Maison de la Rivière

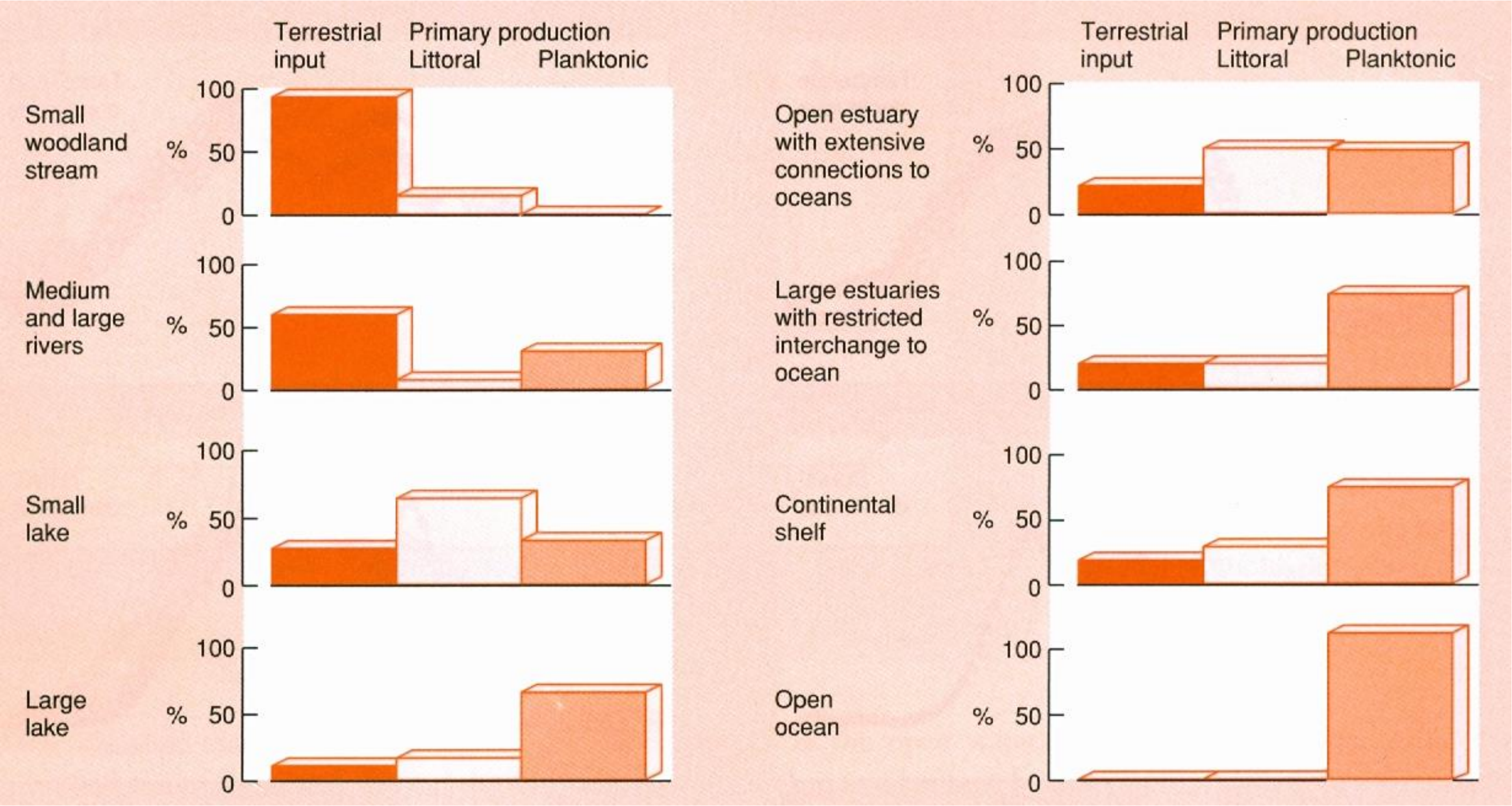
06 mai

Organic carbon
and ecosystem energetics

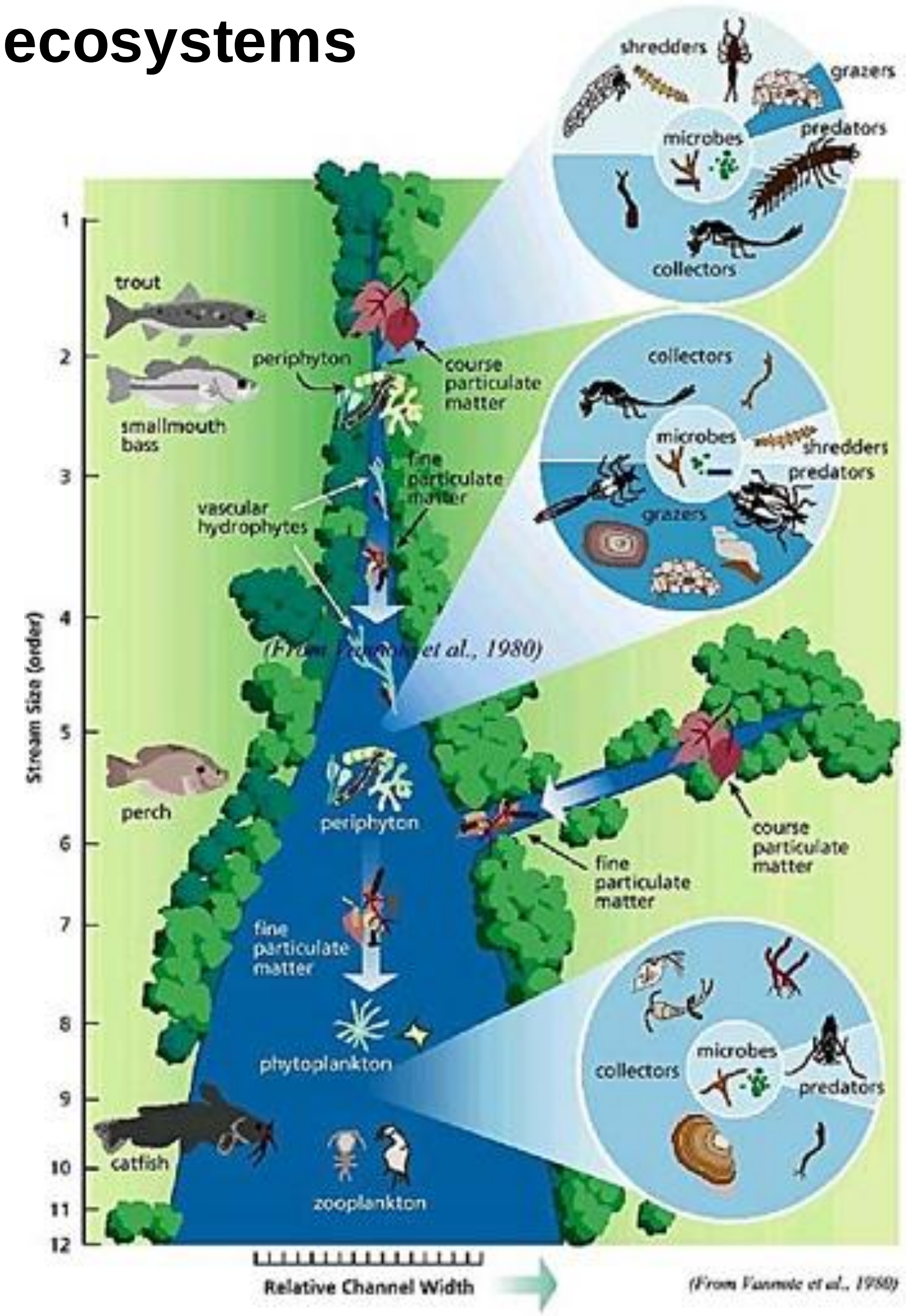
Where does the organic energy come from in lakes and river

Different surface-to-perimeter ratios

Different sources and forms of energy



Various forms of organic carbon in aquatic ecosystems

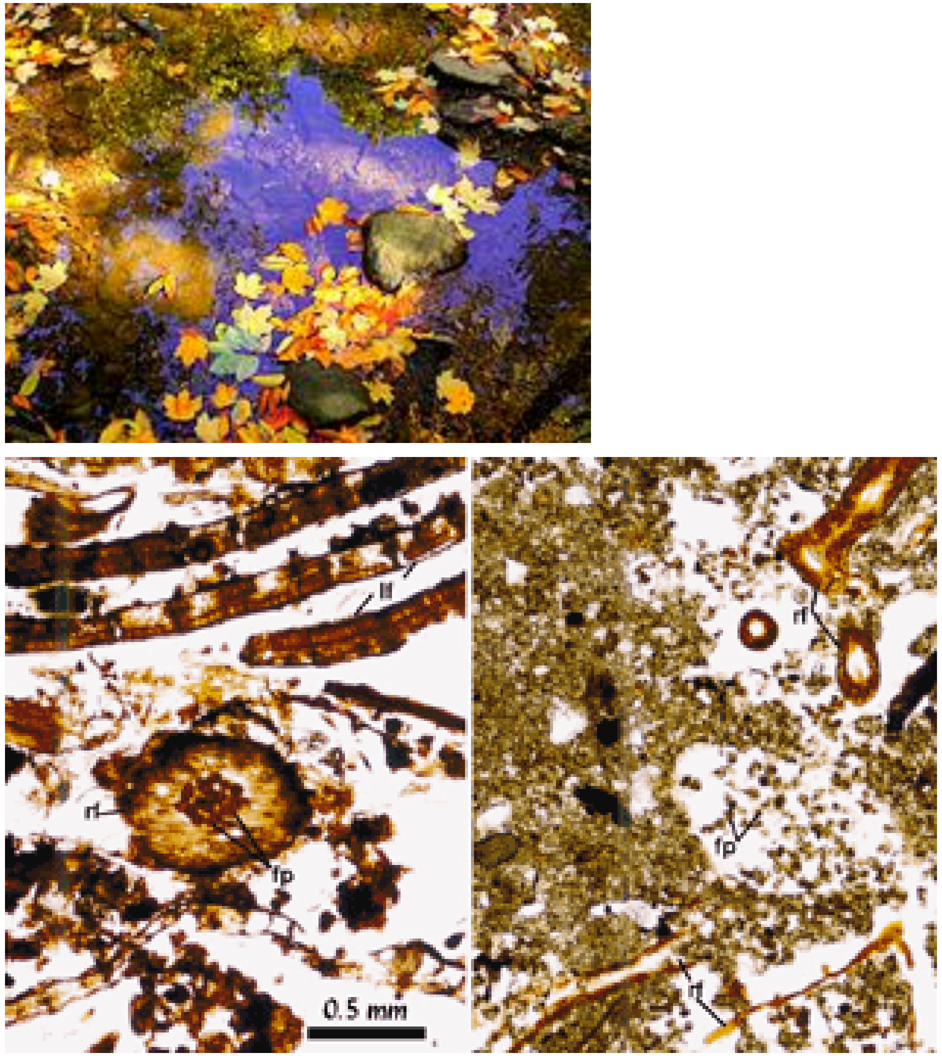


Allochthonous (produced outside the ecosystem boundaries) versus autochthonous (produced inside the ecosystem boundaries) sources of organic carbon

Particulate organic matter (POC)
Dissolved organic carbon (DOC)

EPFL

Coarse Particulate Organic Matter (CPOM)



Fine Particulate Organic Matter (CPOM)

How much DOM, FPOM and CPOM is transported by streams?

Decadal carbon discharge by a mountain stream is dominated by coarse organic matter

Jens M. Turowski[1]*, Robert G. Hilton[2], Robert Sparkes[3,4]

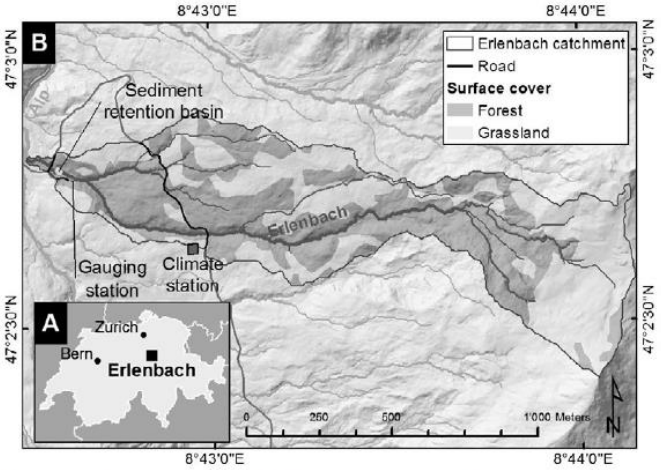
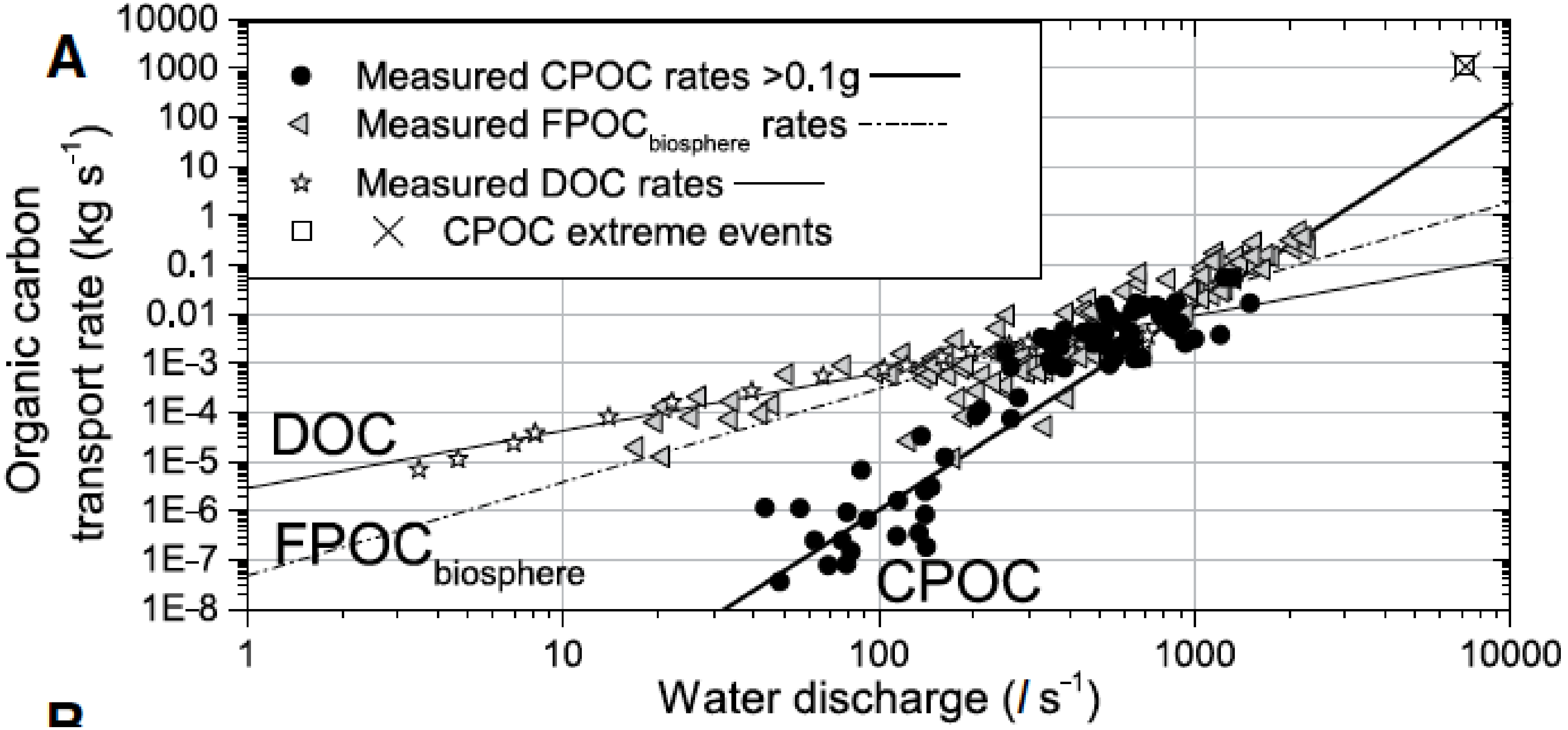


Figure 1. A: Location of the Erlenbach catchment in Switzerland. B: Map of the catchment.

How much DOM, FPOM and CPOM is transported by streams?

Decadal carbon discharge by a mountain stream is dominated by coarse organic matter

Jens M. Turowski[1]*, Robert G. Hilton[2], Robert Sparkes[3,4]



- DOC flux dominates overall
- Change point when larger debris (i.e., CPOC) are mobilized at a critical discharge (cf Hulmstroem curve)

The Natural Wood Regime in Rivers

ELLEN WOHL, NATALIE KRAMER, VIRGINIA RUIZ-VILLANUEVA, DANIEL N. SCOTT, FRANCESCO COMITI, ANGELA M. GURNELL, HERVE PIEGAY, KATHERINE B. LININGER, KRISTIN L. JAEGER, DAVID M. WALTERS, AND KURT D. FAUSCH

The roles of wood

- Geomorphic and environmental heterogeneity foster biodiversity
- Geomorphology and lateral connectivity / floodplains
- Nutrient and organic matter dynamics

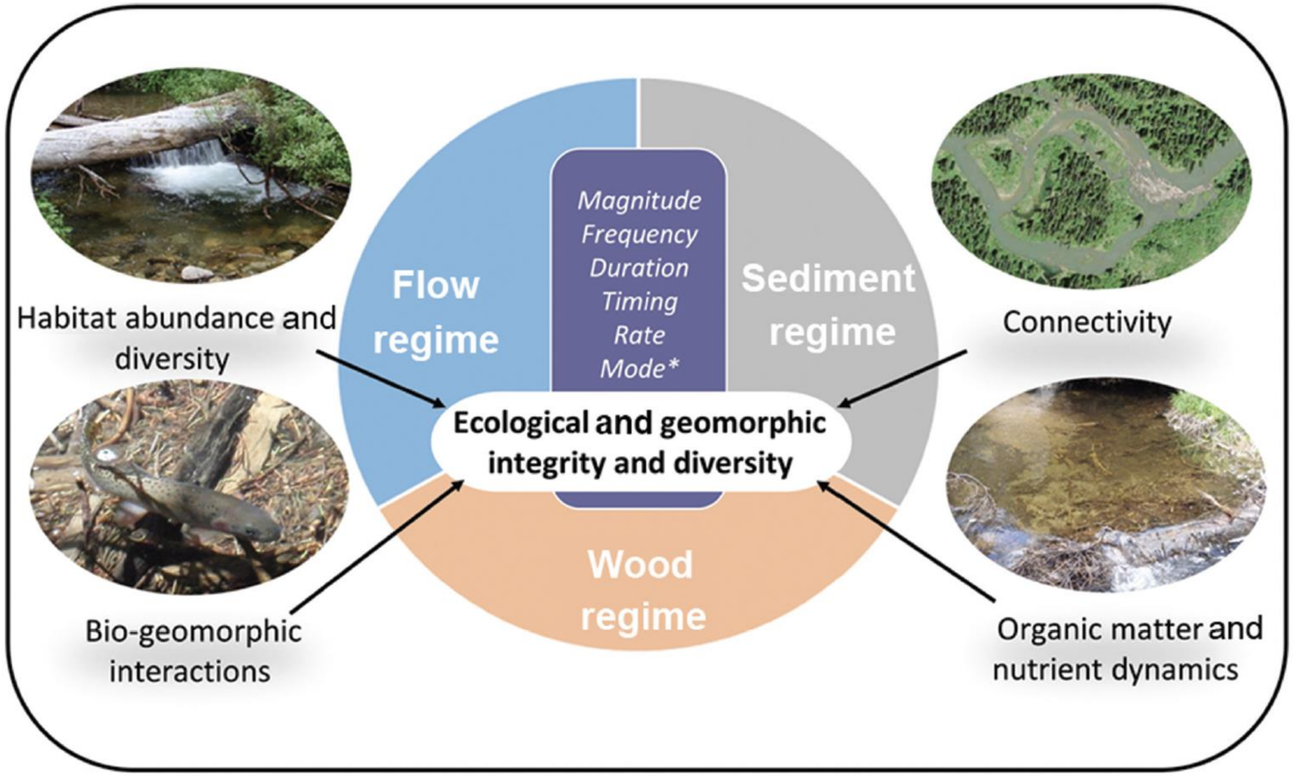
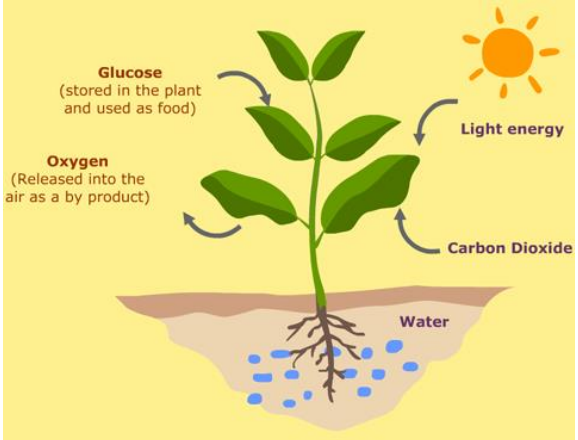


Figure 1. Characteristics of the river corridor influenced by interactions among water, sediment, and wood. Characteristics listed around the margins (e.g., physical habitat template) are influenced by the presence of mobile and stored wood. In the central box, Mode refers only to the wood regime.*

Figure 6. Examples of structures used to limit downstream mobility of wood. (a and b) Rienz River, Italy; (c) Chiene River, Switzerland (the chair is outlined in yellow for scale); (d) Sihl River, Switzerland (people are outlined in yellow for scale). The structure on the Sihl River is unique in size and design. It is installed parallel to the flow in the outer bend of a meander to retain wood (which might otherwise reach the City of Zurich) but to allow sediment to be transported.

DOC (or DOM): Energy basis for microbial heterotrophs

Photosynthesis (CHO)

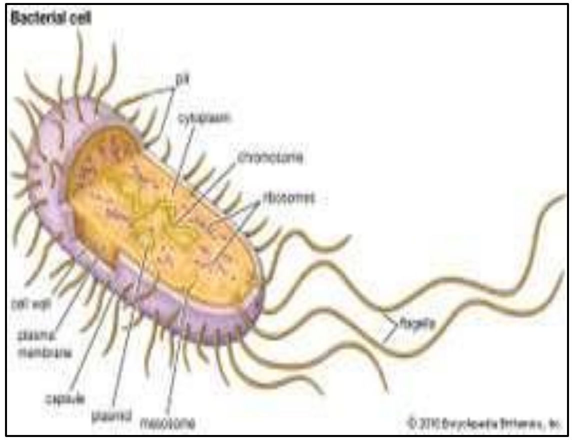


CO_2 assimilation

DOC →

← CO_2

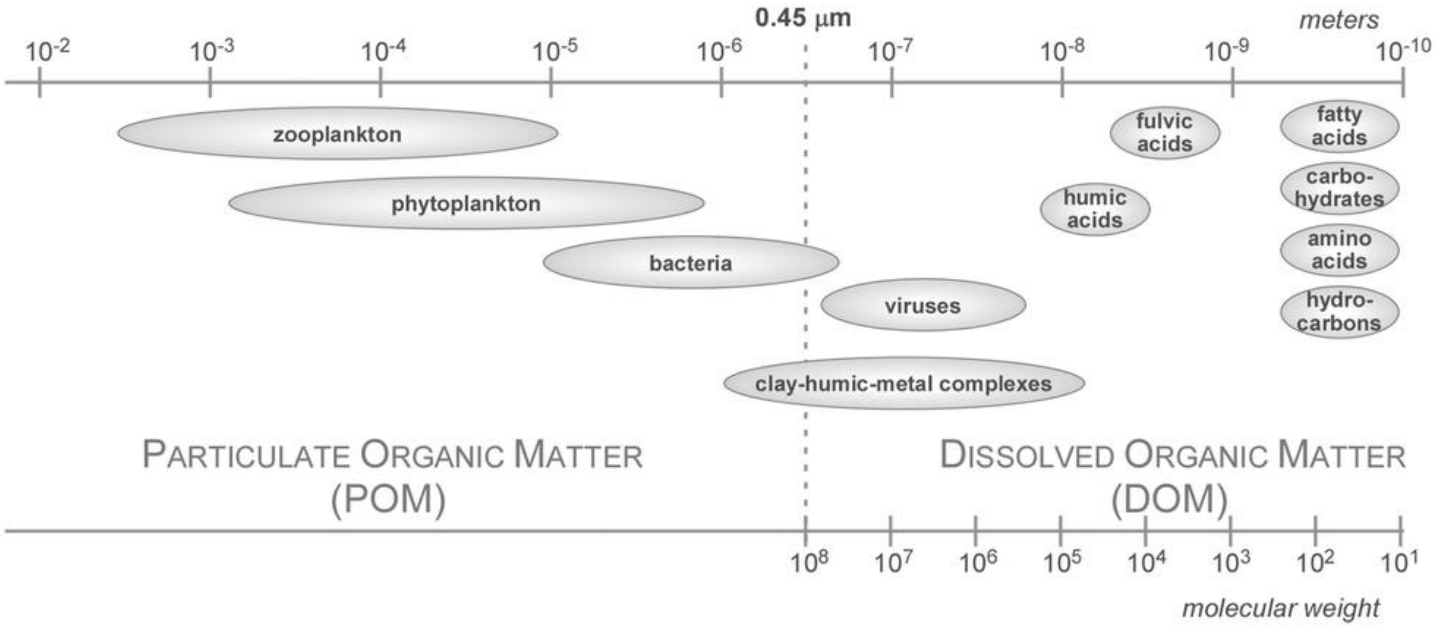
Respiration
DOC metabolism



CO_2 and CH_4 production

DOC as the largest pool of reduced carbon in the world's aquatic ecosystems

A major intermediary to the global carbon cycle



Browning of surface waters
- Light regime
- Metabolism
- Contaminant transport

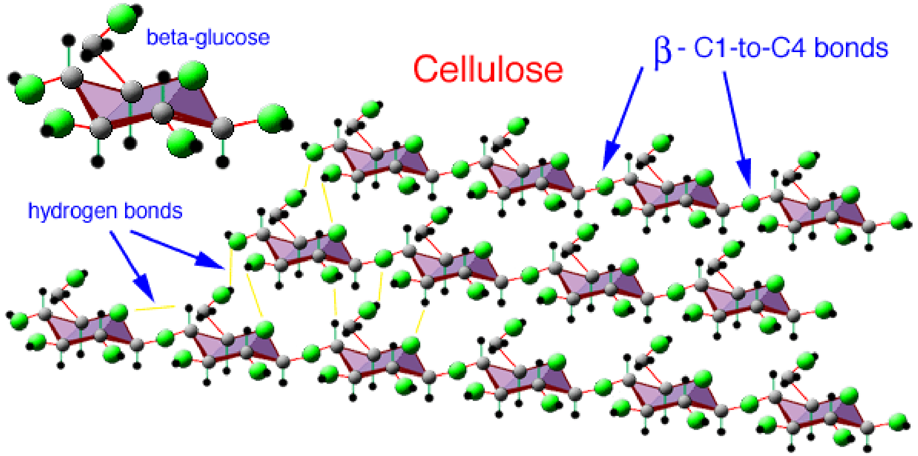
DOM pool

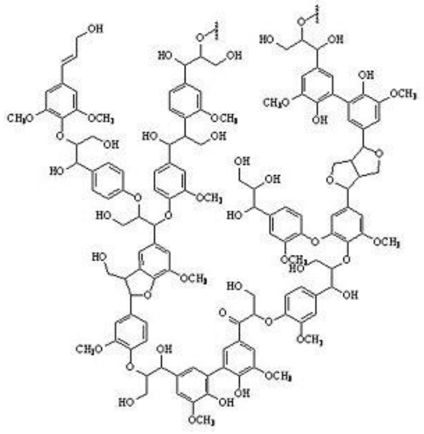
Humic substances (majority of the DOC)

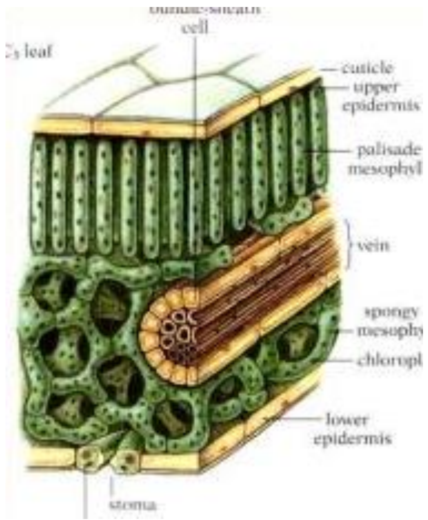
The formation of humic substances occurs during the degradation of aquatic and terrestrial plant material (celluloses, hemicelluloses, and lignin) by fungi and bacteria.

Humic substances in soils and sediments can be divided into three main fractions:
humic acids, fulvic acids, humin

Generally highly abundant in freshwaters, colored (brown, yellow) and conferring color to the water



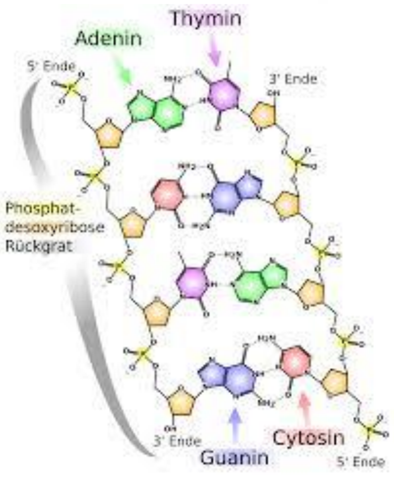


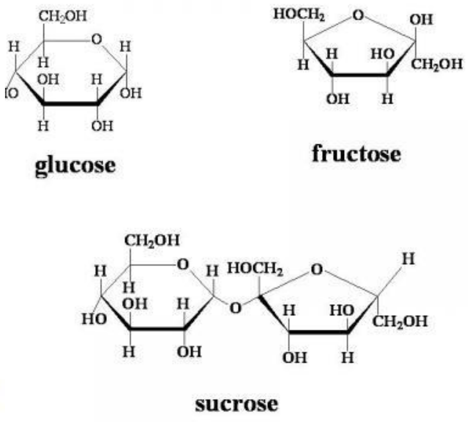


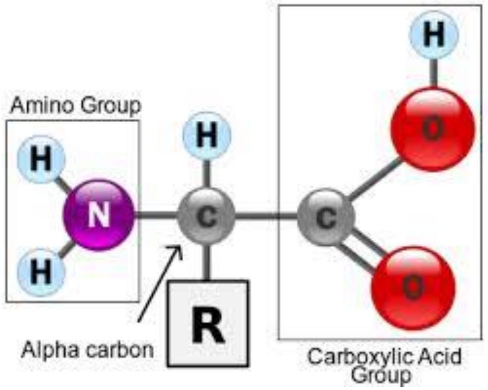
DOM Pool

Non-humic substances

Carbohydrates
Proteins
Peptides
Amino acids
Lipids
Waxes
Pigments...







- Biomolecules that also contain N and P
- Low concentrations in freshwaters
- High bioavailability to the microbial metabolism
- High turnover
- Important to biogeochemical cycling

nature
COMMUNICATIONS

ARTICLE

Received 20 Dec 2013 | Accepted 4 Apr 2014 | Published 2 May 2014 DOI: 10.1038/ncomms4804

Chemodiversity of dissolved organic matter in lakes driven by climate and hydrology

Anne M. Kellerman[1], Thorsten Dittmar[2], Dolly N. Kothawala[1] & Lars J. Tranvik[1]

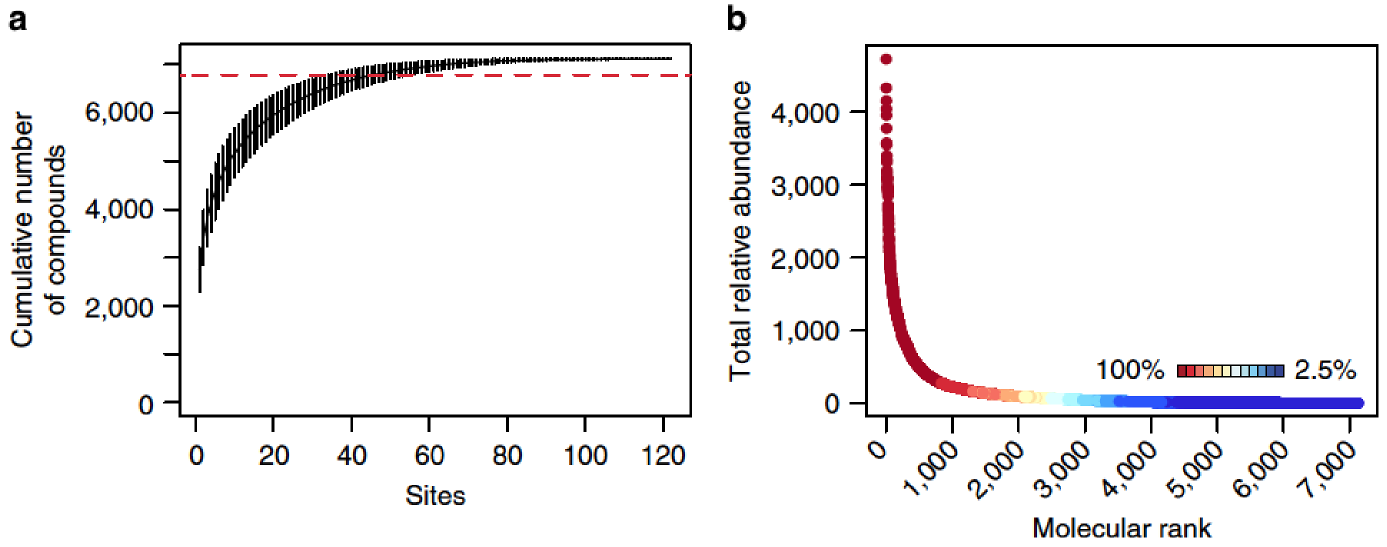
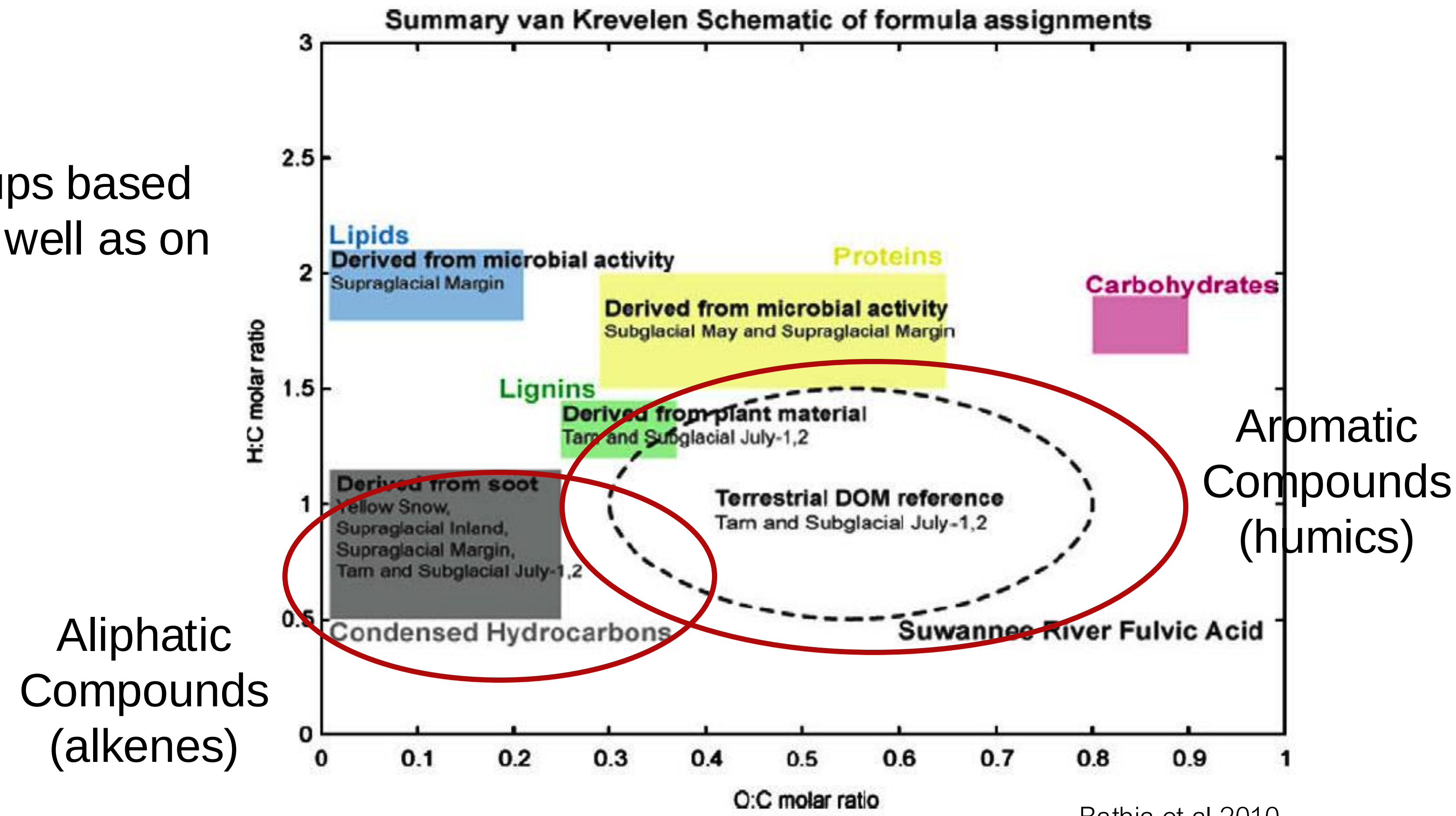


Figure 1 | Molecular distributions of FT-ICR-MS detected compounds across Swedish lakes. (**a**) Number of unique molecules with each added lake. Confidence intervals are calculated over 1,000 permutations. The red dotted line indicates 95% of compounds. (**b**) Rank abundance of the compounds across all lakes shows that the compounds with the highest total relative intensity are most ubiquitous. Molecular compounds are colour coded by the percentage of samples in which they occurred.

- Thousands of DOM molecules contained within the water of streams, rivers and lakes
- Distribution skewed towards relatively few abundant molecules and numerous non-abundant molecules

Van Krevelen diagram

Separating molecular groups based on O:C and H:C ratios, as well as on N and P



Bathia et al 2010

nature COMMUNICATIONS

ARTICLE

Received 20 Dec 2013 | Accepted 4 Apr 2014 | Published 2 May 2014

DOI: 10.1038/ncomms4804

Chemodiversity of dissolved organic matter in lakes driven by climate and hydrology

Anne M. Kellerman[1], Thorsten Dittmar[2], Dolly N. Kothawala[1] & Lars J. Tranvik[1]

Precipitation, hydrological residence time, annual temperature and chemodiversity as drivers of molecular-level patters DOM composition across Swedish lakes

Shown are chemical groups assigned to combustion derived polycyclic aromates, vascular plant-derived polyphenols, unsaturated phenolic compounds and aliphats

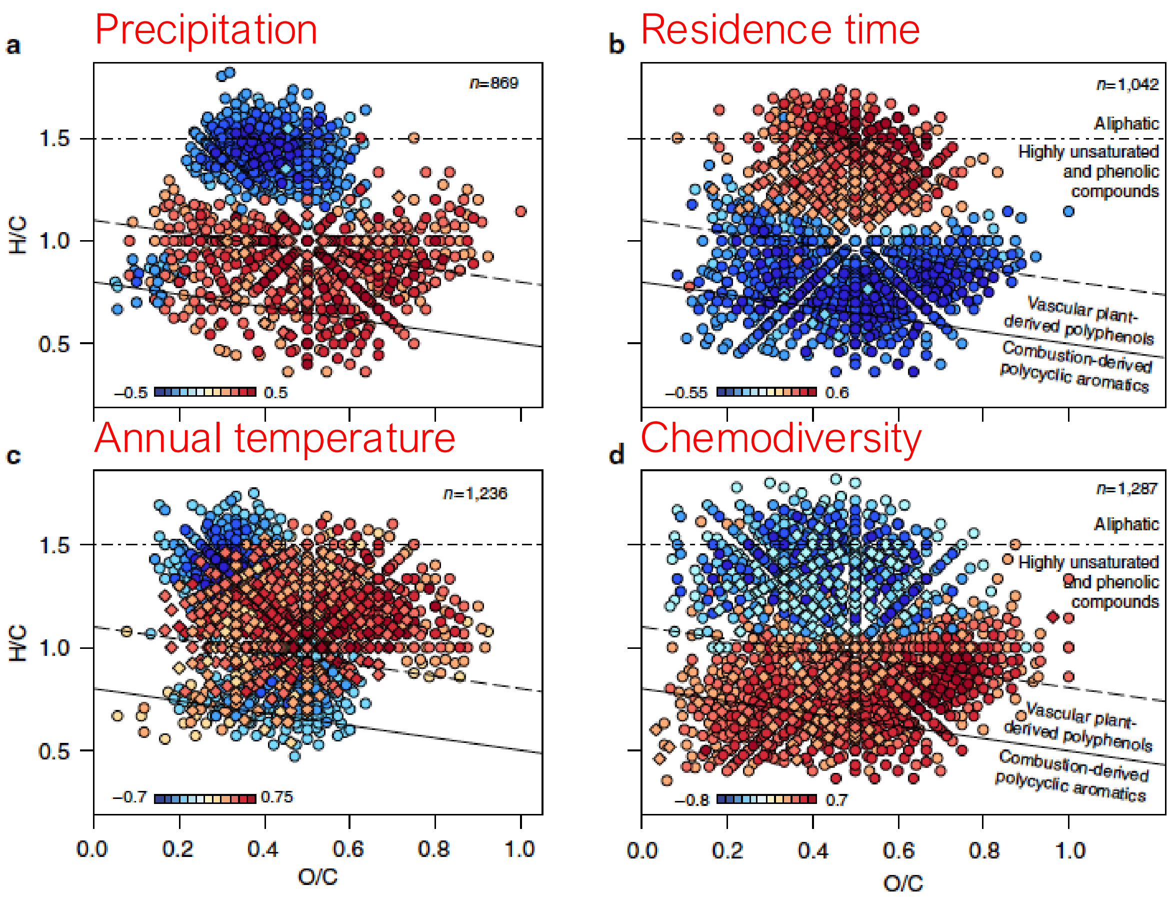


Figure 3 | Molecular-level DOM patterns across 120 Swedish boreal lakes. Significant Spearman rank correlation coefficients (*P*-value <0.02674) of individual molecules with (**a**) mean annual precipitation, (**b**) water residence time, (**c**) mean annual temperature and (**d**) the chemodiversity index. The colour scale indicates Spearman correlations between the intensity of individual molecules and mean annual precipitation, water residence time, mean annual temperature and chemodiversity index (red, positive; blue, negative). Circles indicate compounds without N and diamonds indicate N-containing compounds. Compound groups include combustion-derived polycyclic aromatics (aromaticity index[37] (AI) > 0.66), vascular plant-derived polyphenols (0.66 ≥ AI > 0.50), highly unsaturated and phenolic compounds (AI ≤ 0.50 and H/C < 1.5), and aliphatic compounds (2.0 ≥ H/C ≥ 1.5). Compound category labels for delineation in panels (**b**) and (**d**) also apply to delineated regions in (**a**) and (**c**). Lines separating compound categories on van Krevelen diagrams are for visualization only and exact categorization may slightly differ. The number of positive and negative significant correlations can be found in Supplementary Table 2.

EPFL

Wildfires and black carbon in streams and rivers

Global Charcoal Mobilization from Soils via Dissolution and Riverine Transport to the Oceans

Rudolf Jaffé,[1]*† Yan Ding,[1] Jutta Niggemann,[2] Anssi V. Vähätalo,[3,4] Aron Stubbins,[5] Robert G. M. Spencer,[6] John Campbell,[7] Thorsten Dittmar[2]*†

www.sciencemag.org SCIENCE VOL 340 19 APRIL 2013

- The incomplete combustion of organic molecules produces a chemically diverse suite of pyrogenic residues termed black carbon.
- The significance of black carbon cycling on land has long been recognized, and the recognition of dissolved BC as a major component of the aquatic carbon cycle is developing rapidly.

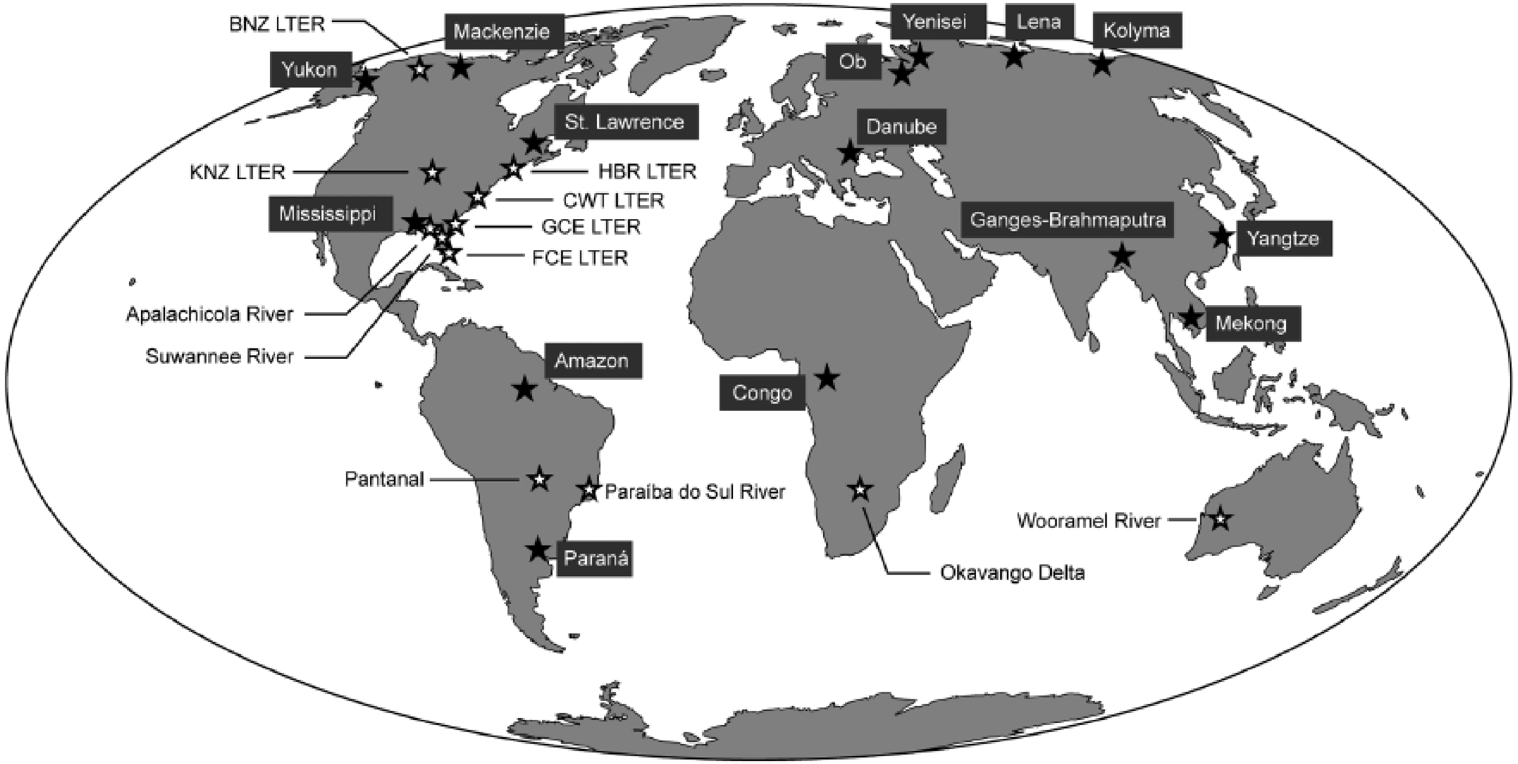


Fig. 1. Map of global freshwater DBC sampling sites. Black stars indicate major world rivers, and white stars indicate all other sites, including minor to intermediate rivers and wetland-associated streams, including Long-Term Ecological Research (LTER) sites. BNZ, Bonanza Creek; KNZ, Konza Prairie; HBR, Hubbard Brook; CWT, Coweeta; GCE, Georgia Coastal Ecosystems; FCE, Florida Coast Everglades.

Wildfires and black carbon in streams and rivers

Global Charcoal Mobilization from Soils via Dissolution and Riverine Transport to the Oceans

Rudolf Jaffé,[1*†] Yan Ding,[1] Jutta Niggemann,[2] Anssi V. Vähätalo,[3,4] Aron Stubbins,[5] Robert G. M. Spencer,[6] John Campbell,[7] Thorsten Dittmar[2*†]

www.sciencemag.org SCIENCE VOL 340 19 APRIL 2013

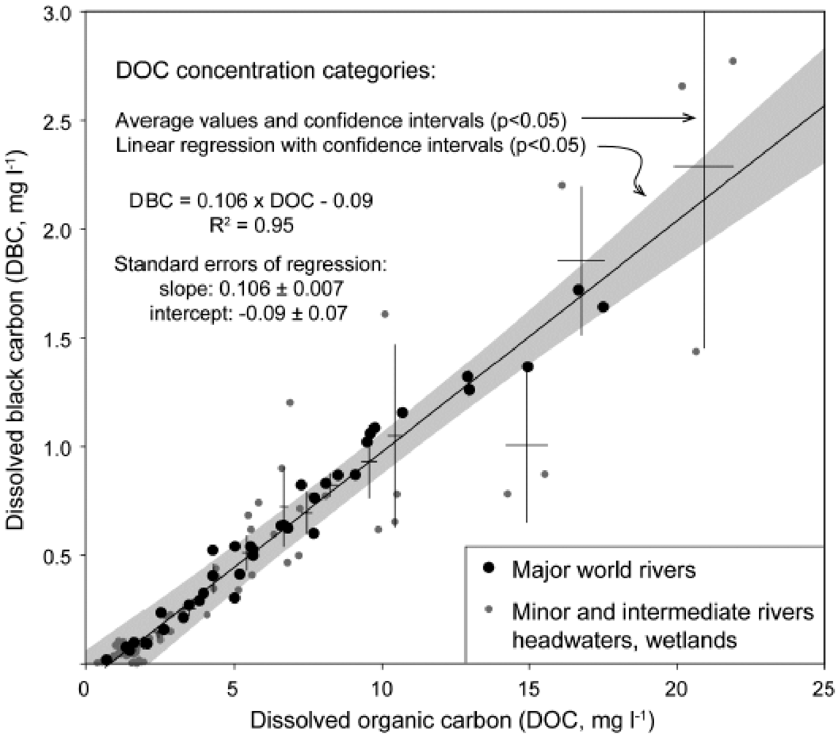


Fig. 2. DBC versus DOC concentrations of global rivers. The regression parameters are for the average values of 15 DOC concentration groups (crosses). Raw data regression yields the same slope and intercept, but the confidence intervals are smaller because of the larger number of samples.

- Black carbon: ca. 26.5±1.8 x 10^6 tons per year
- ca. 10% of DOC concentration
- Interesting because black carbon was long thought to be insoluble
- Highly oxidized, hence potentially of little relevance to the carbon metabolism

EPFL

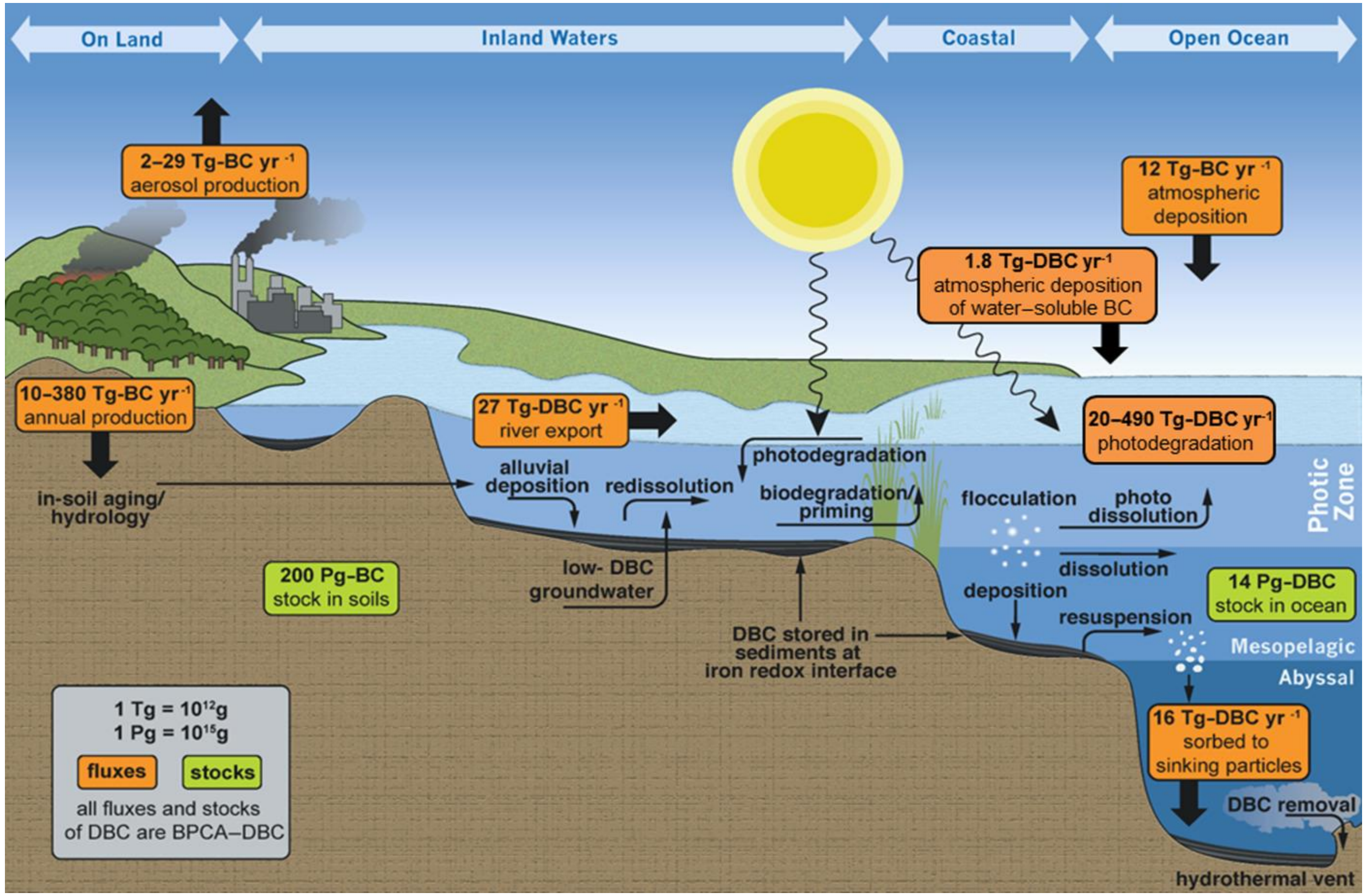
Wildfires and black carbon in streams and rivers

LIMNOLOGY AND OCEANOGRAPHY
LETTERS
ASLO
Open Access

Special Issue-Current Evidence | Open Access

Dissolved black carbon in aquatic ecosystems

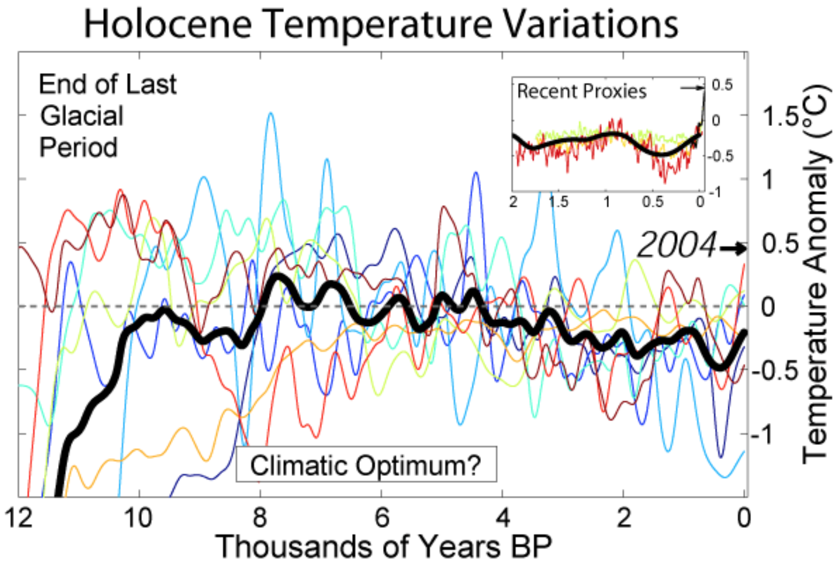
Sasha Wagner, Rudolf Jaffé, Aron Stubbins



Fate of dissolved black carbon

- Photodegradation by solar radiation
- Biodegradation (low) by microorganisms
- Flocculation and deposition (estuaries)
- Storage in oceans

Mountain glaciers as a component of the carbon cycle



Glacier ice includes ancient DOM (ca. 4000 to 8000 years BP, terrestrial organic carbon from climate optimum)

Upon release, this DOC is highly available to the downstream metabolism

Potentially contributing to CO_2 outgassing from streams, and sustaining their food webs

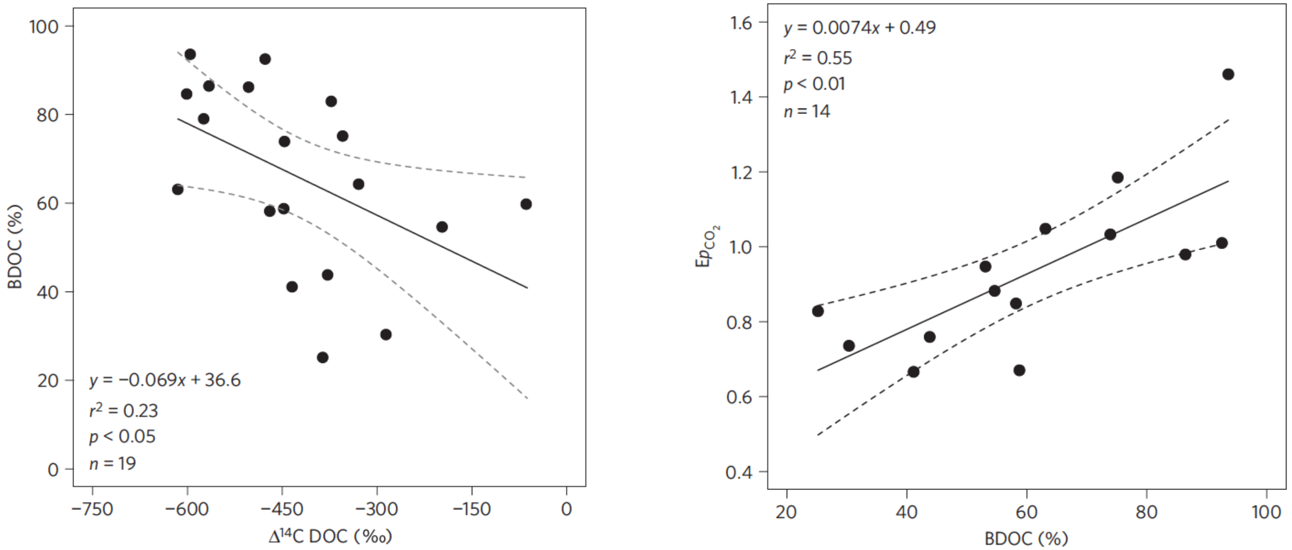


Figure 4 | Ep_{CO_2} in the glacier-fed streams increased with glacier DOC bioavailability. A multiple regression model (adjusted $R^2 = 0.47$, $p < 0.05$, $n = 13$) showed that BDOC (beta = 0.78, $p < 0.01$) rather than stream slope (beta = −0.01, $p = 0.97$) explained the observed variation in Ep_{CO_2}, although the negative regression coefficient for the slope agrees with a downstream pressure effect. Ep_{CO_2} values greater (respectively, less) than 1 denote supersaturation (respectively, undersaturation) of the streamwater p_{CO_2} relative to the atmospheric p_{CO_2}.

Impacts of DOC (1)

Light and production in lakes

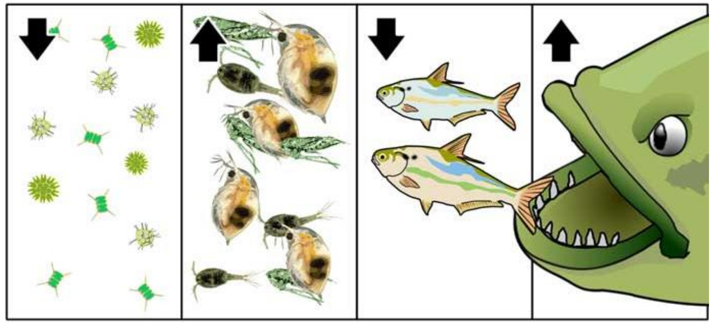
Brown-water lake

nature Vol 460|23 July 2009|doi:10.1038/nature08179

LETTERS

Light limitation of nutrient-poor lake ecosystems

Jan Karlsson[1], Pär Byström[2], Jenny Ask[2], Per Ask[2], Lennart Persson[2] & Mats Jansson[2]



Common wisdom

- Nutrients stimulate primary production (i.e., phytoplankton)
- Primary production stimulates zooplankton production
- Increases fish biomass and ‘catch per unit effort’ (CPUE)

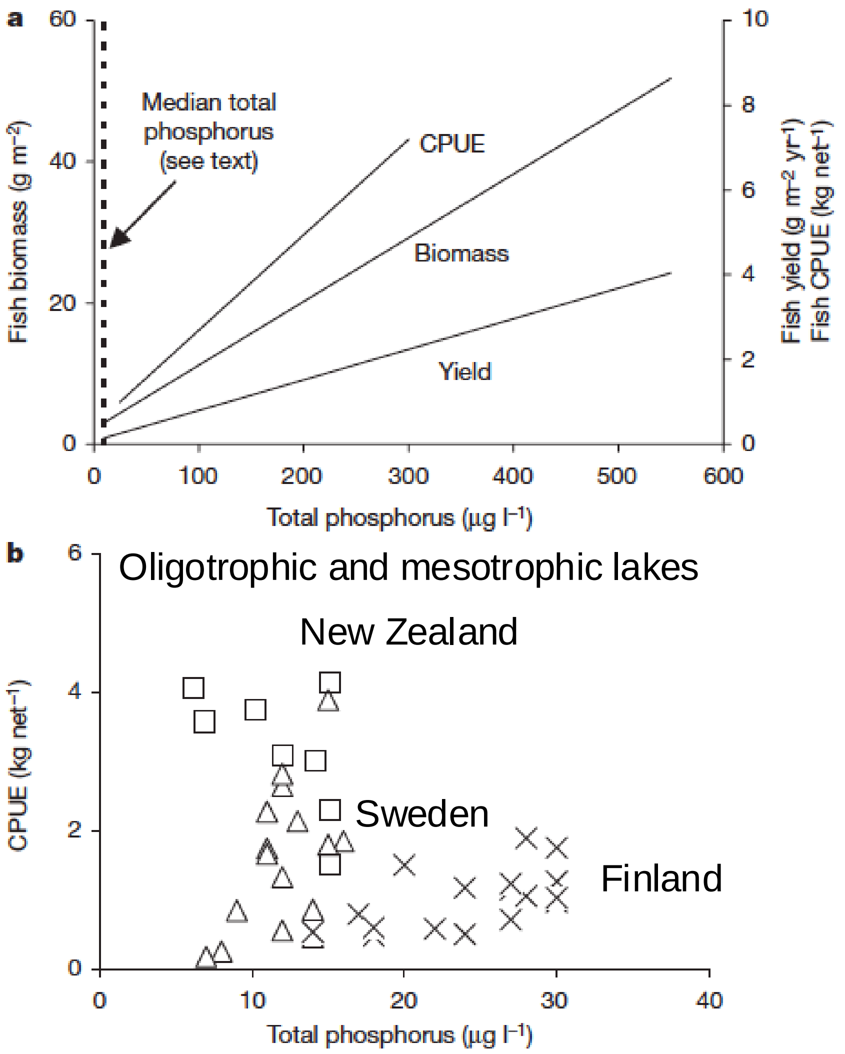


Figure 1 | Fish biomass and yield in temperate lakes. a, Published relationships ($r^2 = 0.75$–0.84) between fish biomass[9], yield[9] and catch per unit effort (CPUE)[10]. The vertical dashed line shows the average (12 $\mu g\,l^{-1}$) of reported median total phosphorus concentration in Norway (2 $\mu g\,l^{-1}$, $n = 1{,}006$), Finland (13 $\mu g\,l^{-1}$, $n = 873$), Sweden (8 $\mu g\,l^{-1}$, $n = 3{,}025$) and Wisconsin (United States) (12 $\mu g\,l^{-1}$, $n = 168$). **b**, Fish CPUE in oligotrophic and mesotrophic lakes (0–30 $\mu g\,l^{-1}$) from Finland (crosses), Sweden (triangles) and New Zealand (squares) as a function of total phosphorus. See Supplementary Tables 3 and 4.

nature Vol 460|23 July 2009|doi:10.1038/nature08179

LETTERS

Light limitation of nutrient-poor lake ecosystems

Jan Karlsson[1], Pär Byström[2], Jenny Ask[2], Per Ask[2], Lennart Persson[2] & Mats Jansson[2]

- Lake ecosystem production along a nutrient (P) gradient
- The whole-lake primary production, basal production by algae and bacteria and production of top consumers was negatively related to total phosphorus in the lake water.
- Therefore, factors other than nutrient supply controlled the biomass production in these lakes.

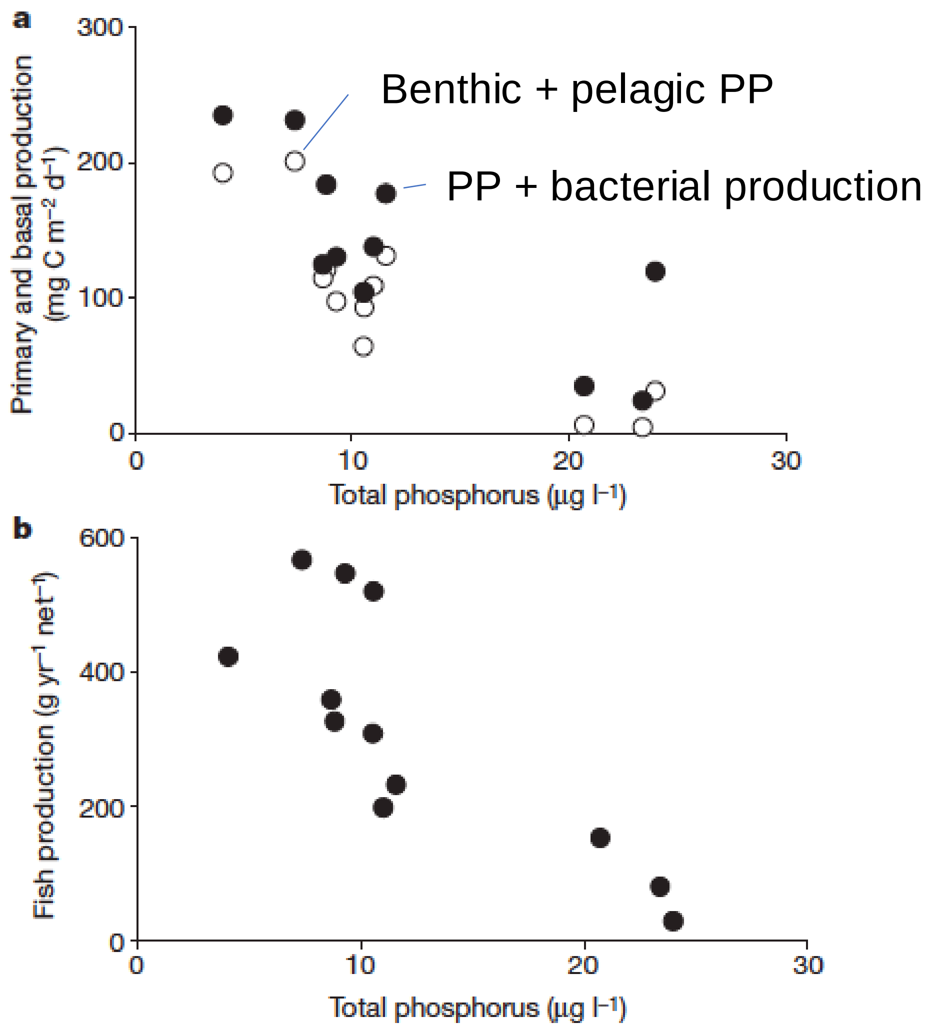


Figure 2 | Production as a function of nutrients. a, Whole-lake (benthic+pelagic) primary production (open circles) and basal production (filled circles, primary production plus bacterial production based on allochthonous organic carbon) as a function of total phosphorus. **b**, Whole-lake fish production as a function of total phosphorus. Solid line, error bars.

nature Vol 460|23 July 2009|doi:10.1038/nature08179

LETTERS

Light limitation of nutrient-poor lake ecosystems

Jan Karlsson[1], Pär Byström[2], Jenny Ask[2], Per Ask[2], Lennart Persson[2] & Mats Jansson[2]

- By comparing small unproductive lakes along a water colour gradient, it was shown that coloured terrestrial organic matter controls the key process for new biomass synthesis (the benthic primary production) through its effects on light attenuation.

- Light (*I*, PAR across the lake volume) is an unexpected driver of fish production in boreal lakes

- Colored DOM (humics) attenuates light, thereby reducing primary production and hence fish production

- Catchment export of coloured organic matter is sensitive to short-term natural variability and long-term, large-scale changes, driven by climate and different anthropogenic influences

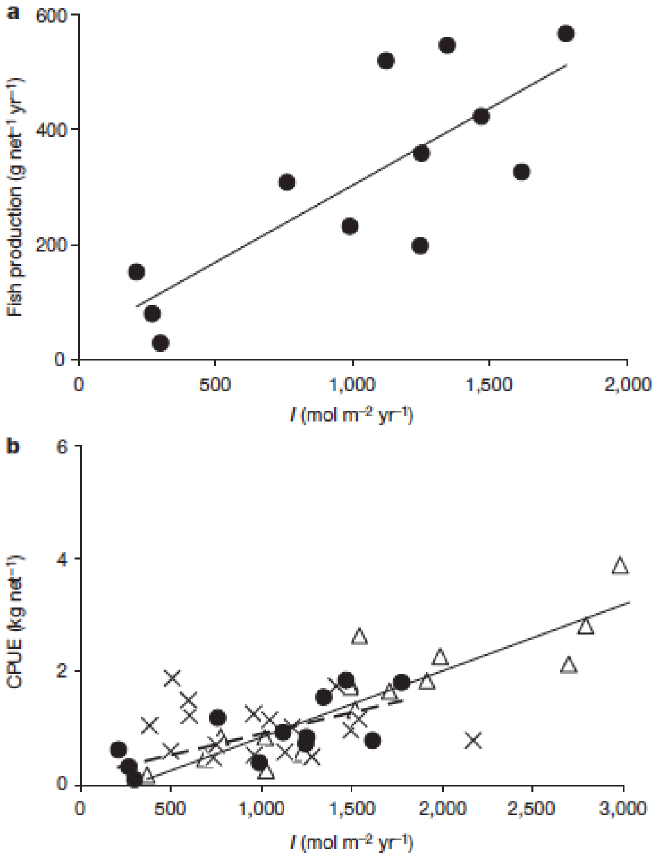


Figure 4 | Fish production and biomass as a function of light. a, Fish production as a function of the annual light climate (*I*, representing the mean PAR in the whole-lake volume during the ice-free period) in the 12 lakes ($r^2 = 0.63$, $P = 0.002$). **b,** Fish CPUE as a function of *I* in the 12 study lakes (circles, $r^2 = 0.50$, $P = 0.010$, dashed line) and in 33 additional lakes ($r^2 = 0.50$, $P < 0.001$, solid line) from Finland (crosses) and Sweden (triangles). There was no difference ($P = 0.76$) in the slope between the two regression lines. For references see Supplementary Table 4.

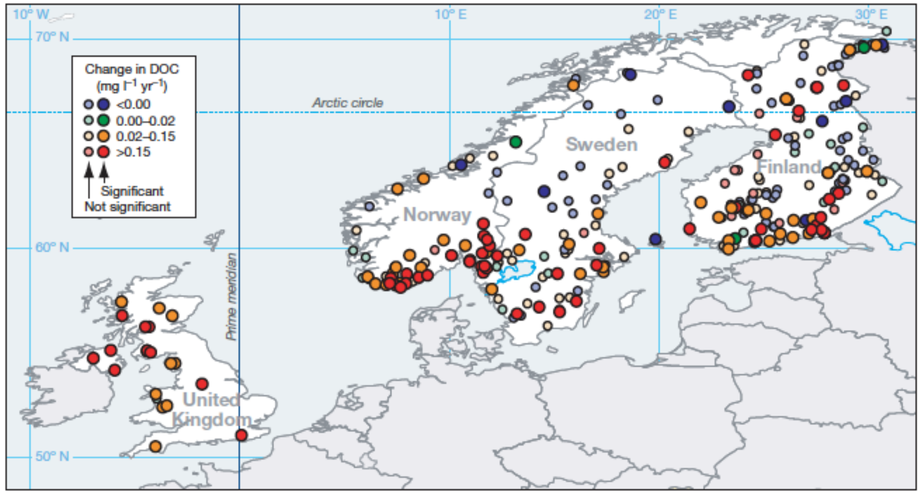
EPFL

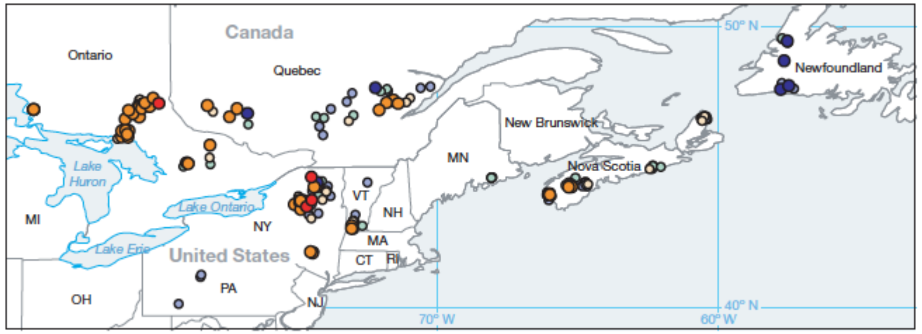
Vol 450|22 November 2007|doi:10.1038/nature06316 nature

LETTERS

Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry

Donald T. Monteith[1]*, John L. Stoddard[2]*, Christopher D. Evans[3], Heleen A. de Wit[4], Martin Forsius[5], Tore Høgåsen[4], Anders Wilander[6], Brit Lisa Skjelkvåle[4], Dean S. Jeffries[7], Jussi Vuorenmaa[5], Bill Keller[8], Jiri Kopácek[9] & Josef Vesely[10]‡





Browning of streams and rivers

- Concentrations of dissolved organic carbon in inland waters are increasing
- Conferring brown color to the water
- Shifts in light regime
- Potential deterioration of drinking water

SCIENTIFIC REPORTS

OPEN

From greening to browning: Catchment vegetation development and reduced S-deposition promote organic carbon load on decadal time scales in Nordic lakes

Received: 10 February 2016
Accepted: 27 July 2016
Published: 24 August 2016

Anders G. Finstad[1,2], Tom Andersen[3], Søren Larsen[3], Koji Tominaga[3], Stefan Blumentrath[2], Heleen A. de Wit[4], Hans Tømmervik[2] & Dag Olav Hessen[3]

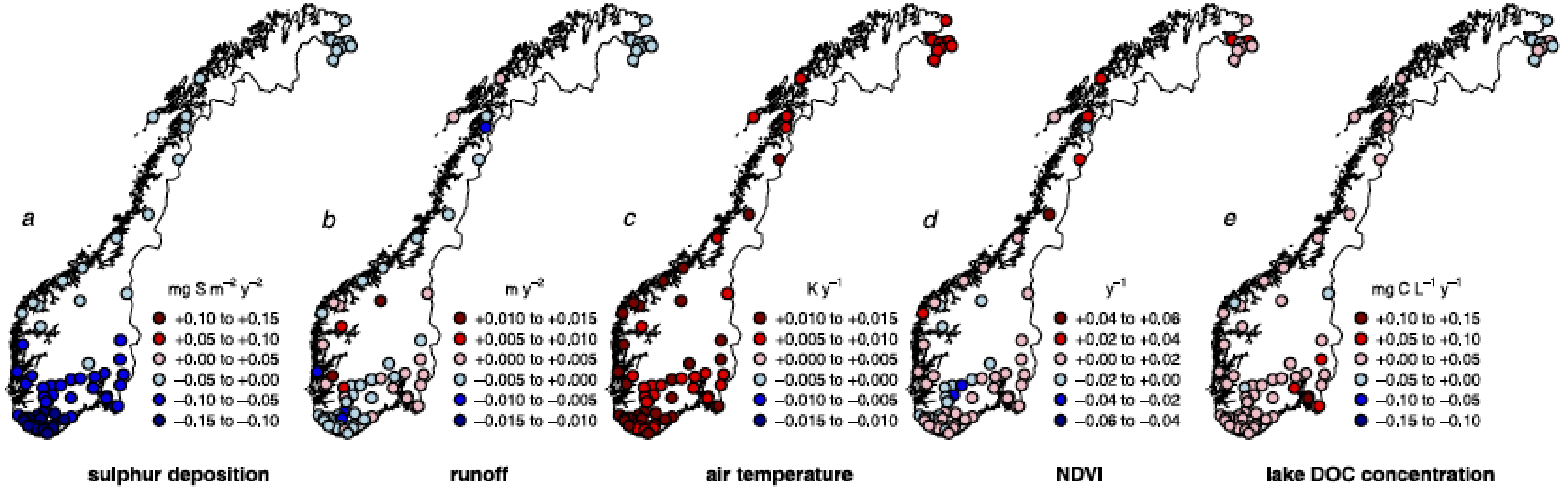


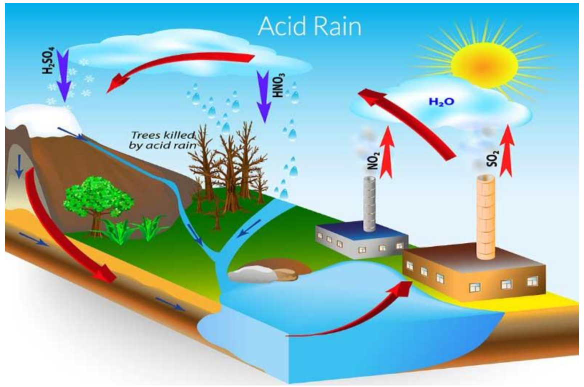
Figure 1. Lake specific trends in total atmospheric S deposition, runoff, surface air temperature, NDVI and lake DOC concentration. Estimated Theil-Sen's slope values (y^{-1}) based on site-specific Regional Kendall Tests for (**a**) catchment total atmospheric S deposition, (**b**) runoff, (**c**) surface air temperature, (**d**) NDVI and (**e**) lake DOC concentration during the study period (1986–2011). Positive temporal trends are depicted using shades of red, whereas negative temporal trends are depicted using shades of blue. A stronger shade in either trend direction denotes a faster trend when compared regionally. The categorization levels were determined using R's *pretty* function on absolute slope values[73]. All S deposition trends where negative, and all temperature trends where positive, 85% of the DOC trends and 76% of the NDVI trends were positive, and 65% of the catchments displayed negative runoff trends. Overall, the mean regional trends for the whole study area for all five variables were significant (positive for NDVI, temperature and DOC, negative for S deposition and runoff, Regional Kendall Tests with lakeID as block, $n = 70$, all with $p < 0.017$). Figure created in R v. 3.2.1 (URL http://www.R-project.org/)[61] using the libraries raster[60] and sp[74].

What causes browning?

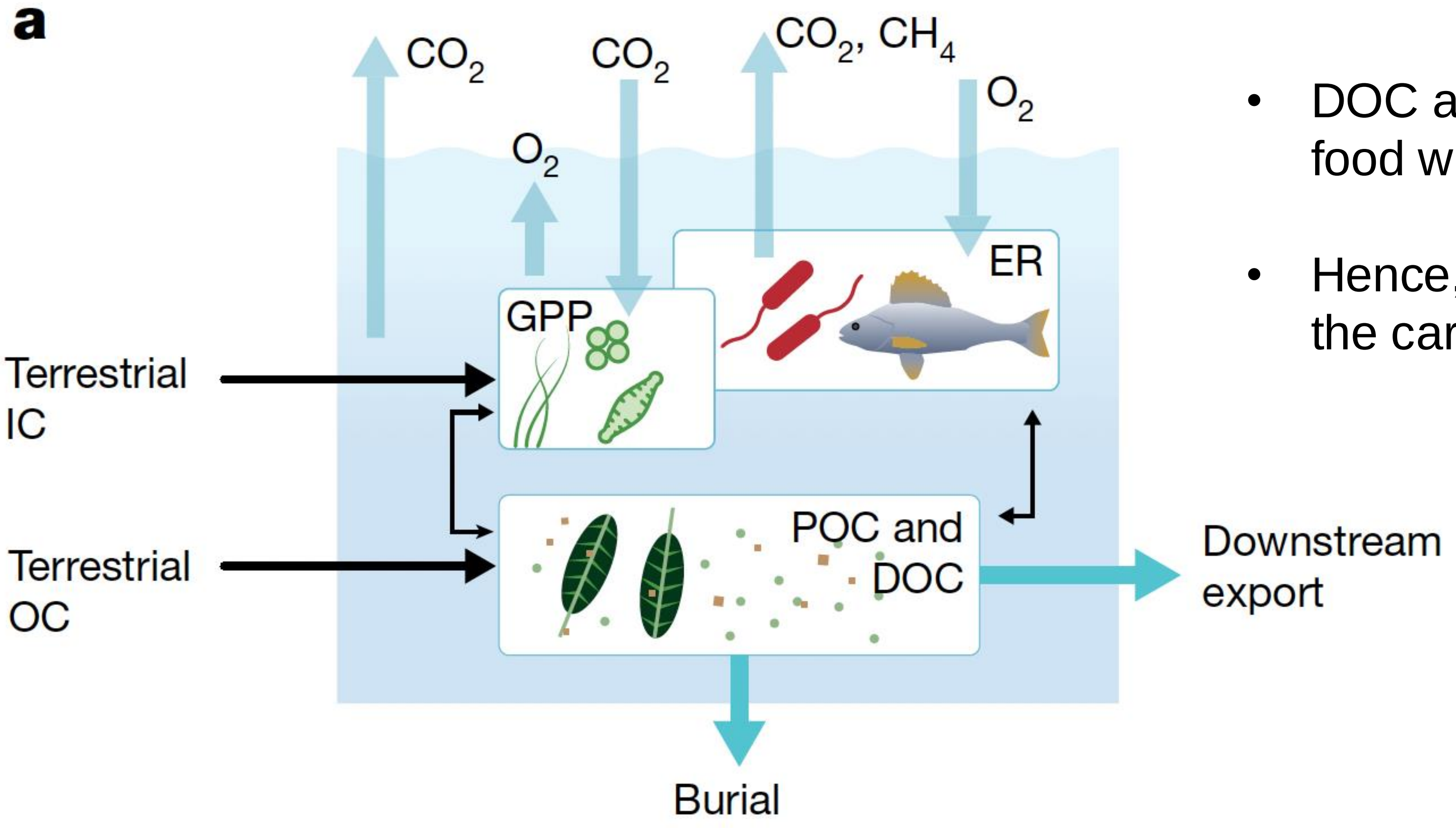
Acid deposition (e.g., sulfur) reduced over the last decades

Less acid retention capacity of the soils

Along with heavy precipitations, phenolic DOC constituents are washed out from soils



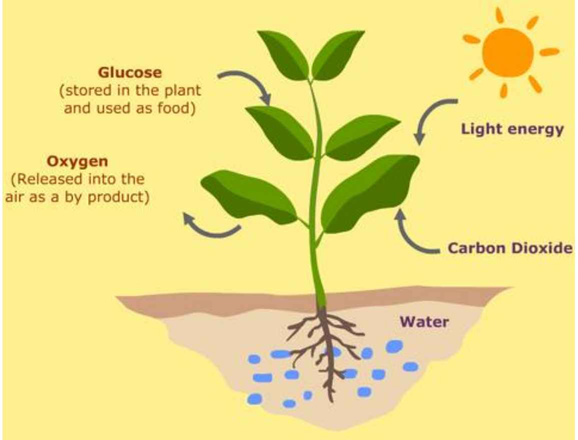
Impacts of DOC (2)



- DOC and POC are central to the aquatic food web and ecosystem metabolism
- Hence, DOC is a major intermediary to the carbon cycle and greenhouse fluxes

DOC (or DOM): Energy basis for microbial heterotrophs

Photosynthesis (CHO)

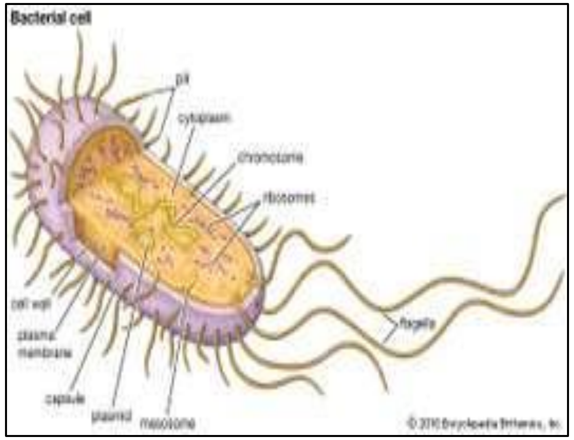


CO_2 assimilation

DOC →

← CO_2

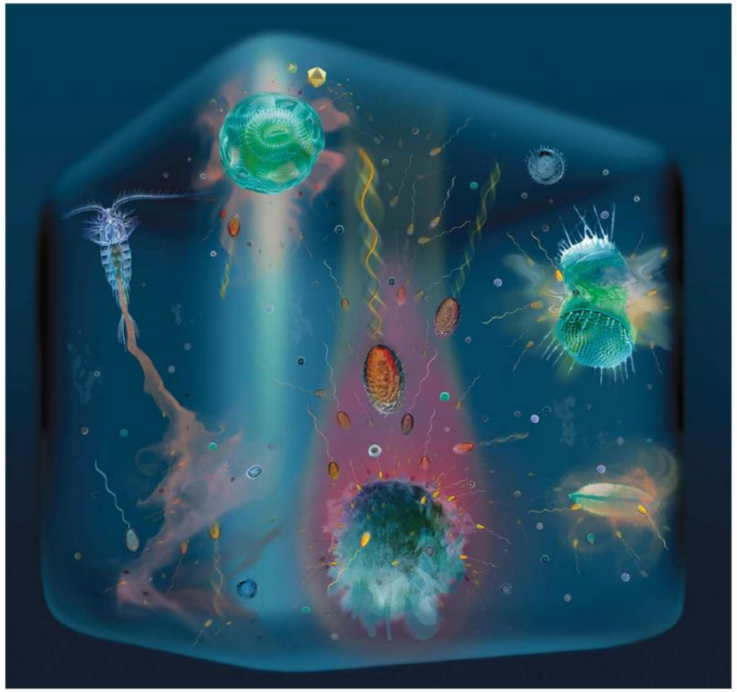
Respiration
DOC metabolism



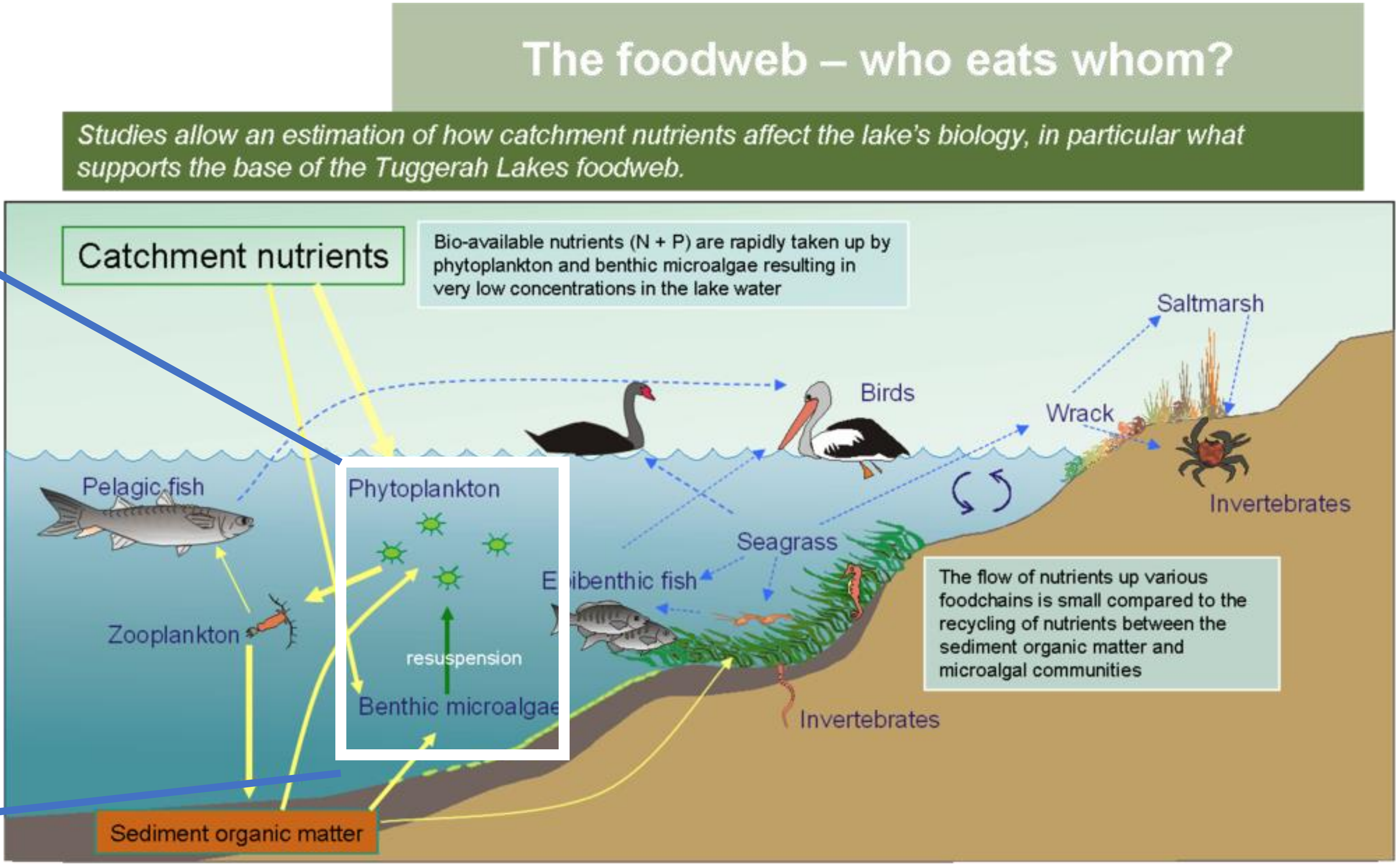
CO_2 and CH_4 production

The aquatic food web and microbial loop

DOM as the basis of the aquatic food web



Marine Microbes See a Sea of Gradients
Roman Stocker
Science **338**, 628 (2012);
DOI: 10.1126/science.1208929



The microbial loop

- Re-cycling of DOM withing the microbial compartment of the aquatic food web
- Less or delayed transfer to higher trophic levels (i.e., traditional food web)
- Spontaneous aggregation of DOC molecules into larger particular entities allows bypassing the microbial loop

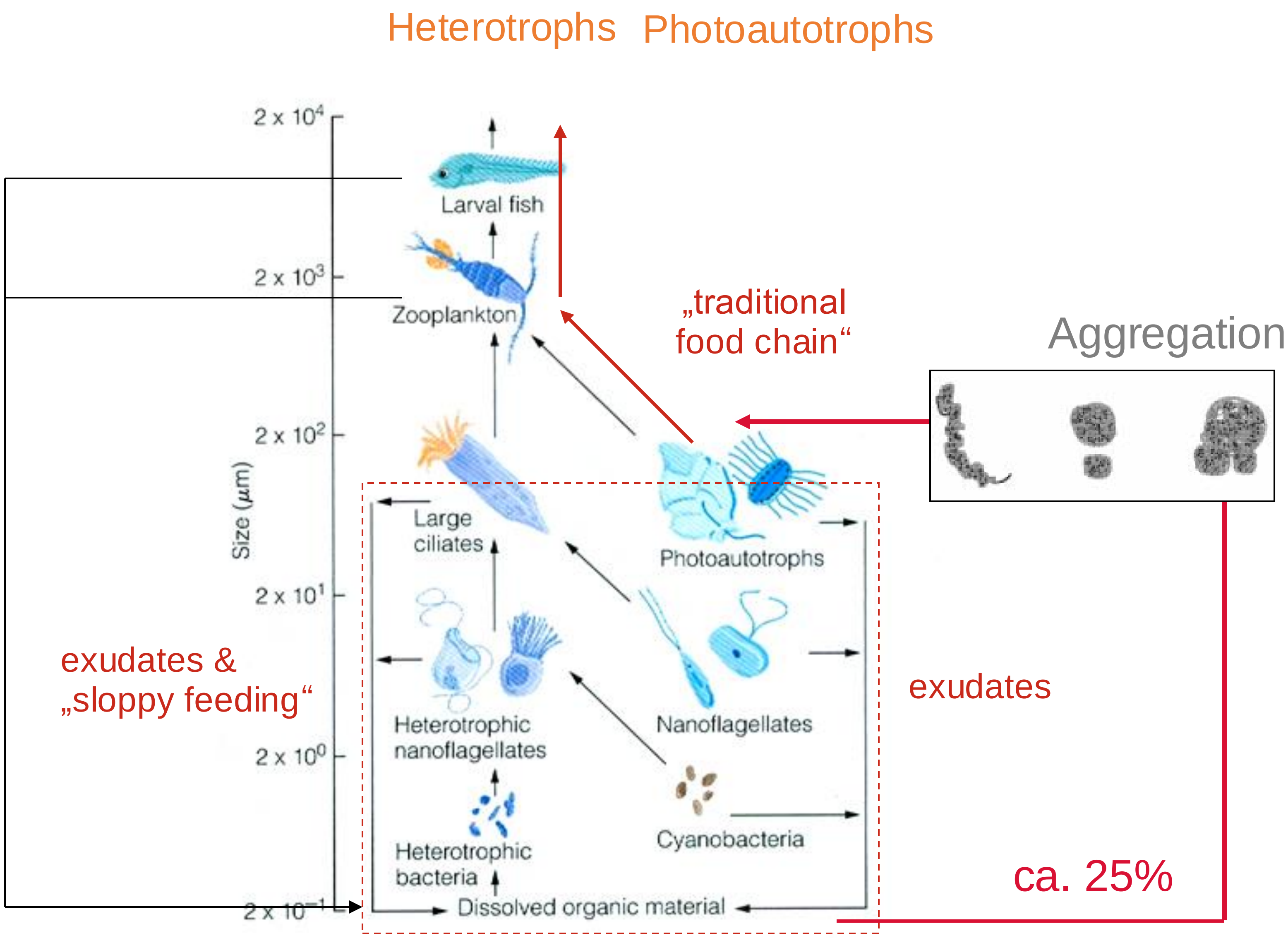


Figure 24.20 | A representation of the *microbial loop* and its relationship to the plankton food web. Autotrophs are on the right side of the diagram, and heterotrophs are on the left.

The microbial loop

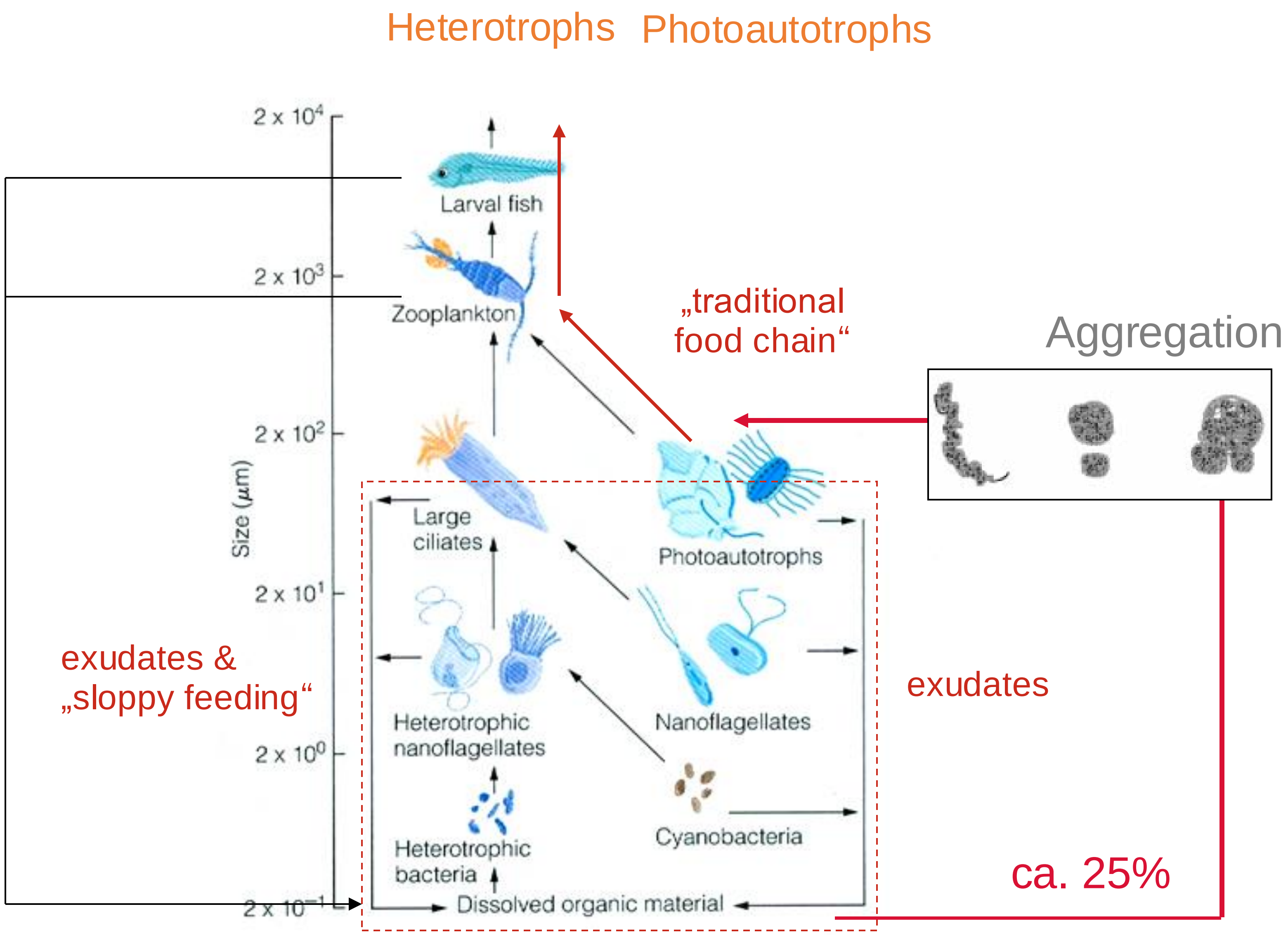


Figure 24.20 | A representation of the *microbial loop* and its relationship to the plankton food web. Autotrophs are on the right side of the diagram, and heterotrophs are on the left.

Microorganisms, also including unicellular grazers and algae, are the major engines of DOC dynamics in aquatic ecosystems

Hence of carbon cycling in aquatic ecosystems

The microbial loop

Size of the pores in the bacterial membranes limits the size (molecular weight) of the DOC molecules that the cell can take up

Extracellular enzymes cleave the larger DOC molecules into smaller entities

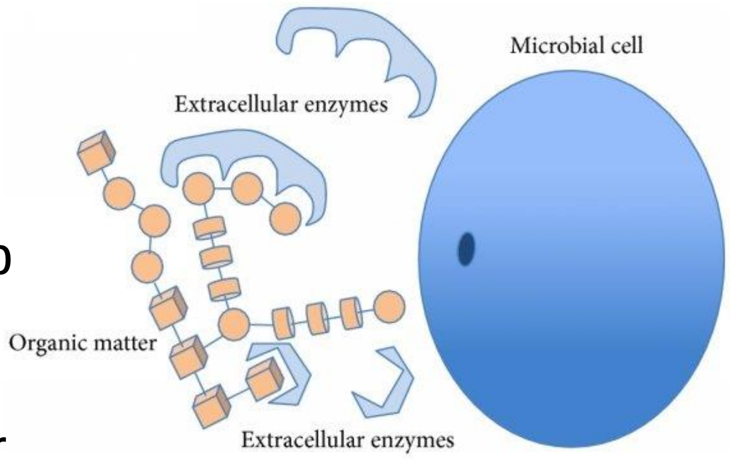
Bacteria are highly abundant and very small, hence a large surface area by cell volume, translating into a potentially large mass flux per liter water or square meter surface area (see hyporheic ‘bioreactor’)

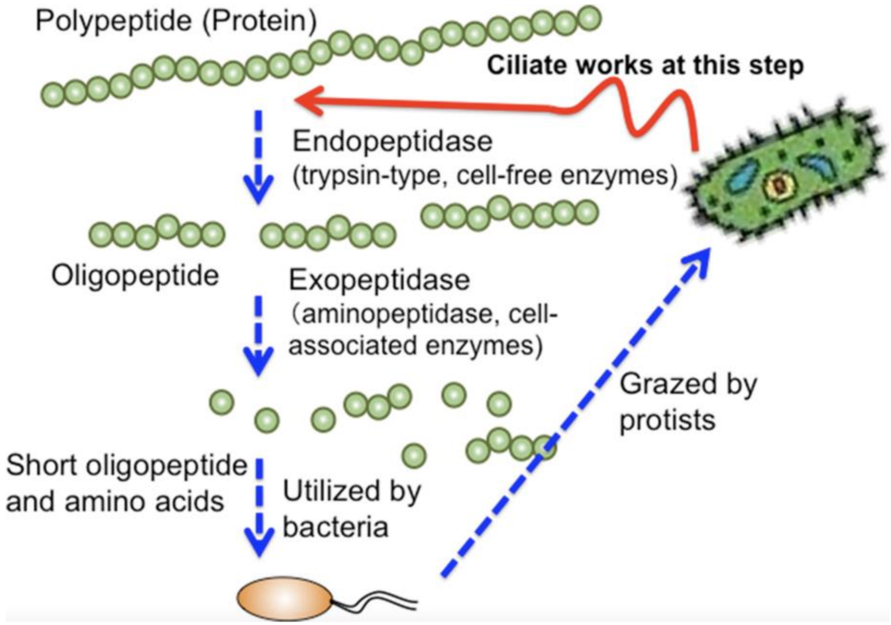
Hindawi Publishing Corporation
Advances in Oceanography
Volume 2014, Article ID 706082, 12 pages
http://dx.doi.org/10.1155/2014/706082

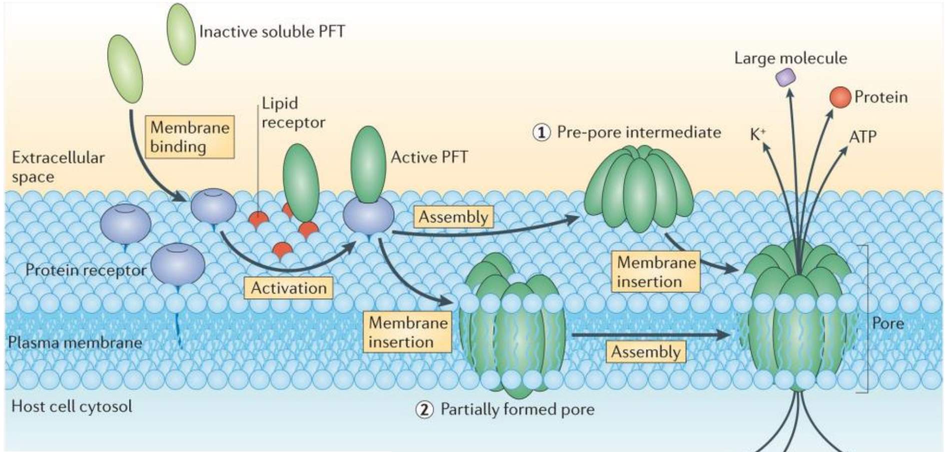
Review Article

Patterns of Microbially Driven Carbon Cycling in the Ocean: Links between Extracellular Enzymes and Microbial Communities

Carol Arnosti







Pore-forming toxins: ancient, but never really out of fashion

Matteo Dal Peraro[1] and F. Gisou van der Goot[2]

Nature Reviews | Microbiology

EPFL

Degradation of organic matter



- Chemical composition
- Temperature
- Redox
- pH
- Invertebrates (shredders, see RCC)
- UV radiation (photodegradation)
- Physical decomposition

nature Vol 466|22 July 2010|doi:10.1038/nature09186

LETTERS

Temperature-controlled organic carbon mineralization in lake sediments

Cristian Gudasz[1], David Bastviken[2], Kristin Steger[1], Katrin Premke[1], Sebastian Sobek[1] & Lars J. Tranvik[1]

The respiratory breakdown of organic carbon (OC) stored in lake sediments increases with temperature

More OC will be respired as temperature increases, therefore less OC will be buried and stored in the lake sediments

[See various lakes that have stored substantial amounts of OC related to lake geometry, mixing, terrestrial OC inputs)]

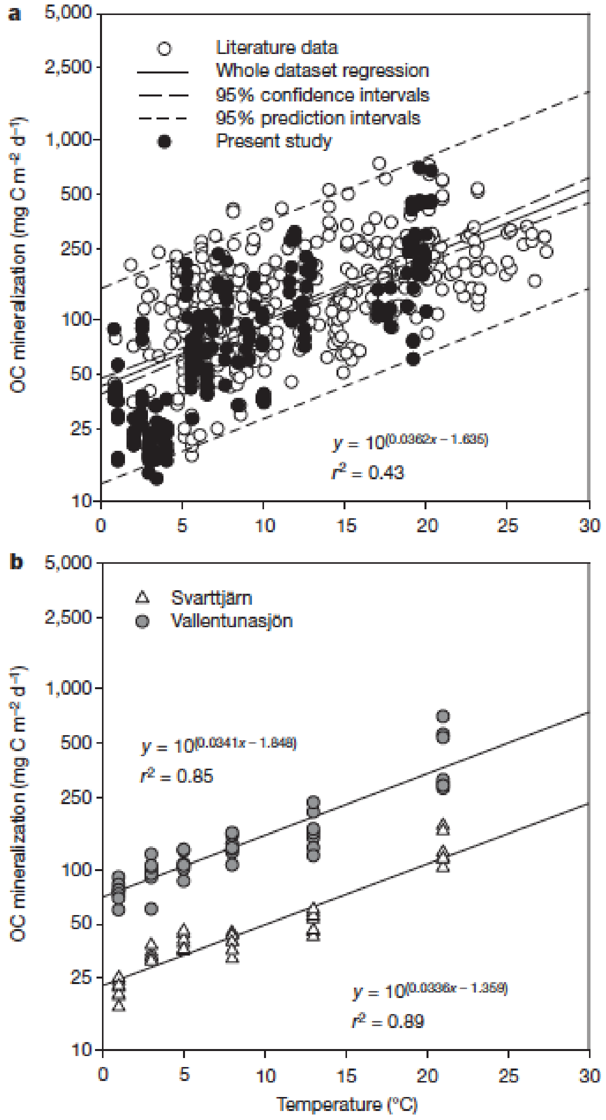


Figure 1 | Temperature-dependent OC mineralization in lake sediments. **a**, The relationship between sediment OC mineralization and temperature in the present study ($r^2 = 0.61$, $P < 0.0001$, $n = 219$), published literature ($r^2 = 0.26$, $P < 0.0001$, $n = 355$) (Supplementary Notes) and the two combined data sets, ($r^2 = 0.43$, $P < 0.0001$, $n = 574$), equation at lower right. **b**, OC mineralization measured under experimental manipulation of temperature in two extreme lakes in terms of the loading of the organic carbon—the humic Svarttjärn, equation at lower right, and the highly eutrophic Vallentunasjön, equation at upper left ($n = 42$ for each lake). The slopes were not statistically different (t-test, $P = 0.87$). The y-axis of the OC mineralization is represented on a log scale.

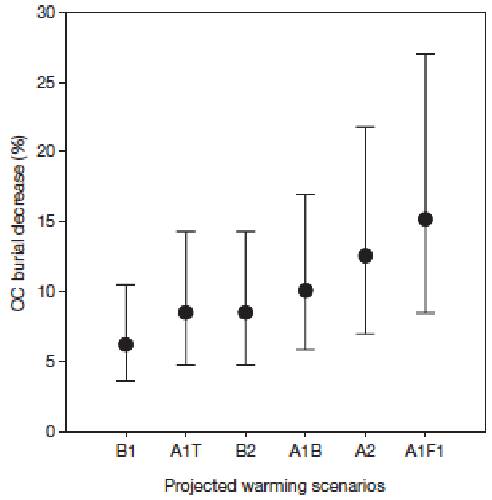


Figure 3 | Organic carbon burial decrease. The predicted percentage decrease in OC burial in lake sediments over the boreal zone under different climate warming scenarios by the end of the twenty-first century[7]: B1, A1T, B2, A1B, A2 and A1F1. Filled circles, decrease in OC burial based on the most likely scenarios for temperature change; vertical bars, response to a likely range of temperatures.

EPFL

nature Vol 466|22 July 2010|doi:10.1038/nature09186

LETTERS

Temperature-controlled organic carbon mineralization in lake sediments

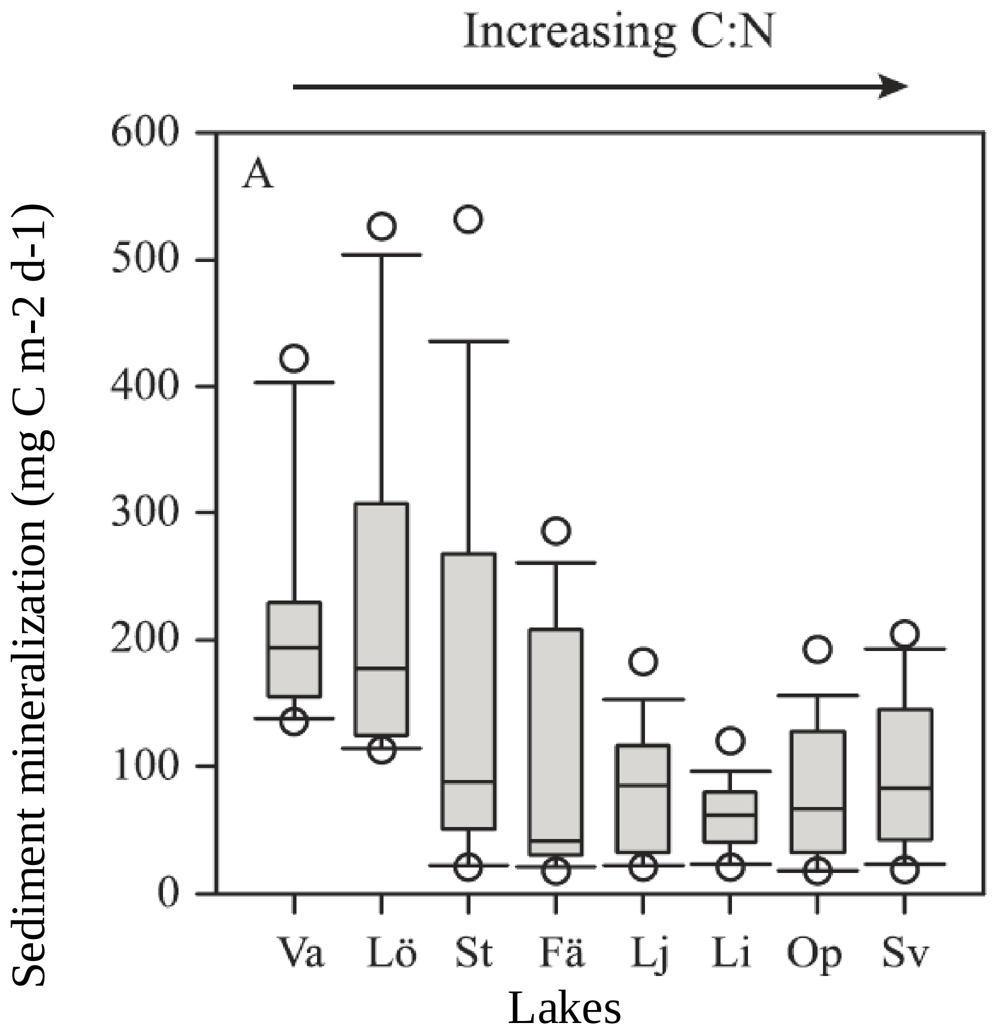
Cristian Gudasz[1], David Bastviken[2], Kristin Steger[1], Katrin Premke[1], Sebastian Sobek[1] & Lars J. Tranvik[1]

C:N = indicator for organic matter quality

Algal material: C:N ~ 6-20
Lignin-rich material: C:N > 20

Stoichiometry of organic matter decomposition

Higher availability of N-containing organic molecules (e.g., for amino acids, proteins)



1142 6 MARCH 2015 • VOL 347 ISSUE 6226 sciencemag.org SCIENCE

Experimental nutrient additions accelerate terrestrial carbon loss from stream ecosystems

Amy D. Rosemond,[1*] Jonathan P. Benstead,[2] Phillip M. Bumpers,[1] Vladislav Gulis,[3]
John S. Kominoski,[1†] David W. P. Manning,[1] Keller Suberkropp,[2] J. Bruce Wallace[1]

- Degradation of leaf litter is a function of soluble reactive phosphorus and nitrogen concentration

- Nutrient limitation and the ecological stoichiometry of degradation, that is N and P are required (e.g., enzymes) to degrade leaf litter

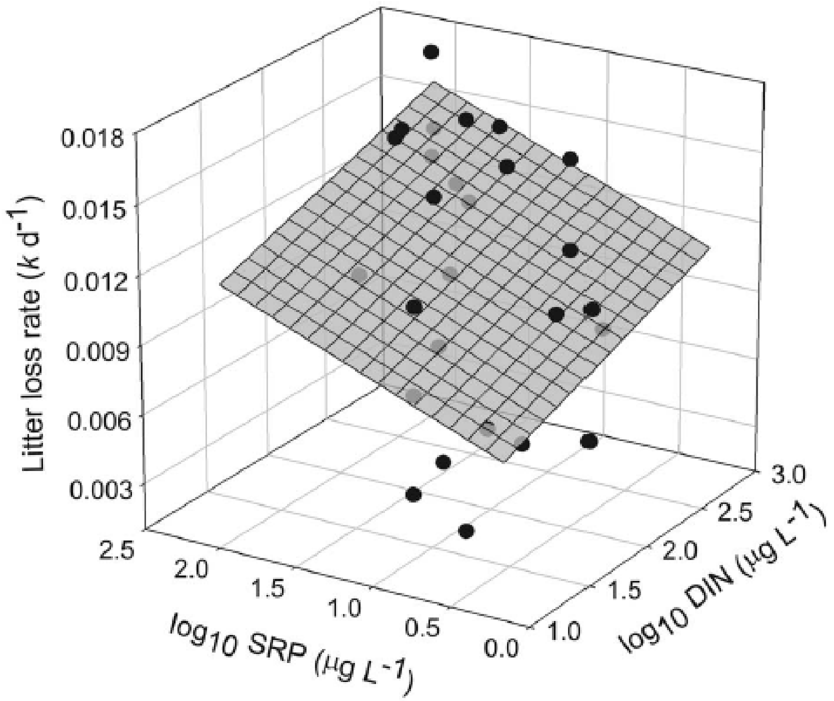


Fig. 2. Terrestrial C loss rates from stream reaches increased with N and P concentrations. The surface represents the predicted loss rate (k, per day) as a function of streamwater dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus (SRP) at mean discharge rate and temperature for the study period derived from the multilevel model [variance explained by fixed and random effects (conditional R^2) = 0.83; parameter estimates are in table S3]. Each data point is the estimated litter loss rate for a particular stream-year derived from the first level of our hierarchical model (*12*). Mean (range) annual concentrations of nutrients in micrograms per liter tested in our experiments were moderate and reflect concentrations commonly observed due to watershed land-use change; SRP reference: 6 (2 to 12), SRP-enriched: 49 (6 to 117); DIN reference: 53 (13 to 189), DIN-enriched: 347 (66 to 798).

Experimental nutrient additions accelerate terrestrial carbon loss from stream ecosystems

Amy D. Rosemond,[1]* Jonathan P. Benstead,[2] Phillip M. Bumpers,[1] Vladislav Gulis,[3] John S. Kominoski,[1]† David W. P. Manning,[1] Keller Suberkropp,[2] J. Bruce Wallace[1]

- Residence time of leaf litter (organic matter) in streams decreases with increasing nutrient (N, P) inputs
- Decomposition and respiration of organic matter stimulated by N and P inputs
- More CO_2 (from respiratory breakdown) evading from streams
- Finer POM/POC exported downstream
- Downstream and vertical (atmosphere) consequences

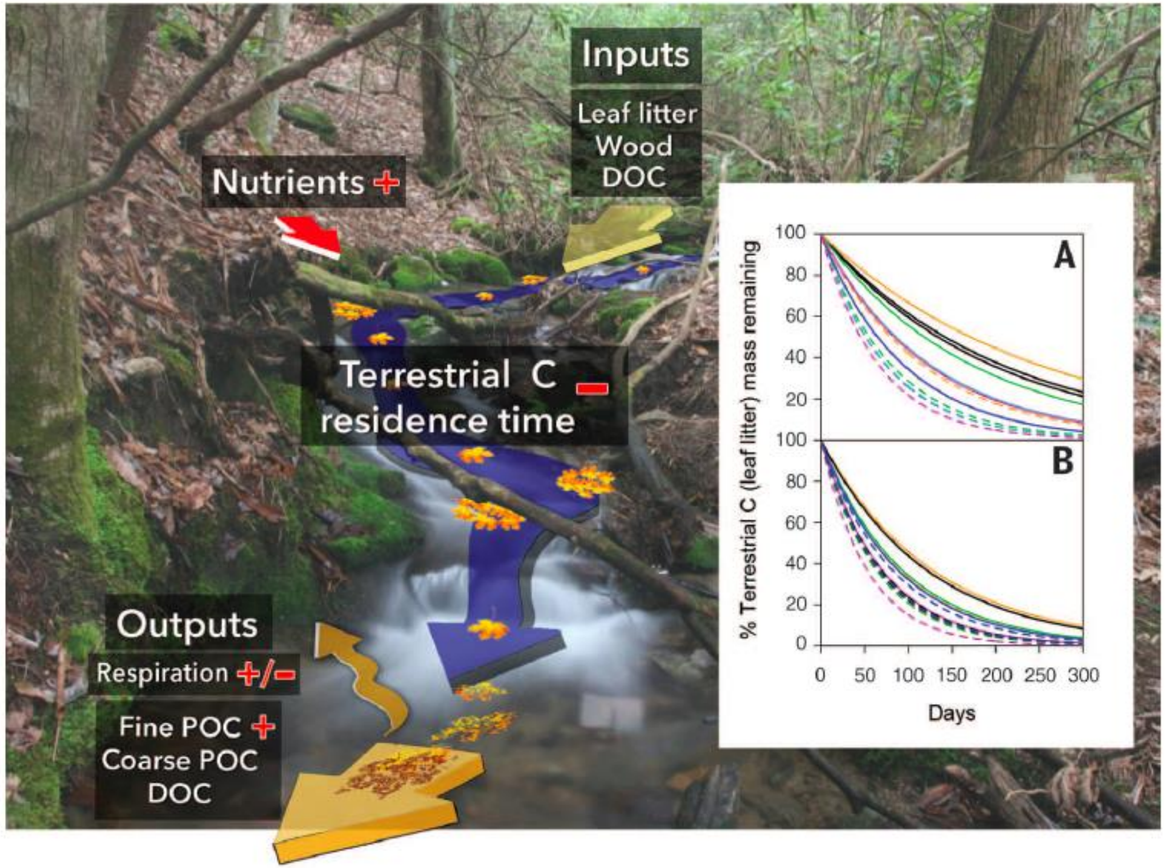


Fig. 1. Terrestrial C residence time was approximately halved with experimental nutrient enrichment. Increased nutrient inputs (+) reduced terrestrial particulate C residence time (−) and increased export of fine detrital particles (+) and respiration rates [which increased on C substrates (*11*) but decreased at reach scales; +/−]. Inset graph: Reach-scale leaf litter loss rates were faster in enriched (dashed lines) than in reference (solid lines) streams; the inverse of these rates is residence time. Colors correspond to the same years in (**A**) (reference versus enriched streams; N+P experiment; $n = 12$ annual rates) and to the same streams in (**B**) (pretreatment versus enriched years; N×P experiment; $n = 15$ annual rates). Data shown for litter loss are untransformed but were natural log–transformed for analyses and the calculation of loss rates (k, per day). The larger image depicts terrestrial organic C inputs, which enter as leaf litter, wood, and dissolved organic carbon (DOC), and outputs as hydrologic export (fine and coarse particles, DOC) and respired CO_2 in deciduous forest streams, using an image of one of the N×P experimental stream sites.

Dissolved organic matter/carbon

- High chemical diversity
- Continuum between particulate and dissolved form
- Concentration and composition changing with discharge/hydrological connectivity
- Fuels metabolism of microbial heterotrophs – intermediary to carbon cycle
- DOM bioreactivity depends on age and chemical composition
- Browning of surface water
- Drinking water, light regime/primary production
- Increasing temperature stimulates the respiration of organic carbon in lakes
- Biological residence of OC in streams depends on nutrients