (0.36, 419) / -1.13 (0.22, 38)
Meuse	2009	n.a. / n.a.	0.44 (0.19, 55) / -0.94 (0.36, 182)
Middle Appenines	2009	n.a. / n.a.	-0.24 (0.26, 5) / n.a.
Minho	2009	n.a. / n.a.	n.a. / -0.5 (0.41, 81)
Minho Lima	2009	n.a. / n.a.	0.08 (0.29, 4) / n.a.
Mosel	2009	n.a. / n.a.	0.66 (0.11, 3) / -0.81 (0.07, 9)
Neagh Bann	2009	-0.56 (0.29, 12) / -1.11 (0.4, 13)	0.06 (0.25, 29) / -1.51 (0.43, 199)
Nemunas	2009	-0.91 (0.37, 11) / -1.69 (0.33, 11)	0 (0.28, 38) / -1.42 (0.16, 11)
North Adriatic	2009	n.a. / n.a.	-0.18 (0.22, 5) / -1.46 (0.26, 45)
North Appenines	2009	n.a. / -0.55 (0.45, 2)	0.03 (0.38, 57) / -0.89 (0.7, 173)
North East (UK)	2009	-0.62 (0.08, 3) / -1.4 (0.5, 3)	-0.08 (0.53, 19) / -0.67 (0.2, 3)
North West (Irl.)	2009	n.a. / n.a.	-0.71 (0.61, 2) / -1.32 (0.73, 70)
North West (UK)	2009	-0.66 (0.23, 16) / -1.82 (0.21, 17)	-0.17 (0.53, 55) / n.a.
Northumbria	2009	n.a. / n.a.	-0.14 (0.59, 6) / -1.08 (0.5, 12)
Oder	2009	-1.21 (0.01, 2) / n.a.	0.33 (0.23, 37) / -0.92 (0.33, 58)
Po	2009	-0.41 (0.31, 6) / -1.38 (0.48, 6)	0.41 (0.04, 4) / n.a.
Pregolya	2009	n.a. / n.a.	n.a. / -0.98 (0.17, 7)
Rhine	2009	-0.09 (0.41, 10) / -1.83 (0.46, 10)	0.36 (0.28, 182) / -0.81 (0.17, 44)
Rhone	2009	n.a. / n.a.	-0.09 (0.46, 315) / -0.78 (0.22, 53)
Sado	2009	-0.54 (0.13, 4) / -1.4 (0.09, 4)	n.a. / n.a.
Scheldt	2009	-0.63 (0.54, 6) / -0.68 (0.32, 6)	0.63 (0.2, 81) / -1.29 (0.23, 22)
Schlei	2009	-0.48 (0.12, 3) / -1.09 (0.23, 3)	0.46 (0.2, 9) / n.a.
Scotland	2009	n.a. / n.a.	-0.43 (0.74, 207) / n.a.
Segura	2009	n.a. / n.a.	-0.29 (0.17, 6) / n.a.
Seine	2009	n.a. / -1.77 (0.24, 11)	0.64 (0.21, 217) / -1.28 (0.48, 61)
Serchio	2009	n.a. / n.a.	-0.44 (0.32, 11) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
Severn	2009	n.a. / n.a.	0.4 (0.48, 11) / n.a.
Solway	2009	n.a. / n.a.	-0.15 (0.55, 45) / n.a.
South East (UK)	2009	n.a. / n.a.	0.69 (0.21, 4) / n.a.
South West (Irl.)	2009	n.a. / -1.91 (0.41, 16)	n.a. / n.a.
South West (UK)	2009	n.a. / n.a.	0.53 (0.3, 16) / n.a.
Tagus	2009	n.a. / -0.86 (0.46, 2)	-0.08 (0.63, 213) / n.a.
Tagus West	2009	-0.42 (0.26, 6) / n.a.	-0.59 (0.57, 6) / n.a.
Thames	2009	n.a. / n.a.	0.67 (0.26, 9) / n.a.
Venta	2009	-1.16 (0.69, 5) / -1.53 (0.16, 5)	-0.03 (0.22, 16) / n.a.
Vistula	2009	n.a. / n.a.	0.14 (0.25, 59) / n.a.
Vouga	2009	n.a. / n.a.	0.02 (0.37, 12) / n.a.
Warnow	2009	-1.26 (0.44, 3) / -1.11 (0.38, 3)	0 (0.18, 7) / n.a.
Weser	2009	-0.22 (0.82, 2) / -1.16 (0.2, 2)	0.5 (0.16, 44) / n.a.
West Aegean	2009	n.a. / n.a.	-0.1 (0.24, 9) / n.a.
West Estonian	2009	n.a. / n.a.	0.06 (0.37, 22) / n.a.
Western Wales	2009	n.a. / n.a.	0.12 (0.41, 12) / n.a.
Adour	2010	-0.43 (0.39, 17) / -1.58 (0.55, 17)	0.2 (0.41, 357) / -1.8 (0.14, 2)
Algarve	2010	-0.59 (0.12, 3) / -1.43 (0.04, 3)	-0.49 (0.29, 5) / -1.51 (0.16, 5)
Andalusia	2010	n.a. / n.a.	0.22 (0.47, 30) / -1.13 (0.6, 30)
Anglian	2010	n.a. / n.a.	0.85 (0.17, 86) / -0.9 (0.29, 23)
Basque County	2010	n.a. / n.a.	0.06 (0.21, 39) / -0.05 (0.14, 2)
Black Sea	2010	-0.28 (0.84, 3) / -1.9 (0, 3)	-0.23 (0.53, 8) / -1.25 (0.78, 5)
Cantabrian	2010	n.a. / n.a.	-0.5 (0.47, 205) / -1.89 (0.18, 22)
Catalan	2010	n.a. / n.a.	0.25 (0.52, 274) / n.a.
Cavado	2010	n.a. / n.a.	n.a. / -1.12 (0.43, 276)
Corsica	2010	n.a. / n.a.	-0.58 (0.2, 22) / -1.22 (0.18, 3)
Cyprus	2010	n.a. / n.a.	0.02 (0.71, 28) / -0.82 (0.59, 19)
Danube	2010	-0.38 (0.27, 39) / -1.8 (0.51, 38)	0.1 (0.33, 290) / -1.3 (0.41, 362)
Daugava	2010	n.a. / -1.88 (0.45, 4)	-0.16 (0.05, 3) / -1.49 (0.49, 188)
Douro	2010	n.a. / -1.99 (0.31, 6)	-0.05 (0.46, 66) / n.a.
East	2010	-0.76 (0.31, 4) / n.a.	0.06 (0.33, 3) / -1.52 (0.3, 3)
East Aegean Islands	2010	-0.58 (0.33, 7) / -1.28 (0.14, 5)	-0.02 (0.31, 37) / -0.71 (0.19, 9)
East Alps	2010	-0.41 (0.24, 15) / -1.83 (0.24, 15)	0.18 (0.36, 360) / -1.43 (0.49, 27)
East Estonia	2010	n.a. / n.a.	0.02 (0.39, 40) / -1.03 (0.55, 23)
Ebro	2010	n.a. / n.a.	-0.05 (0.62, 204) / -0.92 (0.75, 66)
Eider	2010	n.a. / n.a.	0.32 (0.06, 2) / n.a.
Elbe	2010	-0.37 (0.71, 17) / -1.96 (0.53, 17)	0.45 (0.33, 52) / -0.98 (0.17, 30)
Ems	2010	n.a. / n.a.	0.5 (0.25, 9) / -1.35 (0.38, 357)
Galician	2010	n.a. / n.a.	0.07 (0.18, 27) / n.a.
Gauja	2010	n.a. / -1.33 (0.4, 10)	n.a. / -1.14 (0.29, 419)
Guadalete	2010	n.a. / n.a.	0.5 (0.51, 22) / n.a.
Guadalquivir	2010	n.a. / n.a.	0.24 (0.54, 122) / -1.18 (0.3, 217)
Guadiana	2010	-0.51 (0.08, 5) / n.a.	-0.12 (0.49, 9) / -1.45 (0.44, 391)
Humber	2010	n.a. / -1.19 (0.34, 5)	0.53 (0.41, 109) / -1.24 (0.38, 10)

Supporting information

Basin	Year	Lake	Stream
Jucar	2010	n.a. / n.a.	0.27 (0.44, 82) / -1.05 (0.38, 55)
Jutland	2010	n.a. / -1.35 (0.22, 10)	n.a. / n.a.
Lielupe	2010	n.a. / n.a.	0.25 (0.64, 10) / n.a.
Loire	2010	0.41 (0.33, 7) / n.a.	0.5 (0.35, 419) / -1.11 (0.18, 35)
Meuse	2010	0.37 (0.13, 2) / n.a.	0.43 (0.2, 55) / -0.96 (0.32, 182)
Middle Appenines	2010	n.a. / n.a.	-0.19 (0.6, 38) / n.a.
Minho	2010	n.a. / n.a.	-0.18 (0.61, 41) / -0.6 (0.44, 80)
Mosel	2010	n.a. / n.a.	0.78 (0.18, 4) / -0.83 (0.07, 9)
Neagh Bann	2010	-0.56 (0.27, 8) / n.a.	0.07 (0.26, 28) / -1.49 (0.46, 199)
Nemunas	2010	-1.36 (0.16, 4) / -1.9 (0.28, 4)	0.03 (0.33, 35) / -1.6 (0.03, 8)
North Adriatic	2010	n.a. / n.a.	-0.23 (0.23, 5) / -1.45 (0.24, 53)
North Appenines	2010	n.a. / n.a.	-0.11 (0.52, 171) / -1.02 (0.64, 258)
North East (UK)	2010	-0.63 (0.18, 3) / n.a.	-0.08 (0.53, 19) / -0.51 (0.54, 7)
North West (Irl.)	2010	n.a. / n.a.	-0.57 (0.34, 7) / -1.62 (0.22, 2)
North West (UK)	2010	-0.63 (0.2, 15) / -1.92 (0.2, 17)	0.06 (0.54, 118) / n.a.
Northumbria	2010	n.a. / n.a.	-0.05 (0.49, 55) / -0.98 (0.63, 19)
Oder	2010	n.a. / n.a.	0.38 (0.23, 22) / -0.93 (0.21, 12)
Po	2010	-0.38 (0.45, 87) / 1 (1.07, 82)	-0.08 (0.39, 286) / n.a.
Pregolya	2010	n.a. / n.a.	n.a. / -0.98 (0.18, 7)
Rhine	2010	-0.09 (0.44, 12) / -1.86 (0.44, 12)	0.37 (0.29, 182) / -0.84 (0.17, 44)
Rhone	2010	n.a. / 1.19 (0.31, 13)	-0.03 (0.44, 391) / -0.77 (0.18, 21)
Sado	2010	-0.45 (0.11, 4) / -1.37 (0.21, 4)	n.a. / n.a.
Scheldt	2010	-0.5 (0.5, 6) / -0.91 (0.24, 6)	0.62 (0.19, 80) / -1.4 (0.24, 22)
Schlei	2010	-0.71 (0.61, 2) / n.a.	0.59 (0.18, 9) / n.a.
Scotland	2010	n.a. / n.a.	-0.41 (0.73, 207) / n.a.
Segura	2010	n.a. / n.a.	0.12 (0.63, 64) / n.a.
Seine	2010	n.a. / n.a.	0.67 (0.2, 217) / -1.37 (0.44, 170)
Serchio	2010	n.a. / n.a.	-0.45 (0.29, 25) / n.a.
Severn	2010	n.a. / n.a.	0.36 (0.38, 90) / n.a.
Shannon	2010	-0.94 (0.38, 10) / n.a.	-0.07 (0.42, 28) / n.a.
Solway	2010	n.a. / n.a.	0.01 (0.47, 76) / n.a.
South Appenines	2010	-0.01 (0.17, 4) / n.a.	-0.01 (0.47, 128) / n.a.
South East (Irl.)	2010	n.a. / n.a.	n.a. / -1.49 (0.08, 3)
South East (UK)	2010	n.a. / n.a.	0.61 (0.4, 52) / -0.87 (0.28, 7)
South West (Irl.)	2010	-1.2 (0.49, 2) / n.a.	0.06 (0.51, 23) / n.a.
South West (UK)	2010	n.a. / n.a.	0.44 (0.36, 134) / n.a.
Tagus	2010	n.a. / n.a.	-0.02 (0.59, 262) / n.a.
Tagus West	2010	-0.45 (0.16, 6) / n.a.	-0.46 (0.68, 9) / n.a.
Thames	2010	n.a. / n.a.	0.79 (0.21, 52) / n.a.
Venta	2010	n.a. / n.a.	0.09 (0.27, 9) / n.a.
Vistula	2010	-0.77 (0.39, 3) / -0.77 (0.2, 3)	0.06 (0.11, 13) / n.a.
Vouga	2010	n.a. / n.a.	-0.01 (0.36, 12) / n.a.
Warnow	2010	-0.41 (0.27, 3) / -1.19 (0.36, 4)	0.34 (0.28, 7) / n.a.
Weser	2010	-0.12 (0.67, 2) / -1.4 (0.42, 2)	0.55 (0.18, 44) / n.a.

Appendix S7.2

Basin	Year	Lake	Stream
West Aegean	2010	n.a. / n.a.	-0.14 (0.24, 10) / n.a.
West Estonian	2010	n.a. / n.a.	0.09 (0.32, 22) / n.a.
Western	2010	-1.24 (0.09, 2) / n.a.	n.a. / n.a.
Western Wales	2010	n.a. / n.a.	0.05 (0.36, 119) / n.a.

Supporting information

Appendix S7.3 River basins

River basins mapped by the European Environment Agency, EEA (2012) are shown in Figure S7.3.1 and the legend is shown in Table S7.3.1.

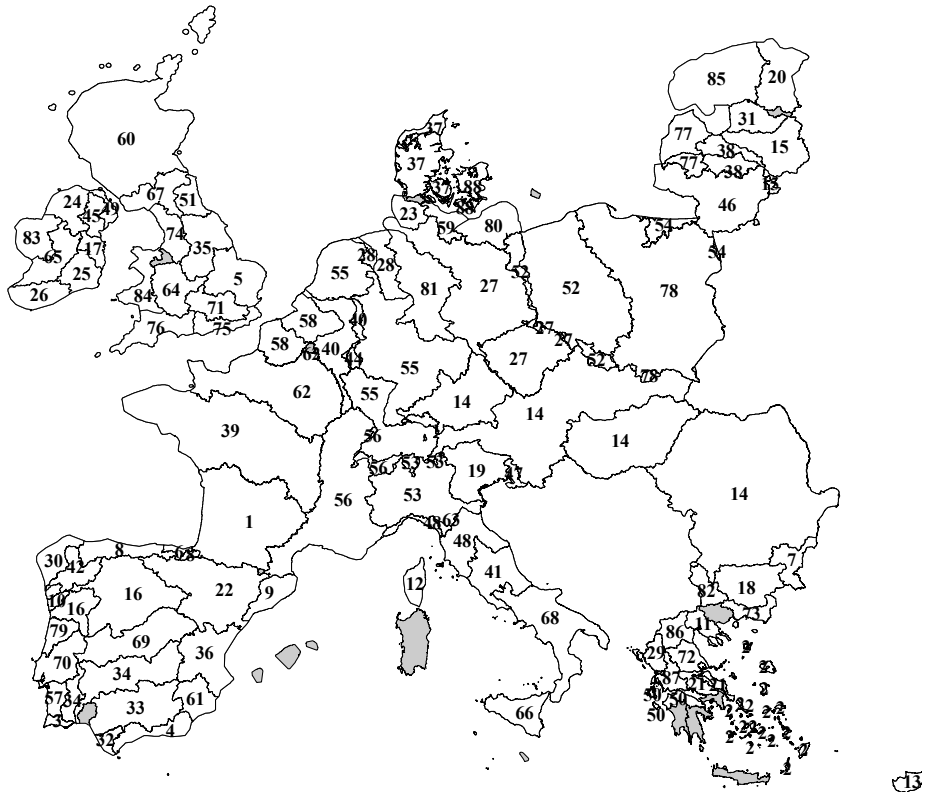


Figure S7.3.1. River basins of temperate Europe.

Appendix S7.3

Table S7.3.1 Legend of river basin numbers used in Figures 7.3 and 7.4 of the main text.

Number	Basin	Number	Basin
1	Adour	37	Jutland
2	Aegean Isl.	38	Lielupe
3	Algarve	39	Loire
4	Andalusia	40	Meuse
5	Anglian	41	Middle Appenines
6	Basque County	42	Minho
7	Black Sea	43	Minho Lima
8	Cantabrian	44	Mosel
9	Catalan	45	Neagh Bann
10	Cavado	46	Nemunas
11	Central Macedonia	47	North Adriatic
12	Corsica	48	North Appenines
13	Cyprus	49	North East (UK)
14	Danube	50	North Peloponnese
15	Daugava	51	Northumbria
16	Douro	52	Oder
17	Eastern (IRL)	53	Po
18	East Aegean Isl.	54	Pregolya
19	Eastern Alps	55	Rhine
20	Eastern Estonia	56	Rhone
21	Eastern Sterea	57	Sado
22	Ebro	58	Scheldt
23	Eider	59	Schlei
24	North West (IRL)	60	Scotland
25	South East (IRL)	61	Segura
26	South West (IRL)	62	Seine
27	Elbe	63	Serchio
28	Ems	64	Severn
29	Epirus	65	Shannon
30	Galician	66	Sicily
31	Gauja	67	Solway
32	Guadalete	68	Southern Appennines
33	Guadalquivir	69	Tagus
34	Guadiana	70	Tagus West
35	Humber	71	Thames
36	Jucar	72	Thessalia

Supporting information

Number	Basin
73	Thrace
74	North West (UK)
75	South East (UK)
76	South West (UK)
77	Venta
78	Vistula
79	Vouga
80	Wamow
81	Weser
82	West Aegean
83	Western (IRL)
84	Western Wales
85	West Estonian
86	West Macedonia
87	West Sterea
88	Zealand

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SUMMARY

Increases in nutrient flows have led to increasing stressor levels in the environment. Ultimately, nutrient pollution may affect species growth, reproduction, and mortality, and, thereby, species occurrence as well as the richness of the community as a whole. In this thesis, nutrient pollution is assessed in three environmental compartments, i.e. marine waters, freshwaters, and on land. In each compartment, a different environmental problem was tackled: acidification of soils and of oceans and eutrophication of freshwaters. These are and, most likely, will remain, environmental issues at the global level.

In order to estimate the effects of nutrient pollution on species or species groups, stressor – response relationships were developed after a detailed data gathering, whereby species-specific effects and their respective stressor level were extracted from peer-reviewed literature. Long term biogeochemical processes, macroevolutionary patterns, and inherent species characteristics hold a vital role in the sensitivity of species to environmental stress and, accordingly, in determining the stressor – response relationships developed in the different chapters of this thesis. Finally, those relationships were applied for life cycle impact assessments (LCIA) and environmental risk assessments (ERA).

The issue of acidification is addressed in chapters 2 and 3 (for the terrestrial compartment) and in chapter 4 (in the marine compartment). In **chapter 2**, an inventory of the soil pH ranges at which different vascular plant species were reported in field surveys was conducted. Subsequently, the occurrence data were employed towards the derivation of relative species richness (RSR) as a function of soil pH in different biomes of the world. A total of 2409 species were inventoried and the individual species tolerance pH range was determined with the lowermost and uppermost pH levels at which the species was confirmed present. The logistic regressions were used to identify the sensitivity of biomes to decreases in RSR following soil pH declines. There, biogeographic patterns such as the discrepancy between pH conditions that maximize species richness in biomes and the difference in sensitivities across biomes could be identified. (Sub)tropical moist broadleaf forests are more sensitive to pH declines than other biomes while desert and xeric shrublands maintain their a high RSR at fairly high pH conditions.

In **chapter 3**, the cumulative increase in the potentially not occurring fraction (PNOF) of vascular species as a function of soil pH was derived from the lowermost surveyed pH level for each species in different terrestrial

biomes. The PNOF – pH relationships were then employed to derive quantitative relationships of the marginal increase in PNOF as a result of a marginal decline in soil pH (defined in LCIA as marginal effect factors) and, combined with existing models of atmospheric transport and soil chemistry, endpoint characterization factors (CFs) for terrestrial acidification were derived on a global scale for nitrogen oxides, ammonia, and sulfur dioxide emissions. The CFs express the environmental impact on the ecosystem per unit of acidifying pollutant emission (namely, the increase in the PNOF per unit of emission). CFs are provided at multiple levels of spatial resolution (highest resolution at 2.0° x 2.5°). The variability across CFs (of the magnitude of six orders) is determined mainly by the variability in soil sensitivity to atmospheric depositions.

In **chapter 4**, the cumulative increase in the potentially affected fraction (PAF) of marine calcifying species (e.g., arthropods, cnidarians, among others) as a function of water pH was estimated with species sensitivity distributions (SSDs). There, the PAF – pH relationships were developed from experimental data conveying subtle (EC₁₀) and severe (EC₅₀) effects on species growth, reproduction, and mortality. Subsequently, the PAF – pH functions were applied in an ERA by estimating the change in PAF expected with seawater pH declines in two global climate change scenarios. A decline in 0.15 and 0.30 in ocean pH may cause an increase of the PAF by 0.04 to 0.06 and 0.12 to 0.14, respectively (based on EC₅₀ results). This is the first study which uses SSDs in order to estimate global climate change impacts on ocean biota.

The issue of freshwater eutrophication is addressed in chapters 5, 6, and 7. Similarly to chapter 2, species-specific ranges (total of 2294) of total phosphorus (TP) are developed in **chapter 5** to derive RSR – TP relationships for four different climate types, i.e. cold, temperate, xeric, and (sub)tropical. In this case, the stressor – response relationships were developed separately for two species groups, i.e. autotrophs and heterotrophs, and two freshwater types, i.e., lakes and streams, to identify the sensitivity of biomes to decreases in RSR following TP level increases. Notable biogeographic patterns such as the lower optimal TP levels which maximize species richness in cold lakes compared to temperate lakes, for example, could be identified. These patterns arise due to differentiated biogeochemical and hydrologic processes to which species were subjected at an evolutionary scale.

Summary

In **chapter 6**, the PNOF of heterotrophic species as a function of TP was developed with the uppermost surveyed TP level for lakes and streams in the temperate region. The PNOF – TP functions were subsequently employed towards the derivation of three different effect models for LCIA, which describe the increase in PNOF with an increase in TP levels, in the two freshwater types (i.e. lakes and streams). These effect factors were then combined with an existing model of P transport in freshwaters to derive endpoint CFs, expressing the ecological impact of phosphorus emissions to freshwater. Freshwater type and spatial variability driven by P transport are shown as important factors influencing CF results.

In **chapter 7**, stressor – response functions were derived for potential species absences with TP and NO₃ concentrations and combined with long term monitoring data on nutrient concentrations in Europe to estimate the ecological risk (ER) that invertebrate species within a community assemblage may become absent due to nutrient stress. In this case, the ER posed by additive effects of TP and NO₃ is determined separately for lakes and streams on a yearly basis (from 1985 to 2011). Although limitations to primary productivity have been persistently attributed to P, risks of potential absences of invertebrates appear to be mainly driven by N stress. This study describes how existing concepts of ERA can aid towards the improvement of water quality required by the European Water Framework Directive.

In **chapter 8**, the primary uncertain components involved in the derivation and application of the effect models are described, e.g. the unaccountability of interacting effects among stressors and of ecological effects of declining stressor levels, among others, as well as recommendations for future work on nutrient pollution.

SAMENVATTING

Toenamen in de toevoer van nutriënten gaan gepaard met toenemende gehalten van deze stressoren in het milieu. Nutriëntenvervuiling kan de groei, reproductie en mortaliteit van soorten beïnvloeden en daardoor uiteindelijk ook de aanwezigheid van soorten en de soortenrijkdom van levensgemeenschappen. In dit proefschrift wordt de nutriëntenvervuiling geanalyseerd in drie milieucompartmenten, namelijk zeewater, zoetwater en land. In ieder compartiment is een andere milieuprobleem geanalyseerd: eutrofiering van zoete watersystemen en verzuring van terrestrische bodems en oceanen. Dit zijn en blijven zeer waarschijnlijk milieuproblemen op mondiale schaal.

Na uitgebreide dataverzameling, zijn stressor – respons relaties opgesteld om effecten van nutriëntenvervuiling op soorten of soortengroepen te schatten. Hiervoor zijn soortspecifieke effecten en daaraan gerelateerde gehalten van stressoren afgeleid uit ‘peer-reviewed’ literatuur. Biogeochemische processen op lange termijn, macroevolutionaire processen en inherente soortkenmerken spelen een belangrijke rol in de gevoeligheid van soorten voor milieustress en bepalen bijgevolg de stressor – respons relaties die zijn opgesteld in de verschillende hoofdstukken van dit proefschrift. Tenslotte zijn deze relaties toegepast in milieugerichte levenscyclus effectanalyses (LCIA) en risicobeoordelingen (ERA).

In de hoofdstukken 2 en 3 wordt het thema verzuring uitgewerkt voor het terrestrische milieucompartment en in hoofdstuk 4 voor het mariene compartiment. **Hoofdstuk 2** omvat een inventarisatie van bodem pH bereiken waarbinnen verschillende soorten vaatplanten zijn waargenomen tijdens veldonderzoeken. Vervolgens zijn deze presentiedata gebruikt voor het afleiden van de relatieve soortenrijkdom (RSR) als functie van de bodem pH in verschillende habitattypen op aarde. In totaal zijn 2409 soorten geïventariseerd. De zuurtolerantie (pH-bereik) van iedere individuele soort is bepaald op basis van de minimale en maximale pH-waarde waarbij de betreffende soort nog is waargenomen. Logistische regressies zijn gebruikt om de gevoeligheid van habitattypen te bepalen voor afname van de RSR bij dalende pH. In dit hoofdstuk zijn biogeografische patronen geïdentificeerd, zoals de discrepantie tussen pH condities die de soortenrijkdom in habitattypen maximaliseren en de verschillen in gevoeligheid van habitattypen. (Sub)tropische regenwouden zijn gevoeliger voor daling van de pH dan andere habitattypen terwijl woestijnen en droge struwelen een hoge RSR handhaven bij tamelijk hoge pH condities.

Samenvatting

In **hoofdstuk 3** is de cumulatieve toename van de potentieel niet aanwezige fractie (PNOF) vaatplantsoorten als functie van de bodem pH afgeleid van de minimale pH waarde die voor iedere soort is waargenomen in verschillende terrestrische habitattypen. Vervolgens zijn PNOF – pH relaties afgeleid om kwantitatieve relaties te bepalen voor marginale toename in PNOF als gevolg van marginale daling in bodem pH (in LCIA gedefinieerd als marginale effect factoren). In combinatie met beschikbare modellen voor atmosferisch transport and bodemchemie zijn eindpunt karakterisatiefactoren (CFs) voor terrestrische verzuring op mondiale schaal afgeleid voor emissies van stikstofdioxide, ammoniak en zwaveldioxide. De CFs drukken milieueffecten op een ecosysteem uit per emissie-eenheid verzurende stoffen (namelijk, de toename in PNOF per emissie-eenheid). CFs zijn berekend voor verschillende ruimtelijke schaalniveaus (hoogste resolutie: 2.0° x 2.5°). De variabiliteit van CFs bedraagt circa zes ordes van grootte en wordt vooral bepaald door de variabiliteit in bodemgevoeligheid voor atmosferische depositie.

In **hoofdstuk 4** is de cumulatieve toename van de potentieel aangetaste fractie (PAF) mariene soorten die verkalken (zoals geleedpotigen en neteldieren) als functie van de water pH geschat met soortengevoeligheidsverdelingen (SSDs). Deze PAF – pH relaties zijn opgesteld op basis van experimentele data over geringe (EC₁₀) en ernstige (EC₅₀) effecten op de groei, reproductie en mortaliteit van soorten. Vervolgens zijn de PAF – pH functies toegepast in een ERA waarbij de verwachte PAF bij pH daling van zeewater is geschat voor twee mondiale klimaatscenario's. Een pH daling van 0.15 en 0.30 in een oceaan kan resulteren in een toename van de PAF met respectievelijk 0.04 tot 0.06 en 0.12 tot 0.14 (gebaseerd op EC₅₀ waarden). Dit is de eerste studie waarin SSDs zijn gebruikt om de effecten van mondiale klimaatscenario's op organismen in oceanen te schatten.

Het thema zoetwater eutrofiering komt aan de orde in de hoofdstukken 5, 6 en 7. Conform hoofdstuk 2 zijn ook in **hoofdstuk 5** soortspecifieke milieugrenzen (in totaal 2294) voor totaal fosfor (TP) bepaald om RSR – TP relaties af te leiden voor zoetwater ecosystemen in vier verschillende klimaattypen (koud, gematigd, droog en (sub)tropisch). De stressor – respons relaties zijn in dit geval afzonderlijk ontwikkeld voor twee soortgroepen (autotrofen en heterotrofen) en twee zoetwatertypen (meren en rivieren) om de gevoeligheid van verschillende habitattypen voor afname in RSR bij toenemende TP concentraties te bepalen. Tevens zijn opmerkelijke biogeografische patronen geïdentificeerd, zoals het optimale TP gehalte voor maximale soortenrijkdom die voor meren in koude gebieden lager is dan

voor meren in gematigde streken. Dergelijke patronen zijn waarschijnlijk een gevolg van blootstelling aan verschillende biogeochemische en hydrologische processen op een evolutionaire tijdschaal.

In **hoofdstuk 6** is de PNOF voor heterotrofe soorten als functie van TP afgeleid op basis van de hoogst waargenomen TP gehalten in meren en rivieren in gematigde gebieden. De PNOF – TP functies zijn vervolgens gebruikt voor het afleiden van drie verschillende effectmodellen voor LCIA, die de toename in PNOF bij toenemende TP gehalten beschrijven, in twee typen zoetwatersystemen (meren en rivieren). Deze effectfactoren zijn gecombineerd met een bestaand model voor P transport in zoetwatersystemen voor het afleiden van eindpunt CFs voor de ecologische effecten fosforemissies in die systemen. De factoren watertype en ruimtelijke variabiliteit door P transport hebben grote invloed op CF uitkomsten.

In **hoofdstuk 7** zijn stressor – respons functies afgeleid voor potentiële afwezigheid van soorten in relatie tot TP en NO₃ concentraties. Dergelijke functies zijn vervolgens gecombineerd met data van lange termijn monitoring van nutriëntenconcentraties in Europa voor de schatting van ecologische risico's (ER) zoals het verdwijnen van ongewervelde soorten uit een levensgemeenschap door nutriënten stress. De ER als gevolg van additieve effecten van TP en NO₃ is in dit geval afzonderlijk en op jaarlijkse basis bepaald voor meren en rivieren voor de periode 1985-2011. Hoewel limitering van de primaire productie vooral wordt toegeschreven aan P, blijkt het risico van potentiële afwezigheid van ongewervelde soorten vooral te worden bepaald door N stress. Dit onderzoek beschrijft ook hoe het kan bijdragen aan verbetering van de waterkwaliteit zoals vereist door de Europese Kaderrichtlijn Water.

Hoofdstuk 8 beschrijft belangrijke bronnen voor onzekerheid bij de afleiding en toepassing van effectmodellen, zoals de toerekenbaarheid van inter-acterende effecten van stressoren en ecologische effecten bij afnemende gehalten van stressoren, en geeft aanbevelingen voor toekomstig onderzoek aan nutriëntenvervuiling.

Acknowledgments

ACKNOWLEDGMENTS

Where to start? First, I would like to thank all my supervisors at the Department.

Mark, no need to say that you were my guiding light during these four years and my professional role model. Your supervision was impeccable and I hope we continue working together in the years to come. My next big challenge will be stop asking the question “Mark, what should I do?” and start answering the question “what would Mark do?”.

Jan, I will miss our inspiring one-on-one talks about my broad role as a scientist and the relevance of interdisciplinary research. Thank you for always having willing ears to my frustration bursts. Our discussions often left me with more questions than answers but they calmed me down.

Rosalie and Rob, thank you for the additional supervision and the constructive suggestions. The blend of LCA and ecology expertise by the two of you made me a very well supervised PhD student. Thank you to my co-authors, Pierre-Olivier Roy, An M. De Schryver, Andrew D. Henderson, Olivier Jolliet, Roland Bobbink, Jaap Struijs, Dick de Zwart, Louise Deschênes, Manuele Margni, and Pieter M.F. Elshout, for all their fruitful discussions and for giving me the opportunity to work with them. Thank you to my thesis committee members, Tom Breure, Leon Lammers, and Lex Bouwman, for evaluating the content of this work.

Second, huge thanks to my colleagues at the Department. Aafke, thanks for being my GIS and statistics go-to person (especially towards to end my program). Francesca, thanks for all the MATLAB help. Gina, thanks for helping me through all the Dutch forms. Bor, thanks for all the fun lunches with loud laughs. Thanks to my PhD student fellows: the older ones (Pim, Mark Loos, Loes, Marlia, Patience), the current ones (Rik, Daan, Anne, Alessandra, Isabel, Thomas, Jon, Zoran, Gea, Lisette) and the new ones (Joris, Katia, Jelle, Rasha). Special thanks to my two girls, Anastasia (the sweetest girl with a toughest shell, ever present shoulder to cry on) and Laura (the wisest girl, ever present counselor for the matters of the heart).

Thank you to my fellow colleagues of the Young Scientist Summer Program (YSSP) of the International Institute of Applied Systems Analysis (IIASA), who were responsible for making the summer of 2013 the fastest of my life (especially to David, Melissa, Alessandra, and Claudia). Also thanks to Emilio, Victor, and Ville-Veikko for their help with software and

statistics. Thanks also to Marijn, Linda, and Steffen at IIASA for their supervision during the YSSP. Also, thank you to the members of the LC-IMPACT project for teaching me a lot about LCA.

Finally, a ginormous thanks to my friends and family. Obrigada às minas do Beko pelas recarregadas de bateria em Piracicaba e Sampa e pelas teleconferências no skype. Obrigada à família mais linda do planeta: Sil, Lelé, Fufu, tia Gogô, tio Zé e tio Roberto, Pati e Gu, Cezar e Lú (Luciana), Paulinho e Pri, Má e Tiago, e Lú (Luciano). Super bedankt voor mijn schoonfamilie, Verena, Nico, Fré en Ed. Finally, special thanks to the ‘Deventer-gang’ (Annemarie, Jiska, Alex, Ray, and Richard). You had (and will keep on having) a huge contribution to my life in the Netherlands (and abroad, multiple times) and I cannot thank you enough.

Mama, papa e Rafa, não existem palavras pra começar a descrever a importância que vocês três tiveram nessa trajetória. Sem vocês, não existiria razão para começar (e muito menos terminar) isso. Mama, você é o meu exemplo de mulher perfeita. Papa, minha fonte inspiradora. Rafa, meu chão. Mary, how do I start this? I will keep it simple since there are no words anyways. Thank you for being my North and my sanctuary.

Curriculum vitae

Curriculum vitae

I was born on 28 April 1983 in São Paulo (Brazil), where I stayed until the end of high school. In 2006, I began my undergraduate studies in agronomic engineering at the Luiz de Queiroz College of Agriculture of the University of São Paulo – ESALQ. During my program, I was part of the student council and I was the editor of the student newspaper. In the last six months of 2006, I went to the University of California – Davis (the United States) at the Plant Sciences Department for an research internship on strategies to improve tomato post-harvest, from which I later wrote my B.Sc. thesis. In 2007, I returned to Davis as a laboratory technician to assist on existing research projects on water quality in rice fields of the Central Valley and irrigated pastures of the foothills of California's Sierra Nevada. I started my M.Sc. program in Soils and Biogeochemistry at the same laboratory and I wrote my M.Sc. thesis on strategies for improvement of runoff water quality in irrigated pastures in the end of 2009.

In 2010, I moved to the Netherlands to start my PhD program at the Department of Environmental Science at Radboud University Nijmegen. The research I conducted during my four years in Nijmegen led me to write this thesis. During that time, I had the opportunity of being part of some of the teaching activities of the department as well as being part of the PhD student council of the Research School for Socio-Economic and Natural Sciences of the Environment (SENSE). Towards the end of my PhD work, I was part of the 2013 Young Scientists Summer Program (YSSP) of International Institute for Applied Systems Analysis (IIASA), in Austria. During that summer, I conducted additional research on environmental impact assessments, this time on the topic of land use and forest fragmentation. In 2014, the opportunity arose to go back to IIASA as a post-doctoral researcher of the Ecosystem Services and Management Program (ESM), where I am today. At the moment, I perform nutrient dynamics and crop modeling under different scenarios of phosphorus and nitrogen availability in the soils of the world.

List of publications

Azevedo, LB, Schipper AM, van der Velde M, See L, van Zelm R, Fritz S, Huijbregts MAJ. Relating trends in forest species populations to habitat loss and fragmentation on a global scale (*in preparation*).

Azevedo LB, van Zelm R, Leuven RSEW, Hendriks AJ, Huijbregts MAJ. Combined ecological risks of nitrogen and phosphorus in European freshwaters (*submitted*).

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(Co-)authors' addressess

(Co-)authors' addressess

Ligia B. Azevedo

International Institute for Applied Systems Analysis, Ecosystem Services and Management Program, Schlossplatz 1, A-2361 Laxenburg, Austria
e-mail: azevedol@iiasa.ac.at

Roland Bobbink

B-WARE Research Centre, Radboud University Nijmegen, P.O. Box 6558, 6503 GB Nijmegen, the Netherlands

Louise Deschênes

CIRAIG, Chemical Engineering Department, École Polytechnique de Montréal, P.O. Box 6079, Montréal, Québec, H3C 3A7, Canada

Pieter M.F. Elshout

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

Andrew D. Henderson

University of Michigan, School of Public Health, Department of Environmental Health Sciences, 1415 Washington Heights, Ann Arbor, Michigan 48109, United States

The University of Texas Health Science Center at Houston, School of Public Health, Human Genetics and Environmental Sciences, Division of Epidemiology, 1200 Hermann Pressler, Houston, Texas 77030, United States

A. Jan Hendriks

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

Mark A.J. Huijbregts

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

Olivier Jolliet

University of Michigan, School of Public Health, Department of Environmental Health Sciences, 1415 Washington Heights, Ann Arbor, Michigan 48109, United States

Rob S.E.W. Leuven

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

Manuele Margni

CIRAIG, Chemical Engineering Department, École Polytechnique de Montréal, P.O. Box 6079, Montréal, Québec, H3C 3A7, Canada

Pierre-Olivier Roy

CIRAIG, Chemical Engineering Department, École Polytechnique de Montréal, P.O. Box 6079, Montréal, Québec, H3C 3A7, Canada

An M. De Schryver

ETH Zurich, Institute of Environmental Engineering, 8093 Zürich, Switzerland
Quantis, Parc Scientifique EPFL, Batiment D, 1015 Lausanne, Switzerland

Jaap Struijs

National Institute for Public Health and the Environment, Laboratory for Ecological Risk Assessment (LER Pb 9), Bilthoven, The Netherlands

Rosalie van Zelm

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

Dick de Zwart

National Institute for Public Health and the Environment, Laboratory for Ecological Risk Assessment (LER Pb 9), Bilthoven, The Netherlands