Sample questions

- Describe the microbial loop and discuss its relevance for energy fluxes in a lake.
- Why would the relevance of allochthonous versus autochthonous energy sources to the aquatic metabolism change from small to large lakes?
- Describe the flood pulse concept and discuss its relevance for biodiversity across the aquatic-terrestrial continuum.
- What are the processes causing internal streambed clogging?

Ecosystem metabolism and restoration

The influence of floodplain restoration on whole-stream metabolism in an agricultural stream: insights from a 5-year continuous data set

Sarah S. Roley[1,3], Jennifer L. Tank[1,4], Natalie A. Griffiths[1,5], Robert O. Hall Jr.[2,6], and Robert T. Davis[1,7]

Restoration and stream metabolism

- From an incised channel to a wider channel with floodplains
- Implications for hydraulic geometry

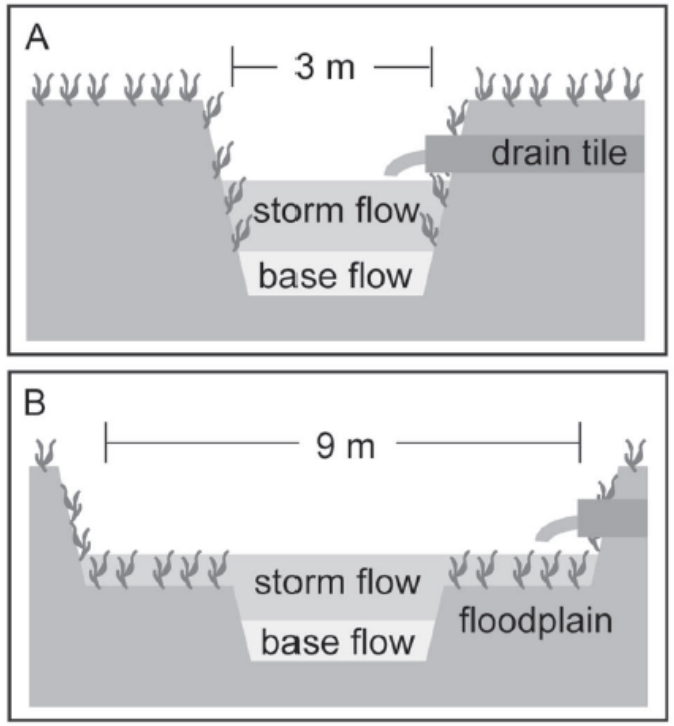
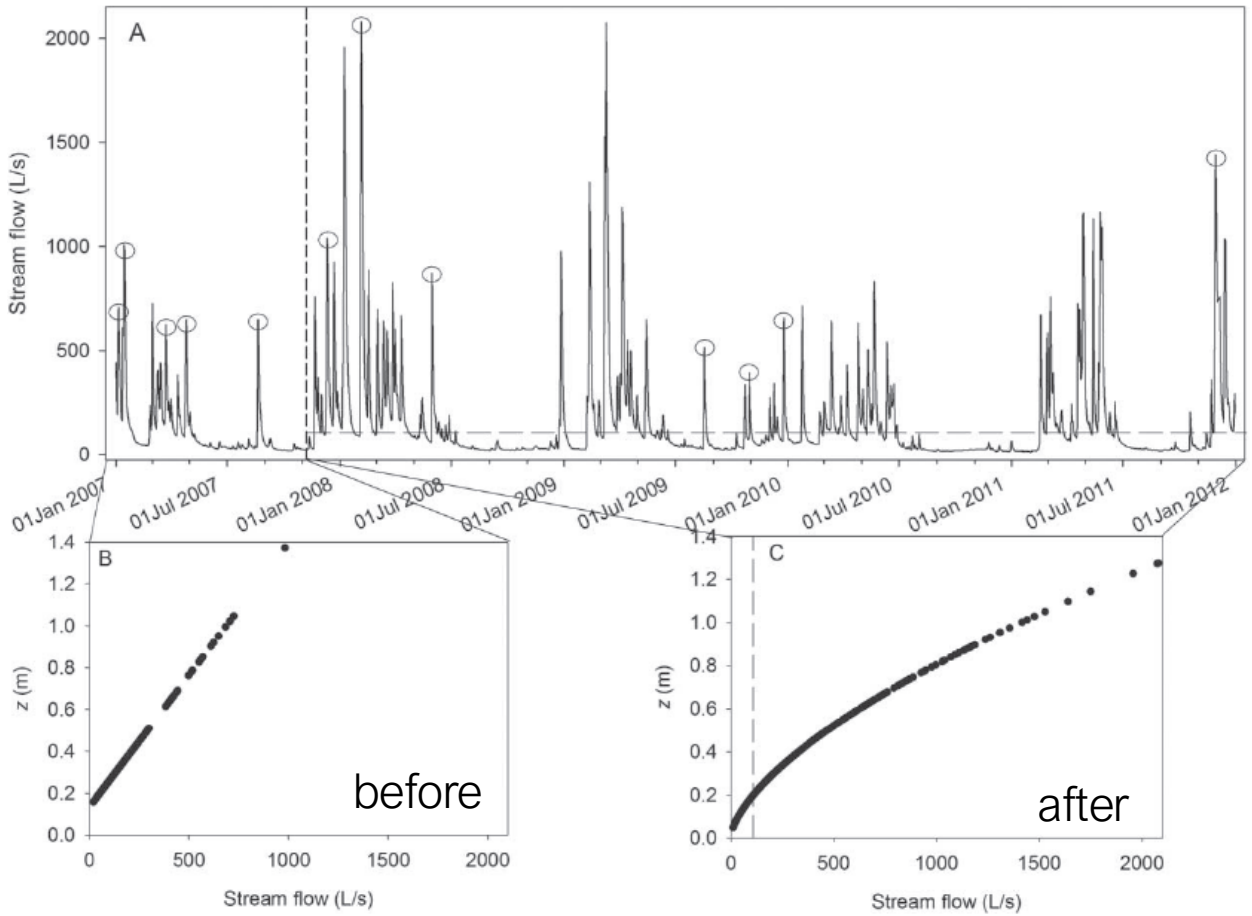


Figure 1. A.—A conventional agricultural ditch. B.—A 2-stage ditch, with floodplains added. Note that the baseflow channel dimensions did not change.

The influence of floodplain restoration on whole-stream metabolism in an agricultural stream: insights from a 5-year continuous data set

Sarah S. Roley[1,3], Jennifer L. Tank[1,4], Natalie A. Griffiths[1,5], Robert O. Hall Jr.[2,6], and Robert T. Davis[1,7]



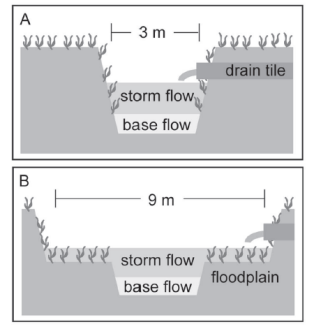


Figure 1. A.—A conventional agricultural ditch. B.—A 2-stage ditch, with floodplains added. Note that the baseflow channel dimensions did not change.

Restoration changes the relationship between discharge and water depth

Figure 2. Discharge (Q) in the treatment (TRT) reach (A) and the regression relationship between Q and depth (z) before (B) and after (C) restoration. In panel A, the vertical dashed line represents the 2-stage ditch restoration date and circles indicate the storms analyzed for resistance and resilience. The horizontal line in panel A and the vertical line in panel C represent the Q at which water begins to flow onto the floodplains.

The influence of floodplain restoration on whole-stream metabolism in an agricultural stream: insights from a 5-year continuous data set

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Control reach

Treatment reach

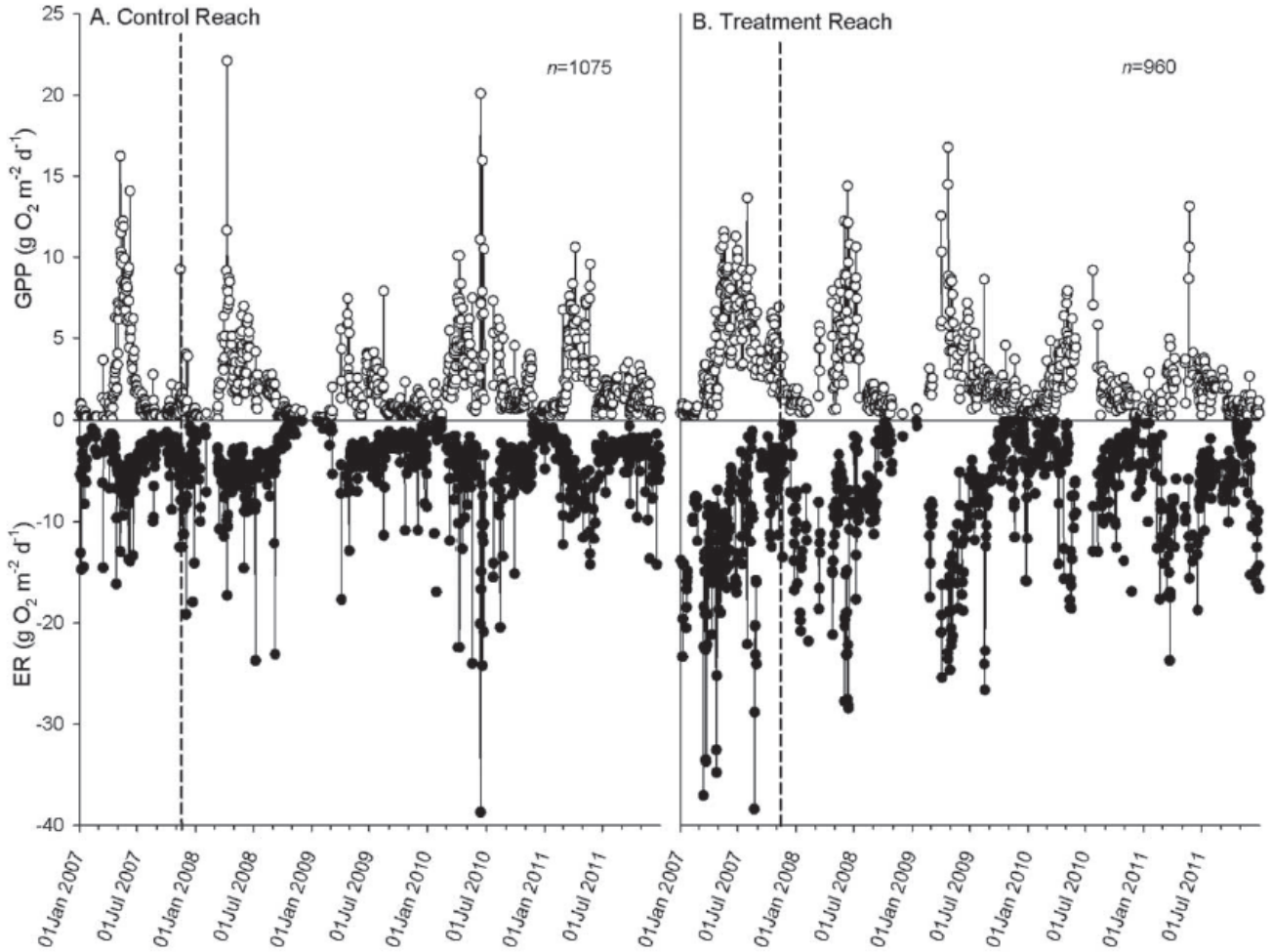

Figure 3. Gross primary production (GPP) and ecosystem respiration (ER) in the control (CTL) (A) and treatment (TRT) (B) reaches. Vertical dashed lines represent the 2-stage ditch restoration date.

The influence of floodplain restoration on whole-stream metabolism in an agricultural stream: insights from a 5-year continuous data set

Sarah S. Roley[1,3], Jennifer L. Tank[1,4], Natalie A. Griffiths[1,5], Robert O. Hall Jr.[2,6], and Robert T. Davis[1,7]

ΔGPP, ΔER as difference between treatment (restored) and control (non restored)

Restoration of the channel geomorphology increases ecosystem metabolism, both for ER and GPP.

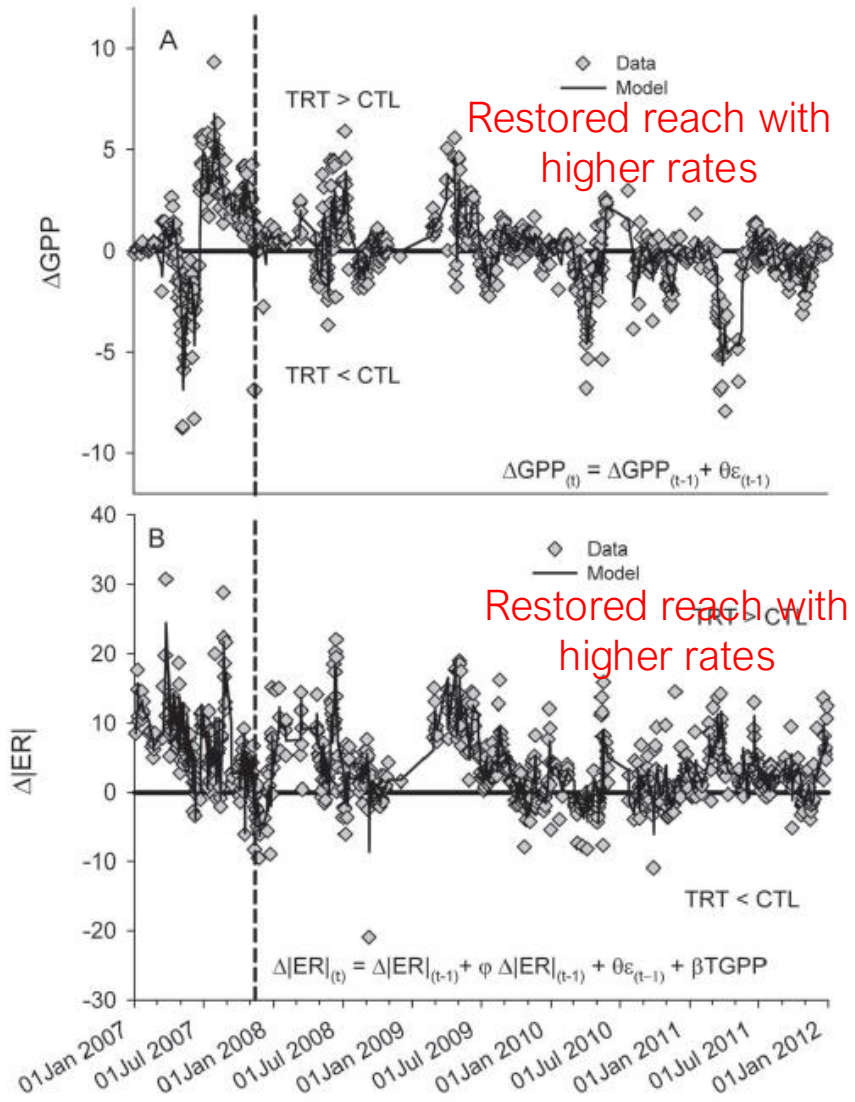

Figure 5. Difference in gross primary production (ΔGPP) (A) and in ecosystem respiration (Δ|ER|) (B) between the treatment (TRT) and control (CTL) reaches with the results of the best-fit auto-regressive integrated moving average (ARIMA) model. Points that fall above 0 are the dates on which the TRT reach had higher rates, and points that fall below 0 are the dates on which the CTL reach had higher rates. The dashed line represents the restoration date. See Table 2 for regression abbreviations.

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LIMNOLOGY
and
OCEANOGRAPHY

ASLO
Limnol. Oceanogr. 00, 2017, 00–00

doi: 10.1002/lno.10726

The metabolic regimes of flowing waters

E. S. Bernhardt,[1]* J. B. Heffernan,[2] N. B. Grimm,[3] E. H. Stanley,[4] J. W. Harvey,[5]
M. Arroita,[6,7] A. P. Appling,[8] M. J. Cohen,[9] W. H. McDowell,[10] R. O. Hall, Jr.,[7,a] J. S. Read,[11]
B. J. Roberts,[12] E. G. Stets,[13] C. B. Yackulic[14]

Restoring a stream by constructing a wastewater treatment plant

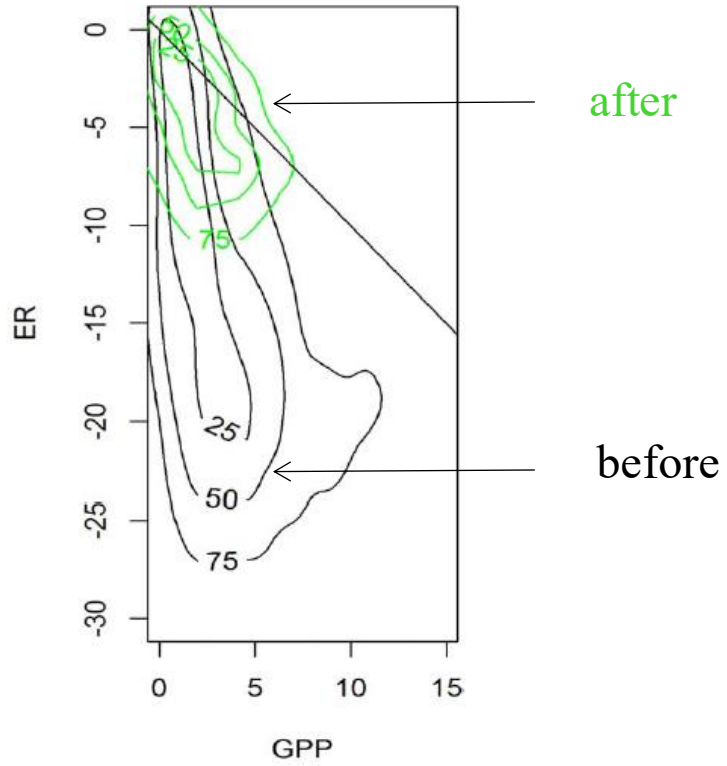

Fig. 8. Two photos of the Oria River and its metabolic fingerprint before (black) and after (green) the construction of a wastewater treatment plant. Photo credits to M. Arroita and A. Elosegi. [Color figure can be viewed at wileyonlinelibrary.com]

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LIMNOLOGY and OCEANOGRAPHY

ASLO

Limnol. Oceanogr. 9999, , 1–16

doi: 10.1002/lno.11053

Twenty years of daily metabolism show riverine recovery following sewage abatement

Maite Arroita, [1,2*] Arturo Elosegi,[1] Robert O. Hall Jr.[2]

WWTP:

- Immediate effect on ammonium concentration
- Gradual effect on DOM concentration

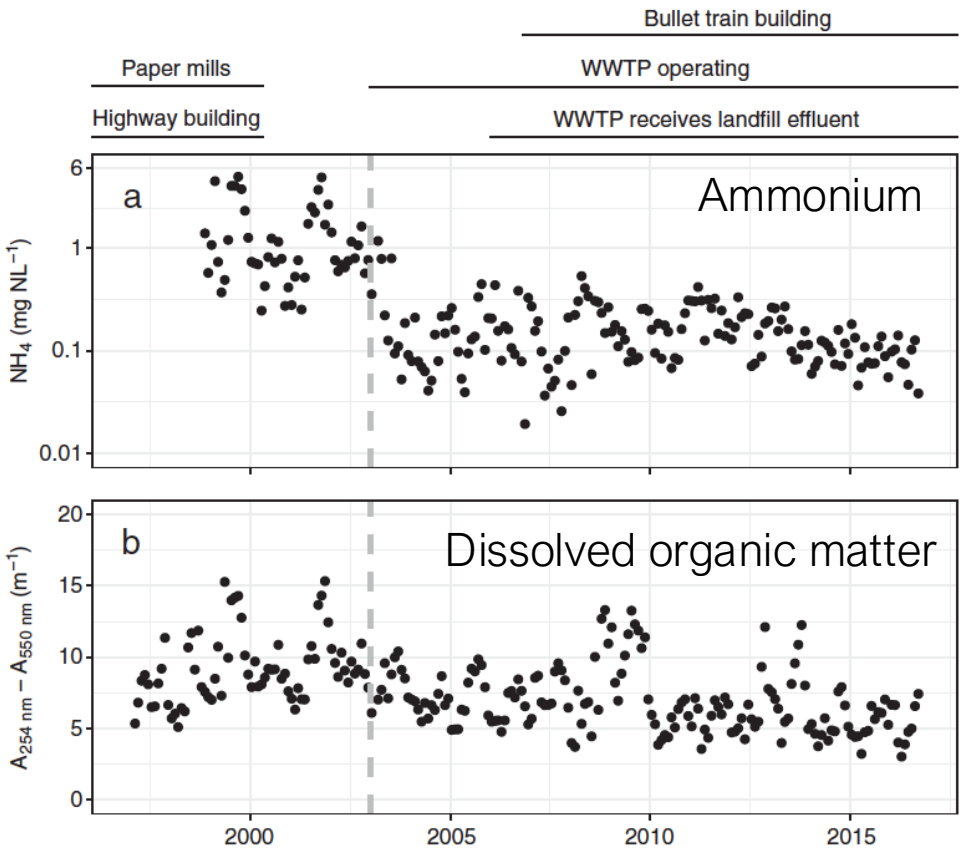

Fig. 1. Monthly means of ammonium (NH_4) concentration (**a**) and DOM absorbance (**b**; $A_{254nm} - A_{550nm}$; proxy for DOM concentration) declined following waste water treatment plant installation (dashed gray line). Note log scale for NH_4.

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Twenty years of daily metabolism show riverine recovery following sewage abatement

Maite Arroita, [1,2*] Arturo Elosegi,[1] Robert O. Hall Jr.[2]

- GPP summer peaks decreased
- ER decreased over the entire year
- Less heterotrophic ecosystem
- Gas exchange rate increased (absence of algal mats and increasing turbulence)
- Improved aeration
- Higher fish biodiversity

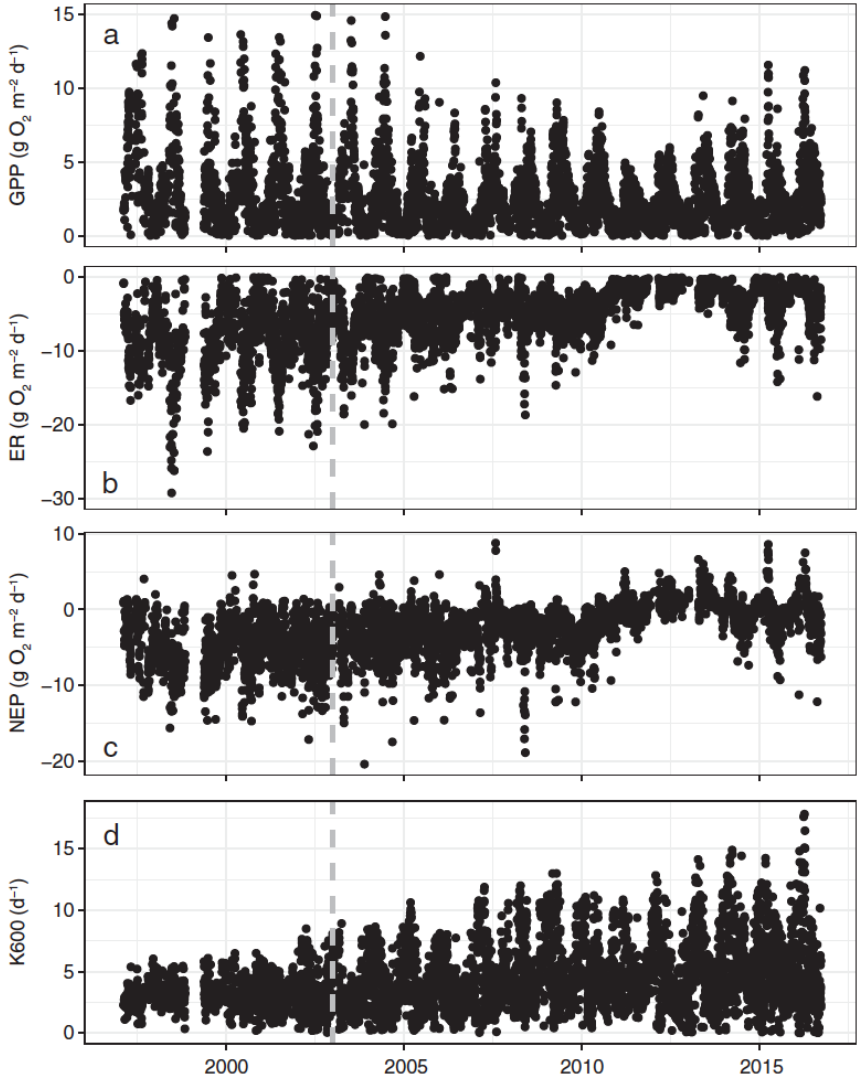

Fig. 2. Following waste water treatment plant installation (dashed gray line) GPP (**a**) and ER (**b**) gradually decreased, NEP shifted from highly heterotrophic to a balance between GPP and ER (**c**), and gas exchange rate coefficient (K600) gradually increased (**d**).

Areal CO_2 evasion flux decreases downstream

(Why is it so high upstream?)

$$F_{CO2} = k_{CO2} \times \Delta_{CO2}$$

k_{CO2} is the gas exchange velocity for CO_2 (including its diffusivity and solubility)

ΔCO_2 is the difference in CO_2 concentration between water and CO_2 equilibrium, which is the atmospheric-equilibrium concentration of CO_2.

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ARTICLES
https://doi.org/10.1038/s41561-019-0324-8

Distinct air–water gas exchange regimes in low- and high-energy streams

Amber J. Ulseth[1,4*], Robert O. Hall Jr[2], Marta Boix Canadell[1], Hilary L. Madinger[3,5], Amin Niayifar[1] and Tom J. Battin[1]

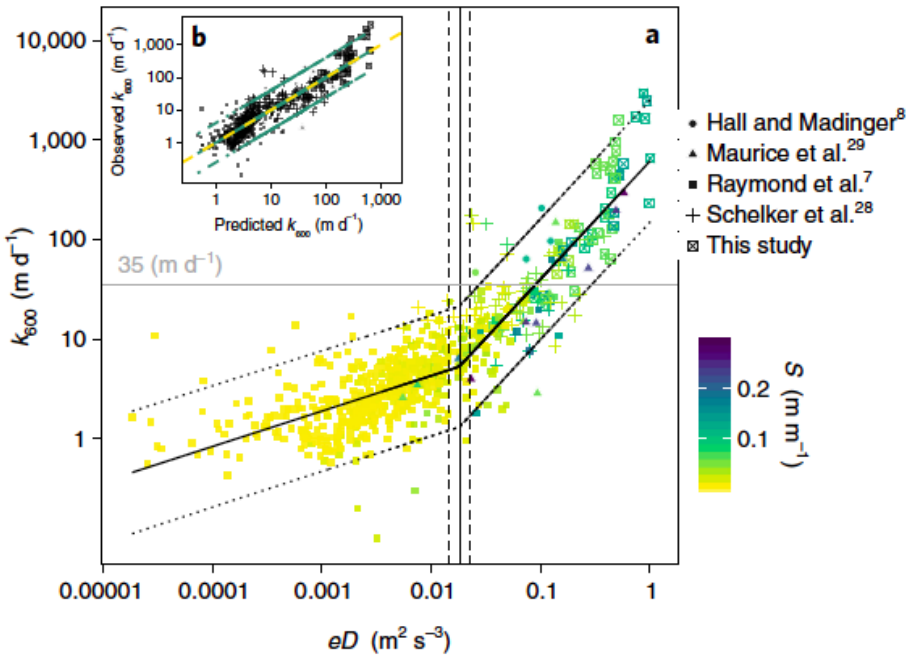

Fig. 2 | k_{600} scaled against eD. a, Model fit (black line, with 95%CI shown by dashed lines) estimated using piecewise linear regression analysis ($R^2 = 0.78$), where $\ln[k_{600}] = 3.10 + 0.35$ (95%CI: 0.31, 0.41) $\times \ln[eD]$ for eD < 0.02 (vertical line, dashed vertical lines are 95%CI (0.016, 0.026)) and $\ln[k_{600}] = 6.43 + 1.18$ (95%CI: 1.10, 1.30) $\times \ln[eD]$ for eD > 0.02. The grey line theoretically equates to the maximum gas exchange due to diffusivity alone. **b**, The inset shows observed versus predicted k_{600}. The solid green line is the model fit (95%CI, dashed green lines), which falls along the 1:1 line (dashed yellow line).

Areal CO_2 evasion flux decreases downstream
(Why is it so high upstream?)

- Headwater streams often drain terrain with elevated slope.
- This implies higher flow velocity and higher bed roughness (see Hjulstroem).
- Roughness and velocity affect energy dissipation (eD; velocity, slope and gravity) at the streambed — increasing turbulence at the streambed propagated to the water surface.
- Turbulence advects gases through the water surface.
- High turbulence entrains air bubbles (white waters) into the water — increasing surface area for gas exchange.

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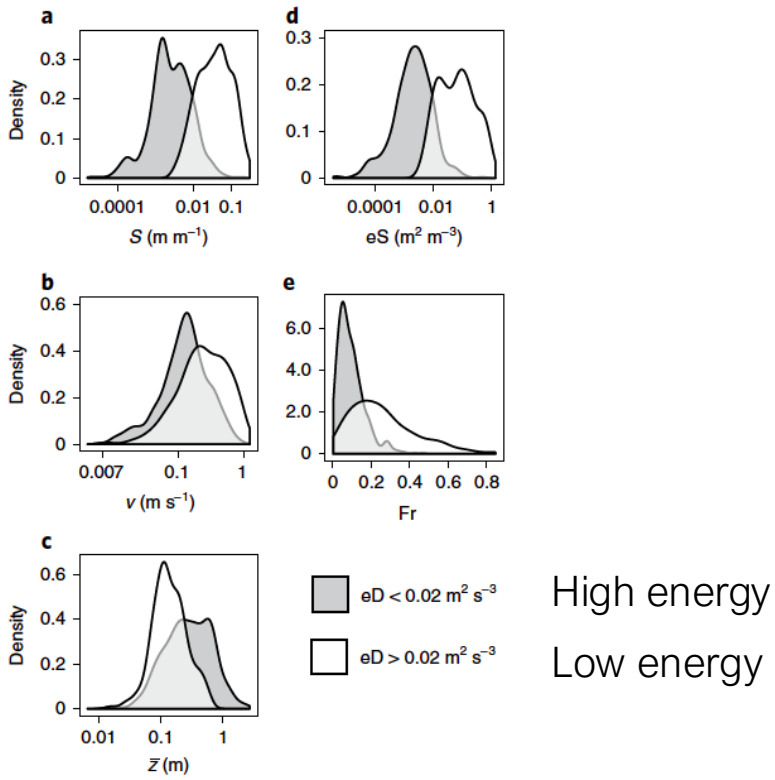

High energy

Low energy

Fig. 3 | Density distributions of stream characteristics for low- versus high-energy streams. a–e, Streams with eD higher than the breakpoint (eD > 0.02 m² s⁻¹) in Fig. 2 had steeper *S* (**a**), higher eS (**d**) and higher Froude number (Fr) (**e**) than those below the breakpoint, as illustrated by the density distributions, while there was greater overlap above and below the breakpoint for stream *v* (**b**) and $\bar{z}$ (**c**).

Areal CO_2 evasion flux decreases downstream
(Why is it so high upstream?)

- Hydraulics and hydraulic geometry different in high- than low-energy streams.
- Hydraulics related to roughness affects gas exchange velocity
- Changes predictably along the fluvial continuum

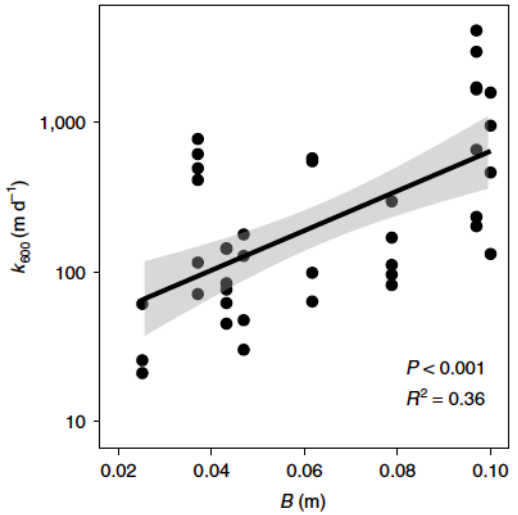

Fig. 4 | Gas exchange increased with streambed roughness. k_{600} increased with median streambed roughness (*B*) across eight of the Swiss alpine stream reaches. The black line is the fit from semi-natural log linear regression, $\ln[k_{600}] = 3.41 + 30.52 \times B$, and the grey band represents 95%CI of the predicted k_{600}.

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ARTICLE
https://doi.org/10.1038/s41467-019-12905-z OPEN

Unexpected large evasion fluxes of carbon dioxide from turbulent streams draining the world's mountains

Åsa Horgby[1], Pier Luigi Segatto[1], Enrico Bertuzzo[2], Ronny Lauerwald[3], Bernhard Lehner[4], Amber J. Ulseth[5], Torsten W. Vennemann[6] & Tom J. Battin[1*]

Mountain streams worldwide are major sources of CO_2 to the atmosphere.

Unexpected because of their relatively low surface area and catchments that are often devoid of terrestrial vegetation and soils.

Steep slopes, high gas transfer

Well connected to groundwater – CO_2 from soil respiration and rock weathering

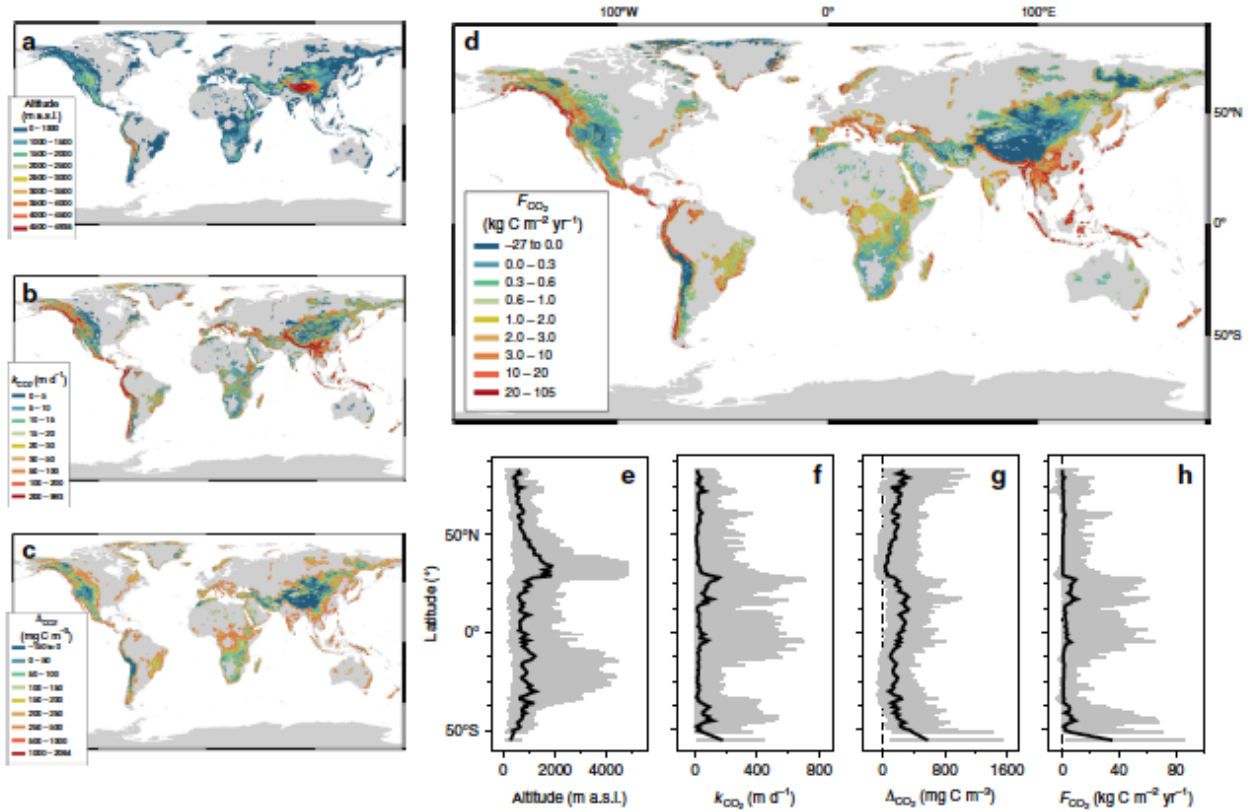

Fig. 3 Global distributions of CO_2 in mountain streams. **a** Altitude of mountain streams, where mountains as defined according to ref. [7]. **b–d** Global distribution of predicted CO_2 exchange velocities (k_{CO_2}), CO_2 gradients between the streamwater and the atmosphere (ΔCO_2) and the areal CO_2 fluxes (F_{CO_2}), respectively. **e–h** Latitudinal transects of these same parameters at 1-degree resolution (shown are median values in black and 5 and 95% confidence intervals in gray)

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LETTER

Gas transfer velocity (k_{600}) increases with discharge in steep streams but not in low-slope streams

Kelly S. Aho [1*] Kaelin M. Cawley,[2] Robert O. Hall Jr.,[3] Robert T. Hensley [2] Walter K. Dodds [4]
Nicolas Harrison,[2] Keli J. Goodman[2]

339 gas tracer experiments to measure gas transfer velociy (k_{600})
Relate k_{600} to discharge and energy dissipation (eD)

How does k_{600} react to varying discharge in high- *versus* low-slope streams?

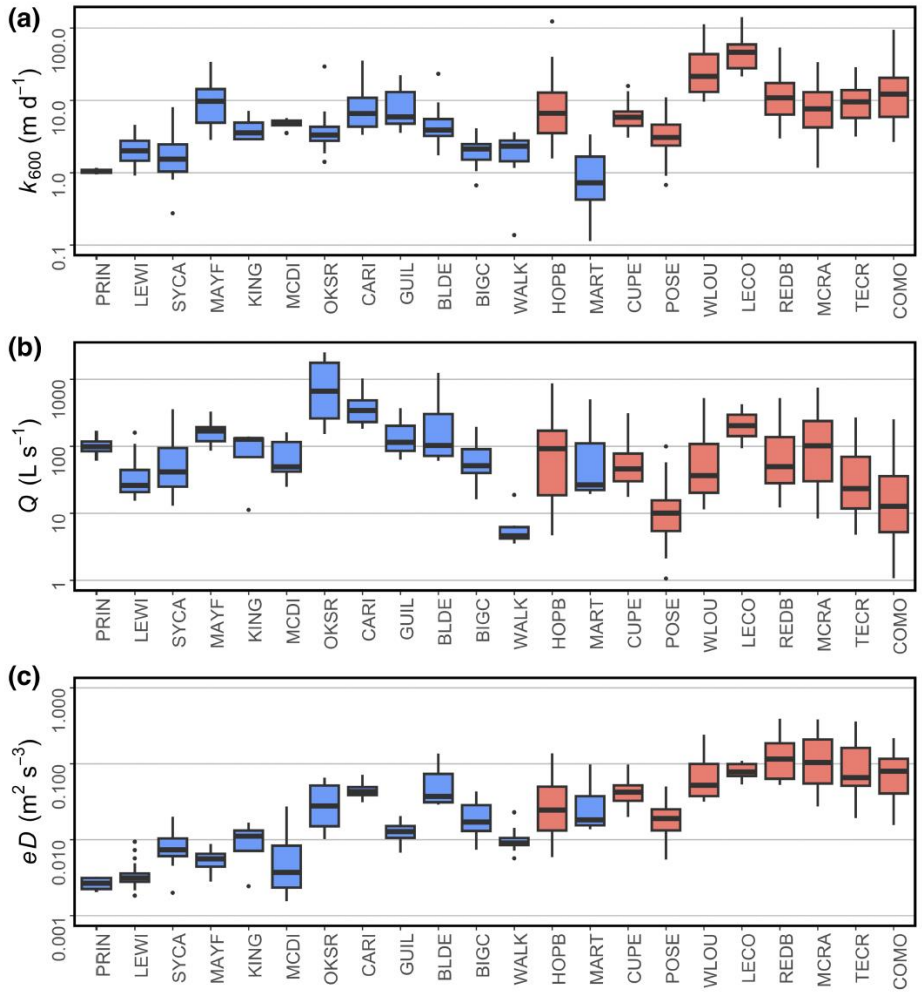

Fig. 1. (**a**) Gas transfer velocity (k_{600}), (**b**) discharge (Q), and (**c**) energy dissipation (eD) for each tracer-gas experiment by site. Sites are arranged in order of increasing slope (e.g., lowest gradient: PRIN; highest gradient: COMO). Boxes represent the median and interquartile range (IQR), whiskers mark the lesser of 1.5 × IQR or minimum/maximum, and points denote outliers more extreme than 1.5 × IQR. Color of the text indicate if k_{600} for the site had a low (blue) or high (red) Q dependency.

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Limnology and Oceanography Letters 2025

doi: 10.1002/lol2.70003

LETTER

Gas transfer velocity (k_{600}) increases with discharge in steep streams but not in low-slope streams

Kelly S. Aho,[1]* Kaelin M. Cawley,[2] Robert O. Hall Jr.,[3] Robert T. Hensley,[2] Walter K. Dodds,[4] Nicolas Harrison,[2] Keli J. Goodman[2]

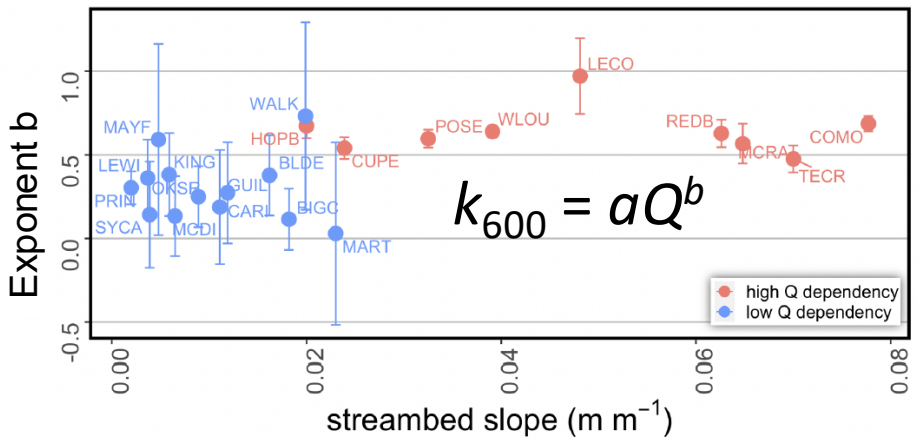

Fig. 3. Estimates of the exponent *b* of the power law relationship $k_{600} = aQ^b$ for each of the 22 NEON sites arranged in order of increasing slope. The error bars represent the standard deviation of the estimate. Colors indicate whether k_{600} for the site had a low (blue) or high (red) *Q* dependency.

- Gas exchange velocity in high-slope streams reacts more to increases in discharge then in low-slope streams
- Effect of energy dissipation (velocity, slope and gravity) more pronounced in high-slope streams
- Results from turbulence as induced by roughness and velocity

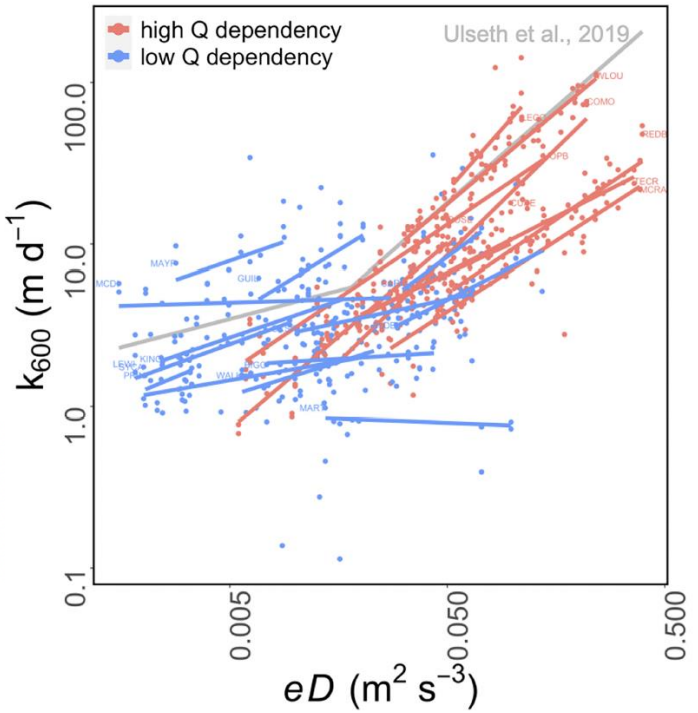

Fig. 4. Relationship between *eD* and k_{600} by site. The input data are shown as points, and the fitted values from the mixed-effect model are shown as lines. Colors indicate if the site had a low (blue) or high (red) *Q* dependency for k_{600}. For context, the gray line shows the two-stage model presented in Ulseth et al. (2019).

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PUBLISHED ONLINE: 10 AUGUST 2015 | DOI: 10.1038/NGEO2507

Sources of and processes controlling CO_2 emissions change with the size of streams and rivers

E. R. Hotchkiss[1*†], R. O. Hall Jr[2], R. A. Sponseller[1], D. Butman[3], J. Klaminder[1], H. Laudon[4], M. Rosvall[5] and J. Karlsson[1]

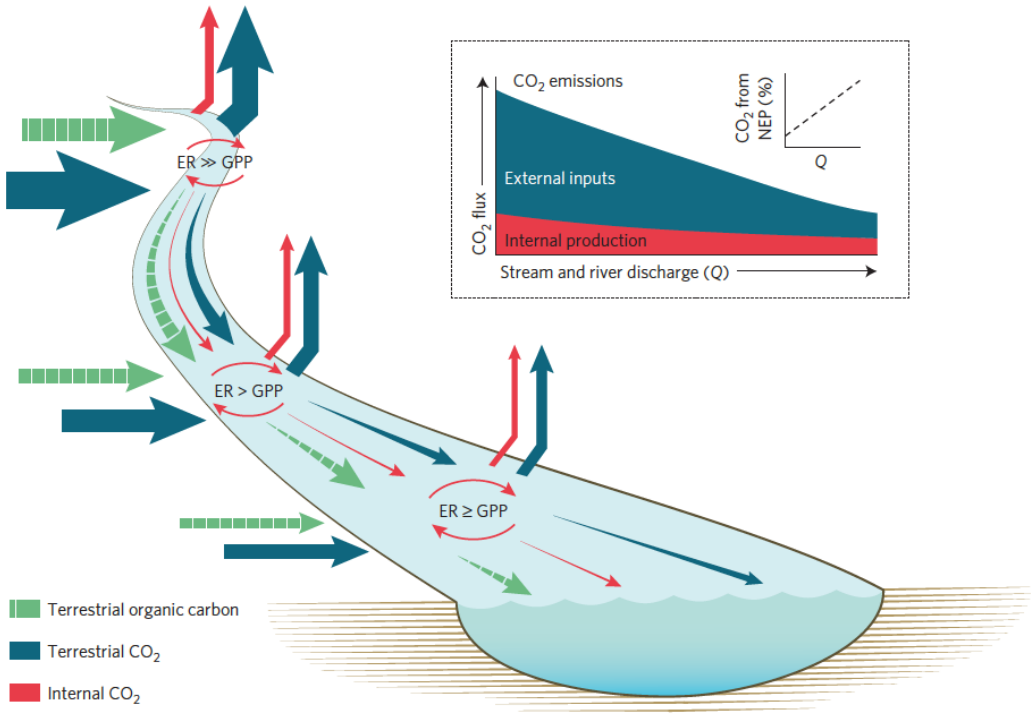

Figure 3 | Sources and magnitude of net CO_2 emissions along a theoretical stream–river continuum. Terrestrially derived CO_2 and organic carbon inputs per unit aquatic area decline downstream, decreasing net CO_2 emission rates in rivers compared to streams. Rapid loss of CO_2 results in a downstream shift in the source contributions to CO_2 emissions, from dominance of external CO_2 in streams to a more balanced supply of internal and external sources in rivers. Thus, aquatic mineralization of terrestrial OC (CO_2 from NEP) should contribute to a higher proportion of annual net CO_2 emissions in large rivers relative to small streams.

- Both sources and magnitude of the CO_2 evasion change downstream
- Allochthonous organic carbon and CO_2 prevail in headwaters
- Allochthonous sources decline downstream because connectivity with the catchment decreases
- Ecosystems (internal) production of CO_2 decreases as well because the ratio of sediment to water decreases (see streambed as bioreactor)

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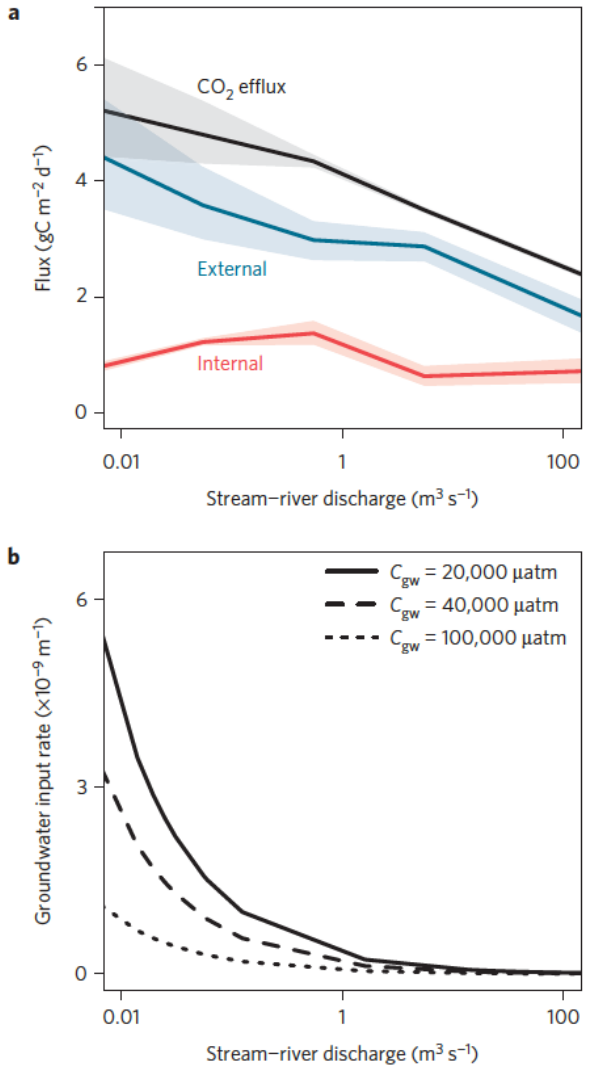

Emission

Groundwater

NEP

Areal CO_2 evasion flux decreases downstream (Why is it so high upstream?)

CO_2 contributions from the groundwater decrease downstream

Figure 2 | Modelled CO_2 fluxes and groundwater input rates along a stream–river continuum. a, Binned discharge-specific estimates for CO_2 efflux and internal production and, by subtraction, external CO_2 inputs. Solid lines are median fluxes; shaded regions represent 25–75% credible intervals. These fluxes were used to model the range of groundwater discharge and input rates needed to sustain a steady state balance between internal CO_2 production, external CO_2 inputs and CO_2 efflux (see Methods and Supplementary Section 2). **b**, Modelled stream–river groundwater proportional input rates (k_{gw}) needed to support estimated CO_2 fluxes (**a**) given a range of potential groundwater CO_2 concentrations (C_{gw}).

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PERSPECTIVE
https://doi.org/10.1038/s41561-018-0245-y

CO_2 evasion along streams driven by groundwater inputs and geomorphic controls

Clément Duvert[1]*, David E. Butman[2], Anne Marx[3], Olivier Ribolzi[4] and Lindsay B. Hutley[1]

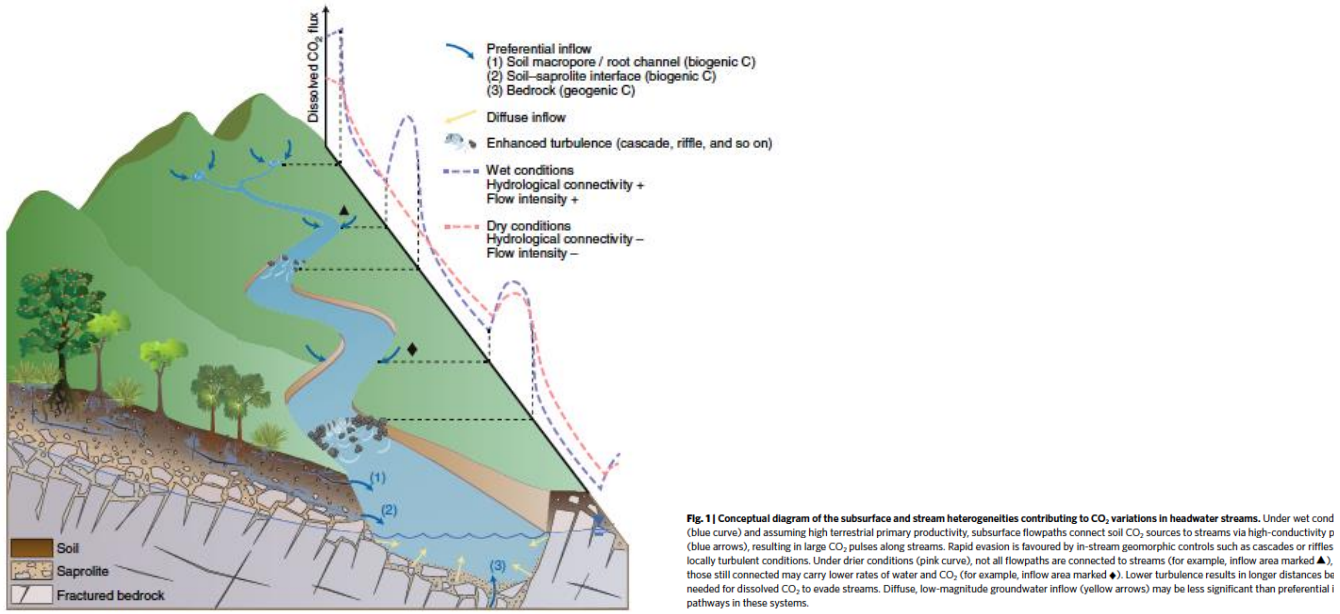

Fig. 1 | Conceptual diagram of the subsurface and stream heterogeneities contributing to CO_2 variations in headwater streams. Under wet cond (blue curve) and assuming high terrestrial primary productivity, subsurface flowpaths connect soil CO_2 sources to streams via high-conductivity p (blue arrows), resulting in large CO_2 pulses along streams. Rapid evasion is favoured by in-stream geomorphic controls such as cascades or riffles locally turbulent conditions. Under drier conditions (pink curve), not all flowpaths are connected to streams (for example, inflow area marked ▲), those still connected may carry lower rates of water and CO_2 (for example, inflow area marked ♦). Lower turbulence results in longer distances be needed for dissolved CO_2 to evade streams. Diffuse, low-magnitude groundwater inflow (yellow arrows) may be less significant than preferential i pathways in these systems.

- Channel and valley geomorphology drives groundwater inputs
- Groundwater inputs are hotspots of CO_2 outgassing
- Particularly pronounced in headwater streams that are tightly connected to groundwater
- Rapid outgassing depending on channel geomorphology and turbulence

CO_2 contributions from the groundwater decrease downstream (Why are they so high upstream?)

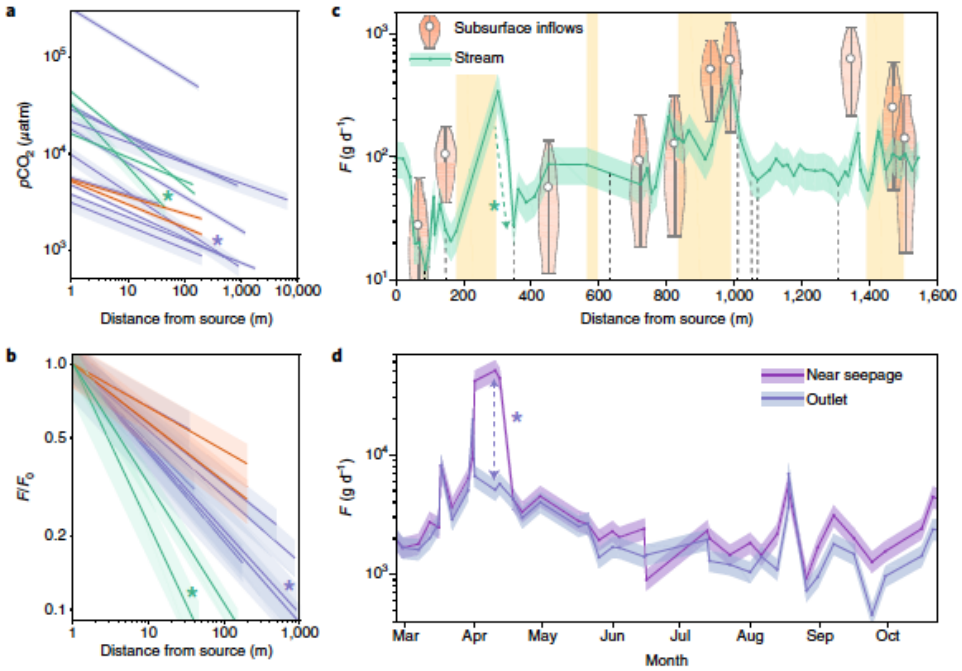

Fig. 2 | Illustration of CO_2 evasion within short distance of subsurface inflows. a, Decrease in the partial pressure of CO_2 (p_{CO2}) values from emerging groundwater to streams. Green, blue and brown represent tropical, temperate and boreal streams, respectively. The shaded areas around each line represent measurement uncertainties as described in the Supplementary Information. The two lines marked with green and purple asterisks in **a** and **b** correspond to data collected as part of this study in Houay Pano (Laos) and Uhlirska (Czech Republic), respectively. All other lines are taken from the literature (see Supplementary References). **b**, Decrease in flow-weighted CO_2 flux (F) from emerging groundwater to streams. Values have been normalized to the subsurface (source) CO_2 flux F_0 to facilitate inter-site comparison. **c**, Longitudinal profile of dissolved CO_2 flux along a steep tropical headwater stream in northern Laos (Houay Pano, 0.64 km²). The green curve represents the in-stream CO_2 flux with its 10th–90th percentile uncertainty range (see Supplementary Information). Yellow shaded areas represent locations of flatter reaches that support riparian vegetation with diffuse inflow of groundwater. Violin plots represent the measured CO_2 inputs delivered by preferential subsurface inflows with their 10th–90th percentile range. Black vertical dotted lines correspond to locations with higher turbulence, such as minor falls. The green asterisk refers to the data points used in **a** and **b**. **d**, Temporal variations in dissolved CO_2 flux along a temperate headwater stream in the Czech Republic (Uhlirska, 1.78 km²). Data were collected in shallow groundwater and at two stream locations, immediately downstream of a subsurface seepage area and at the outlet of the catchment, 900 m downstream of the seepage. The shaded areas around each curve represent their 10th–90th percentile uncertainty ranges. The purple asterisk corresponds to the data points used in **a** and **b**.

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AGU Advances
RESEARCH ARTICLE
10.1029/2024AV001294

Toward Modeling Continental-Scale Inland Water Carbon Dioxide Emissions

Brian Saccardi and Craig B. Brinkerhoff contributed equally to this work.

Brian Saccardi[1], Craig B. Brinkerhoff[2], Colin J. Gleason[2], and Matthew J. Winnick[1]

Groundwater CO_2 inputs matter, but is it all?

CO_2 transport model for the continental USA simulating carbon transport and transformation in more than 22 million hydraulically connected rivers, lakes, and reservoirs

Stream corridor (comprising stream benthic zones, the hyporheic zone, and near-stream riparian zones and floodplains) CO_2 production dominates over groundwater inputs at the continental scale

Water column respiration more important downstream

Depending on stream order!

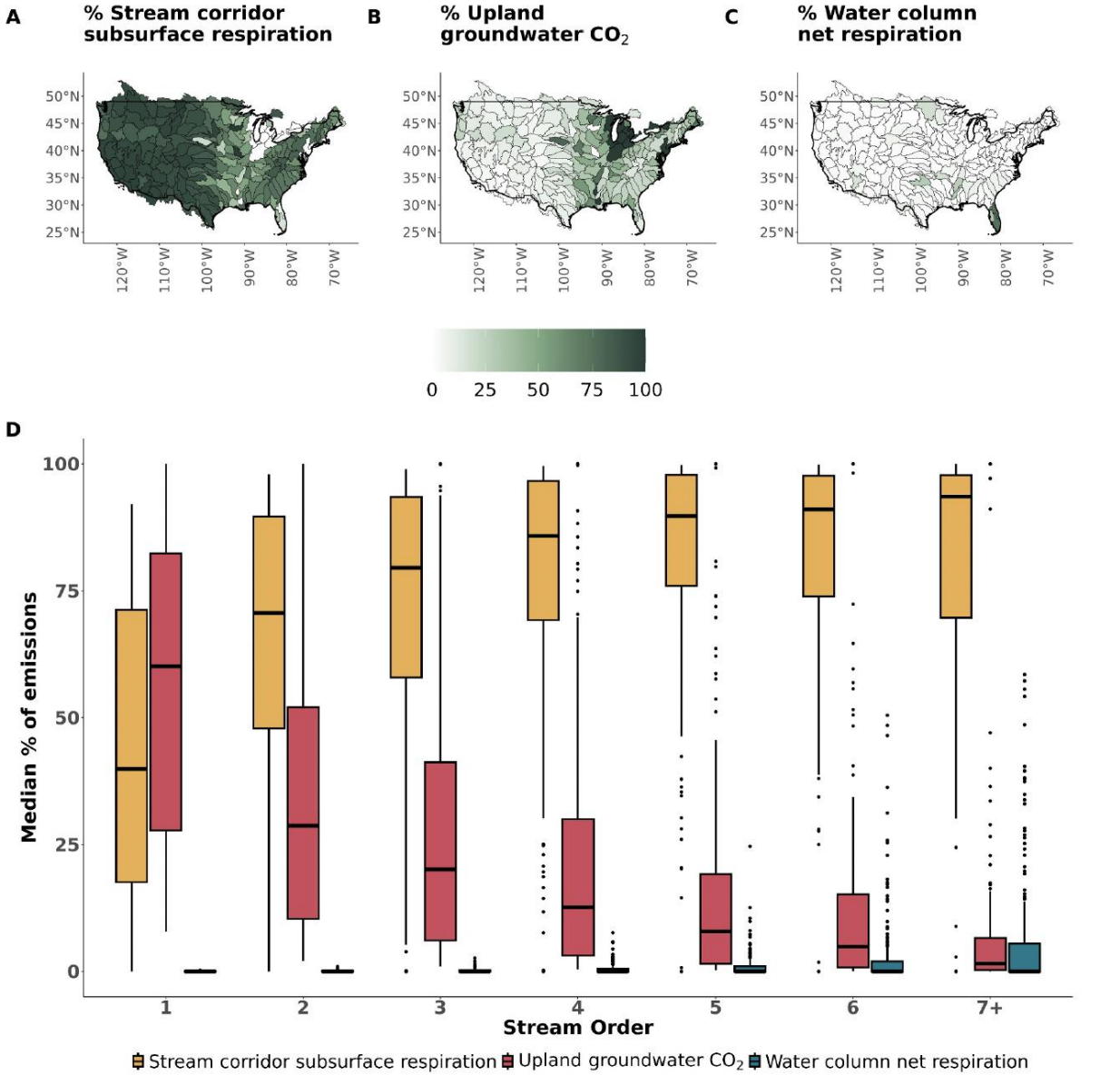


Figure 3. Sources of inland water CO_2 emissions. a–c: Percent of CO_2 lost from a basin that is attributed to stream corridor subsurface respiration (a), upland groundwater CO_2 (b), and net water-column respiration (c). (d) Percent of CO_2 emissions attributed to the same mechanisms as a–c by stream order; boxplots are composed of the median percent value per basin per stream order. See Section 2 for these calculations at the basin-scale (a–c) and the reach-scale (d). Note we lump high stream orders (seven and above) due to the small number of basins with this many stream orders and to represent network main stems as a single boxplot. Figure S9 in Supporting Information S1 separates d by eastern and western CONUS basins.

Temporal variation of CO_2 outgassing

Seasonal


AGU PUBLICATIONS

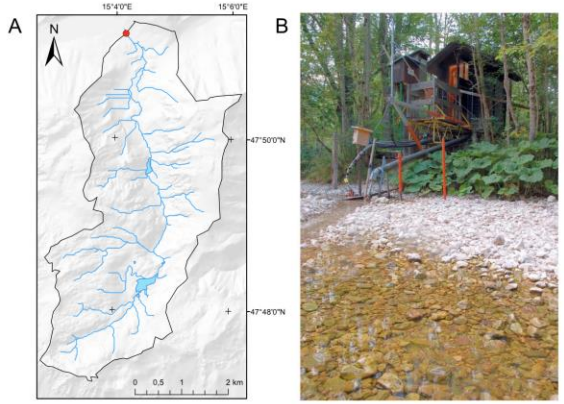
Journal of Geophysical Research: Biogeosciences

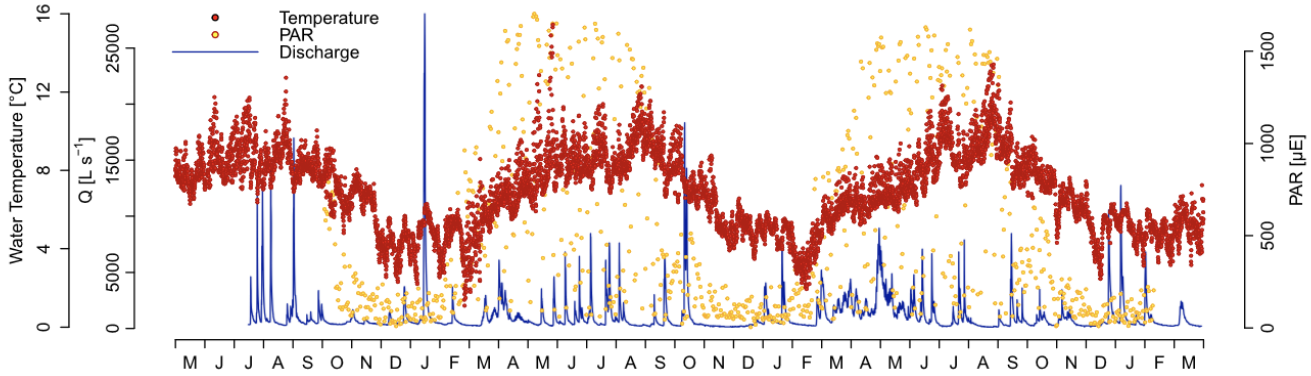
RESEARCH ARTICLE

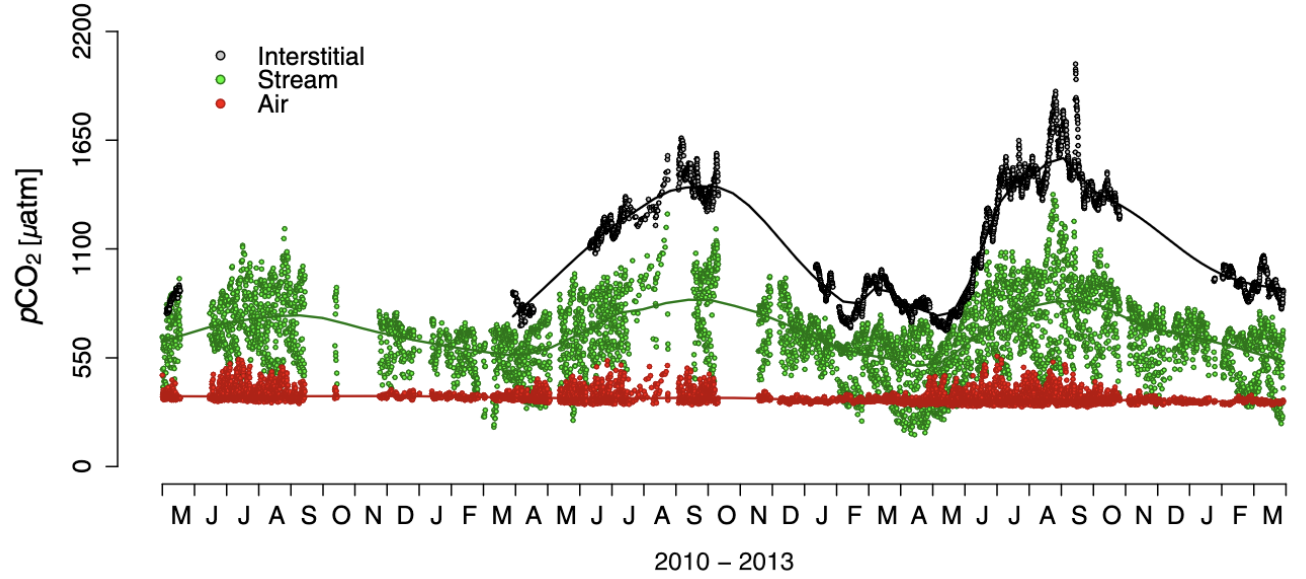
10.1002/2013JG002552

Scales and drivers of temporal pCO_2 dynamics in an Alpine stream

Hannes Peter[1], Gabriel A. Singer[2,3,4], Christian Preiler[3], Peter Chifflard[5], Gertraud Steniczka[3], and Tom J. Battin[2,3]







- Distinct seasonal patterns of streamwater pCO_2
- More pronounced in the hyporheic than surface water
- Few instances of CO_2 undersaturation — in spring, because of positive NEP

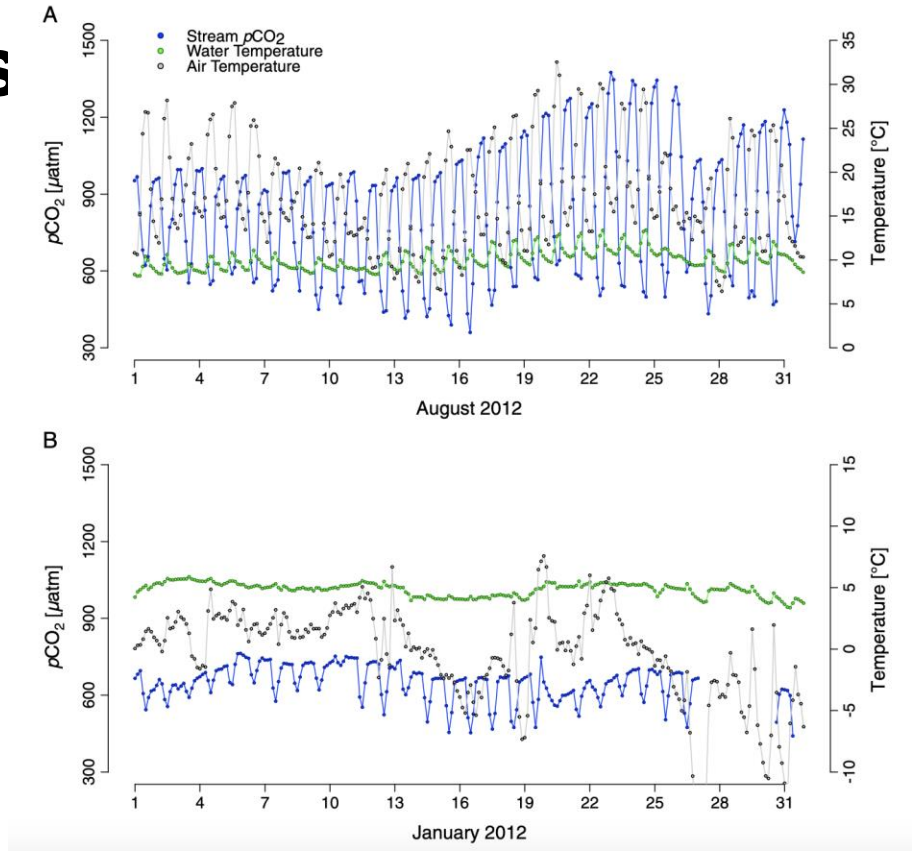
EPFL

Temporal variation of CO_2 outgass

Diel and event-driven

Sub-seasonal variation

- Pronounced day-night cycles of streamwater pCO_2 in summer, less in winter
- Night peaks indicate ecosystem respiration dominating over production
- Post-storm diel pattern indicates recovery and active biomass buildup



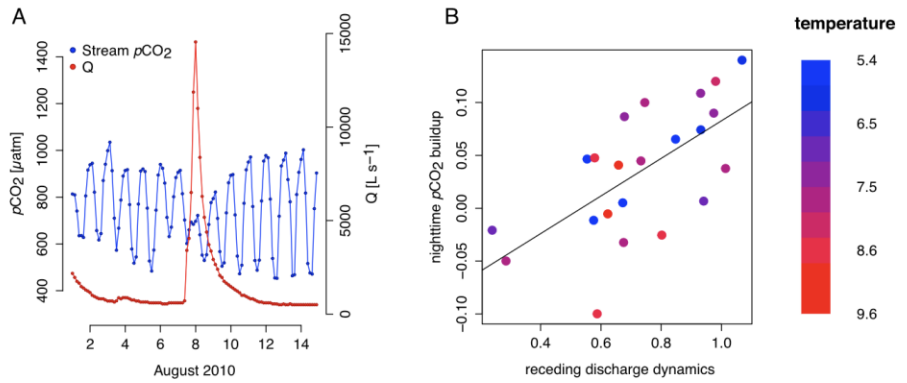


Figure 5. Event-driven pCO_2 dynamics in the stream water in Oberer Seebach. A bed-moving storm event ($Q > 3400\,L\,s^{-1}$) causes the collapse of the diurnal stream water pCO_2 patterns (a). The relationship between the recovery dynamics of nighttime pCO_2 maxima and the recession dynamics of discharge is also shown (b). Plotted are the exponents of power models fitted to the discharge and stream water pCO_2 maxima over 6 days after peak discharge.

Temporal variation of CO_2 outgassin

Diel

nature geoscience ARTICLES
https://doi.org/10.1038/s41561-021-00722-3

Global carbon dioxide efflux from rivers enhanced by high nocturnal emissions

Lluís Gómez-Gener[1,24], Gerard Rocher-Ros[2,24], Tom Battin[3], Matthew J. Cohen[3], Higo J. Dalmagro[4], Kerry J. Dinsmore[5], Travis W. Drake[6], Clément Duvert[7], Alex Enrich-Prast[8,9], Åsa Horgby[1], Mark S. Johnson[10,11], Lily Kirk[12], Fausto Machado-Silva[9], Nicholas S. Marzolf[13], Mollie J. McDowell[10,11], William H. McDowell[14], Heli Miettinen[15], Anne K. Ojala[16], Hannes Peter[1], Jukka Pumpanen[17], Lishan Ran[18], Diego A. Riveros-Iregui[19], Isaac R. Santos[20], Johan Six[6], Emily H. Stanley[21], Marcus B. Wallin[22], Shane A. White[23] and Ryan A. Sponseller[2]

- Overall higher nocturnal CO_2 emssions – independent of the biome
- Highest diel variation in open-canopy streams during summer (light, primary production)
- Important when scaling CO_2 emissions up to assess the role of streams and rivers for the global carbon cycle

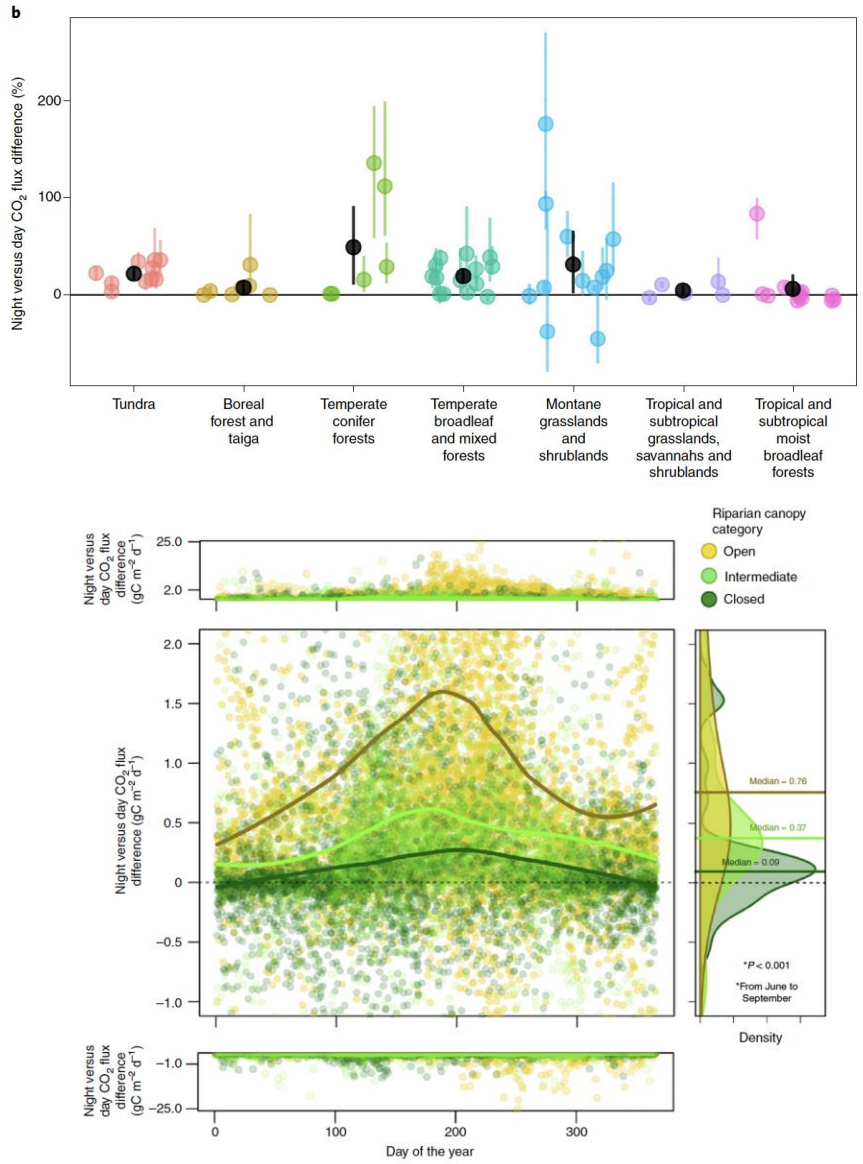


Fig. 3 | Seasonal pattern of diel changes in CO_2 emission fluxes from streams. Seasonal variation in the night versus day difference of CO_2 emission fluxes (gC m^{-2} d^{-1}) grouped by riparian canopy-cover category (open, yellow; intermediate, light green; closed; dark green; 33, 16 and 17 sites and 5,780, 3,814 and 5,130 daily observations, respectively; see Methods and Supplementary Table 2). The coloured solid lines are locally weighted (loess) regression model fits for a visual interpretation. Panels at the top and bottom show extreme positive and negative values, respectively (note change in scaling). Density plots show distributions of night versus day differences of CO_2 emission fluxes (gC m^{-2} d^{-1}) grouped by canopy cover during summer. Differences between canopy levels were evaluated using the non-parametric Kruskal–Wallis test.

Temporal variation of CO_2 outgassing

Drying and diel

Water Research 271 (2025) 122870

Contents lists available at ScienceDirect

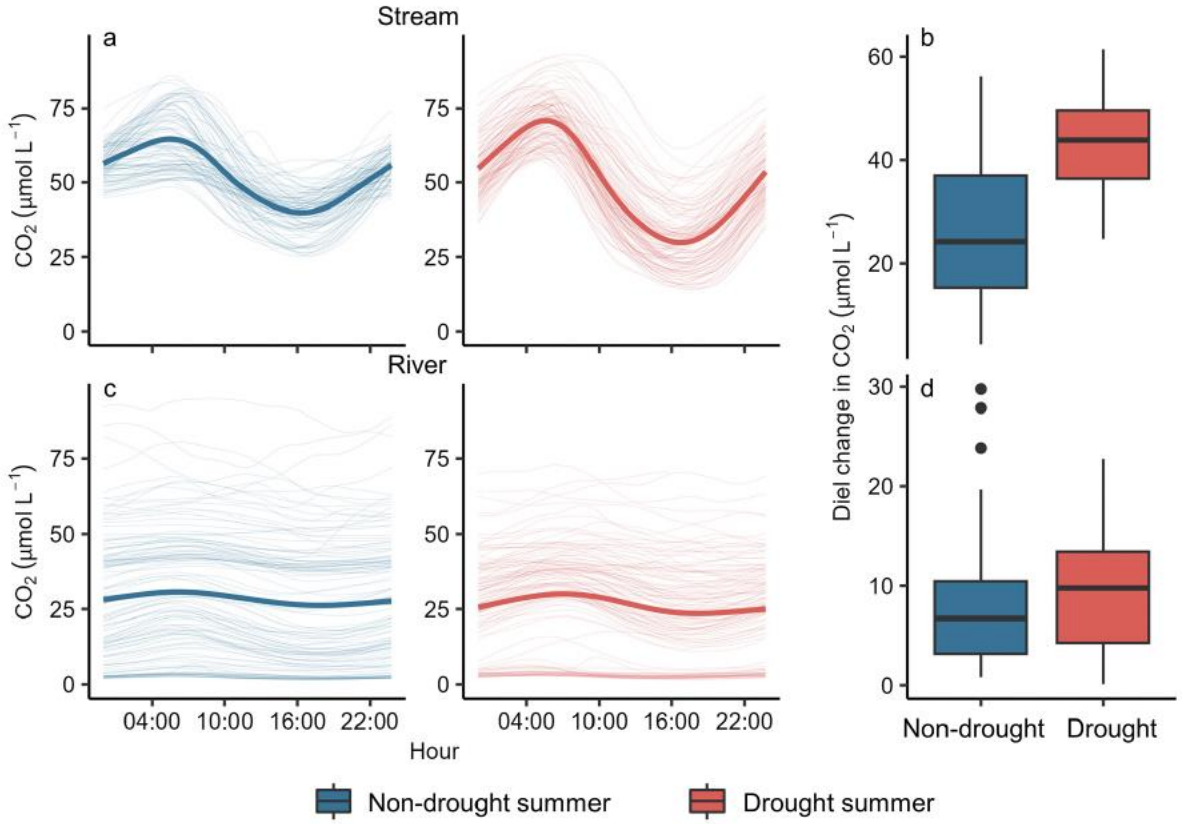
Water Research

journal homepage: www.elsevier.com/locate/watres

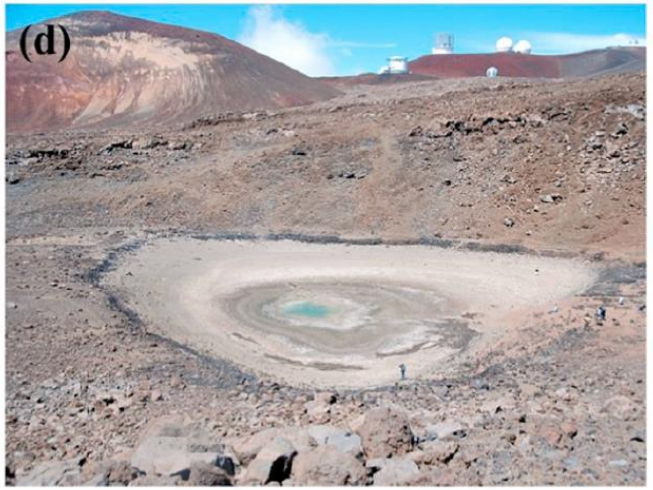
Summer drought enhances diurnal amplitude of CO_2 in two German rivers of different size

Peifang Leng [a,b,*], Michael Rode [c], Matthias Koschorreck [b]

- Stronger diel variation in CO_2 concentration in small streams compared to larger rivers
- Drought effect on diel variation stronger in streams
- Attributable to decreasing depth, rather than temperature and light availability – probably linked to oxygenation



Greenhouse gas emissions from drying streams and rivers



Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Emissions from dry inland waters are a blind spot in the global carbon cycle

Rafael Marcé[a], Biel Obrador[b], Lluís Gómez-Gener[c], Núria Catalán[a], Matthias Koschorreck[d], María Isabel Arce[e], Gabriel Singer[e], Daniel von Schiller[f,*]

- Climate change
- Irrigation
- Water diversion

Greenhouse gas emissions from drying streams and rivers

Received: 28 December 2022 | Revised: 31 July 2023 | Accepted: 18 August 2023
DOI: 10.1111/fwb.14172

REVIEW

Freshwater Biology WILEY

Greenhouse gas dynamics in river networks fragmented by drying and damming

Teresa Silverthorn[1] | Naiara López-Rojo[2] | Arnaud Foulquier[2] | Vincent Chanudet[3] | Thibault Datry[1]

Drying and rewetting streams and rivers are significant sources of greenhouse gases to the atmosphere

- Elevated temperature
- Anoxic/hypoxic conditions
- Increased residence times
- Organic matter accumulation

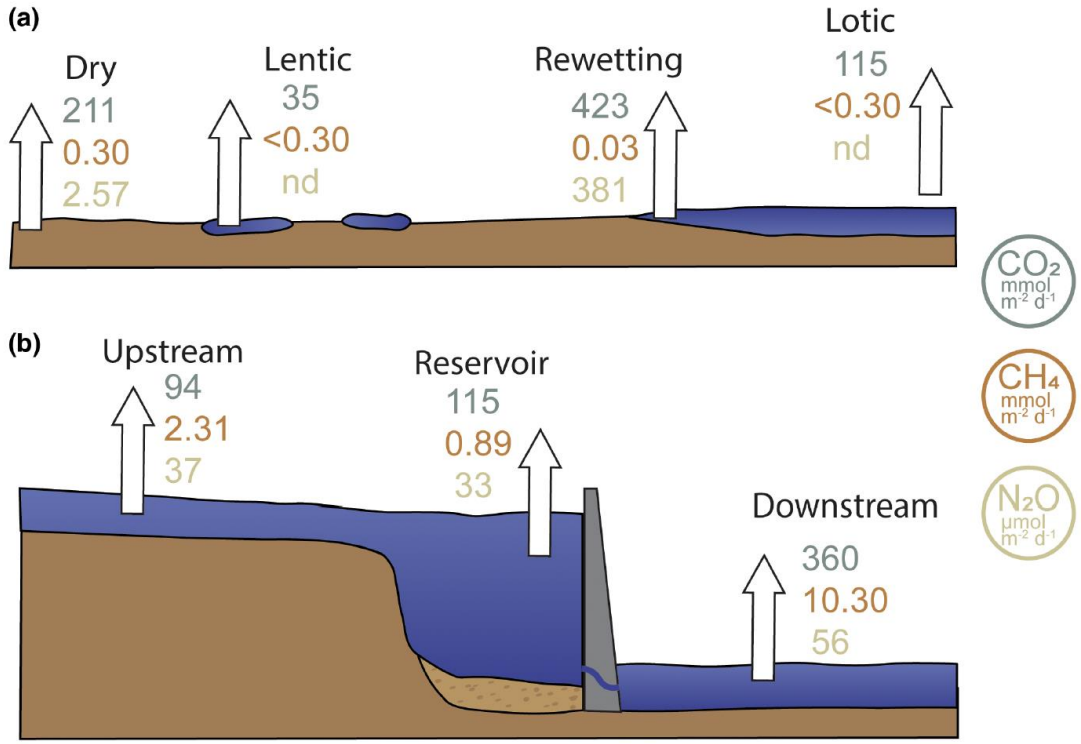


FIGURE 3 Comparison of mean greenhouse gas fluxes from dry sediments (Dry), isolated pools (Lentic), rewetting (Rewetting) and lotic waters (Lotic) in intermittent rivers and ephemeral streams (IRES) (a), as well as reservoirs and their associated (upstream and downstream) rivers (b). Carbon dioxide (CO_2) and methane (CH_4), in blue and orange text, respectively, are reported in units of (mmol m^{-2} day^{-1}). Nitrous oxide (N_2O), in yellow text, is reported in units of µmol m^{-2} day^{-1}. nd, no available data from our literature search. For the full data from our literature review used to make this figure, see Tables S3–S6.

EPFL

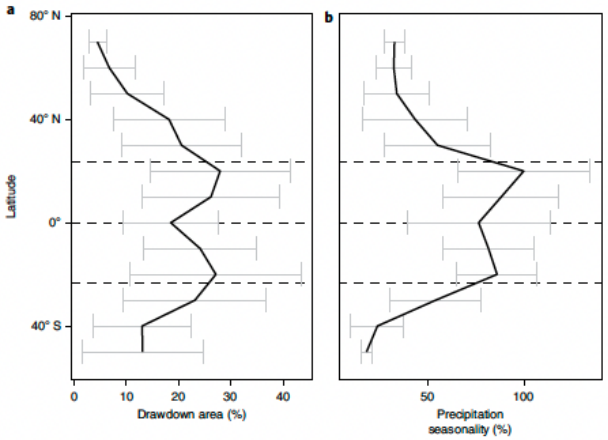
Greenhouse gas emissions from drying streams and rivers

ARTICLES
https://doi.org/10.1038/s41561-021-00734-z
nature geoscience
Check for updates

OPEN

Global carbon budget of reservoirs is overturned by the quantification of drawdown areas

Philipp S. Keller[1]✉, Rafael Marcé[2,3], Biel Obrador[4] and Matthias Koschorreck[1]



- Drawdown areas significantly contribute to areal extent to reservoirs
- Increasing trend with warming and droughts

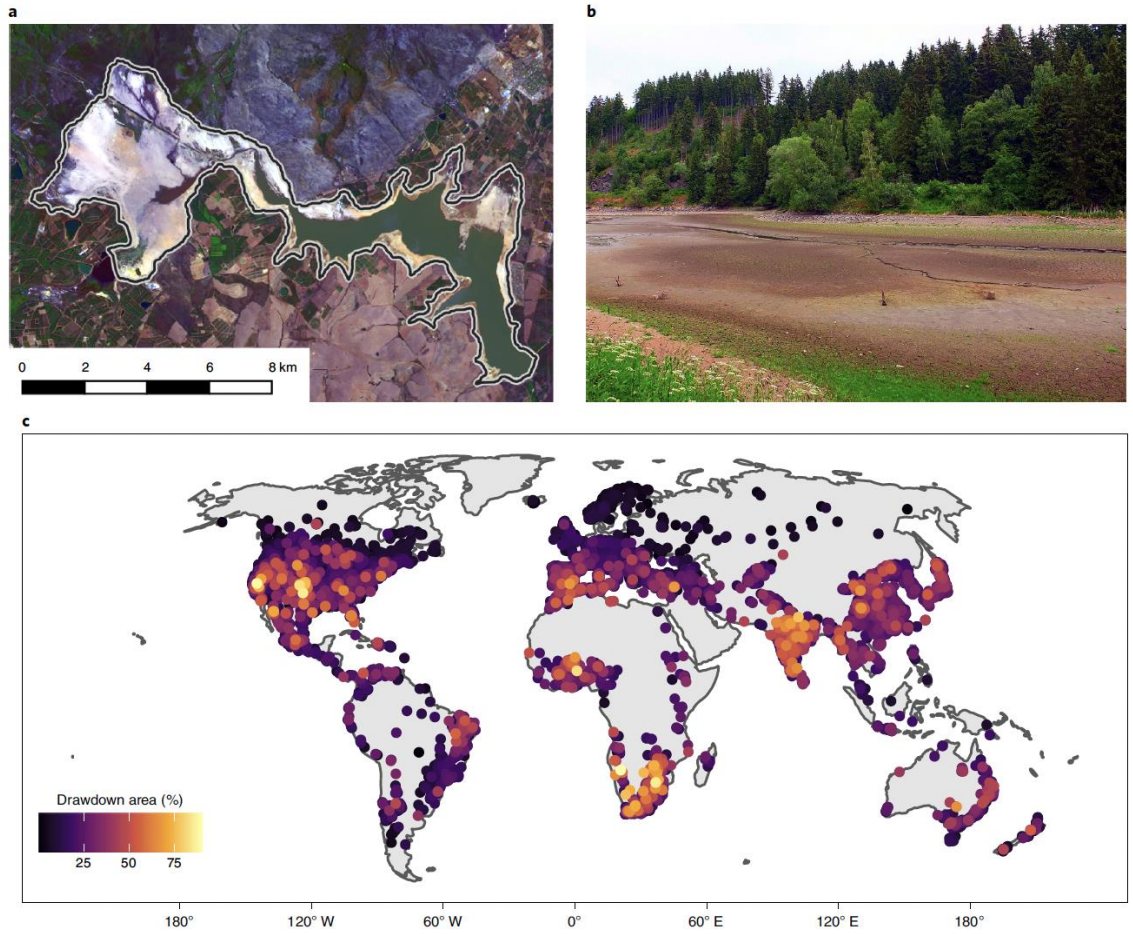


Fig. 1 | The world's reservoir drawdown areas. a, Theewaterskloof Dam, South Africa, during the water crisis of 2018. The black/white line shows the reservoir margin at maximum capacity[31]. Drawdown area = 73% of maximum reservoir area. **b**, Dry part of Hassel pre-dam, Germany, 2014. **c**, Global distribution of 6,749 reservoir drawdown areas. Colours indicate average drawdown area during the period 1985–2015 as percentage of maximum reservoir area. Landsat-8 image in **a** courtesy of USGS; photograph in **b** courtesy of Kurt Friese.

Greenhouse gas emissions from drying streams and rivers

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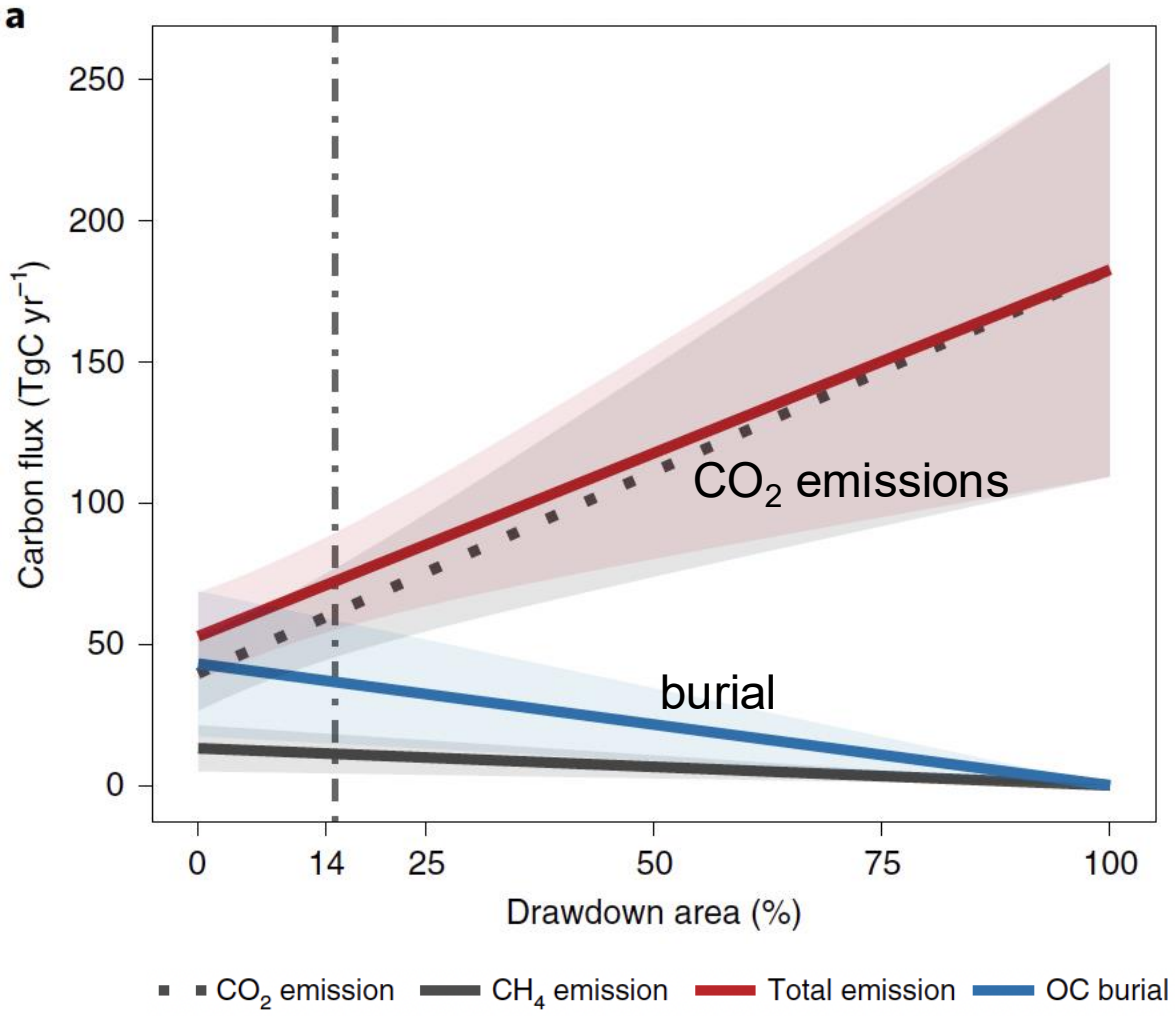
OC burial in reservoirs decreases with drawdown area, CO_2 emissions increase

Therefore, elevated net loss flux of carbon with increasing drawdown area



Greenhouse gas emissions from drying streams and rivers

ARTICLES
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nature geoscience
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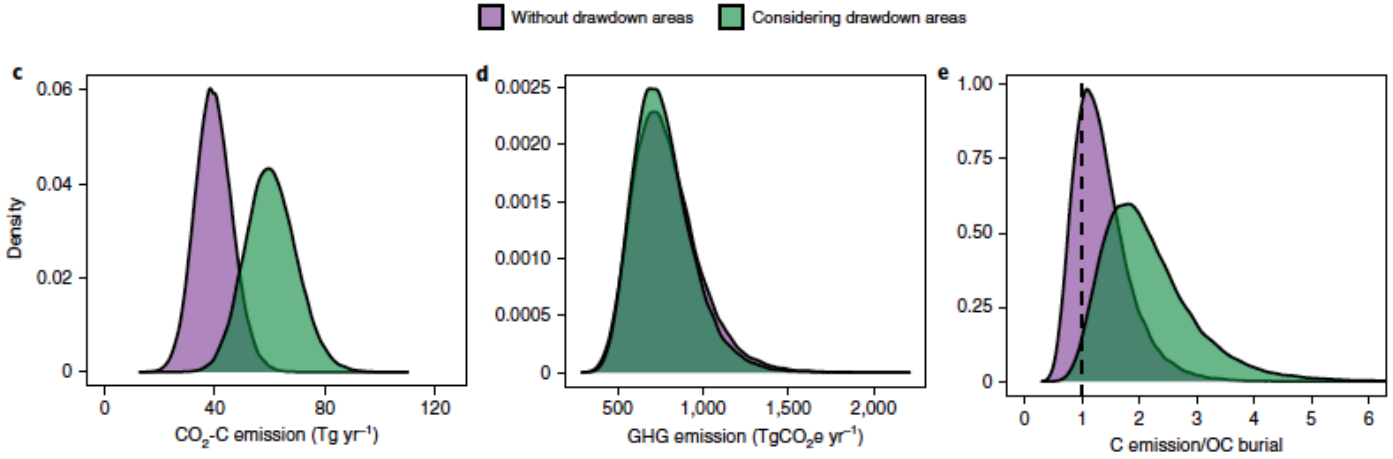
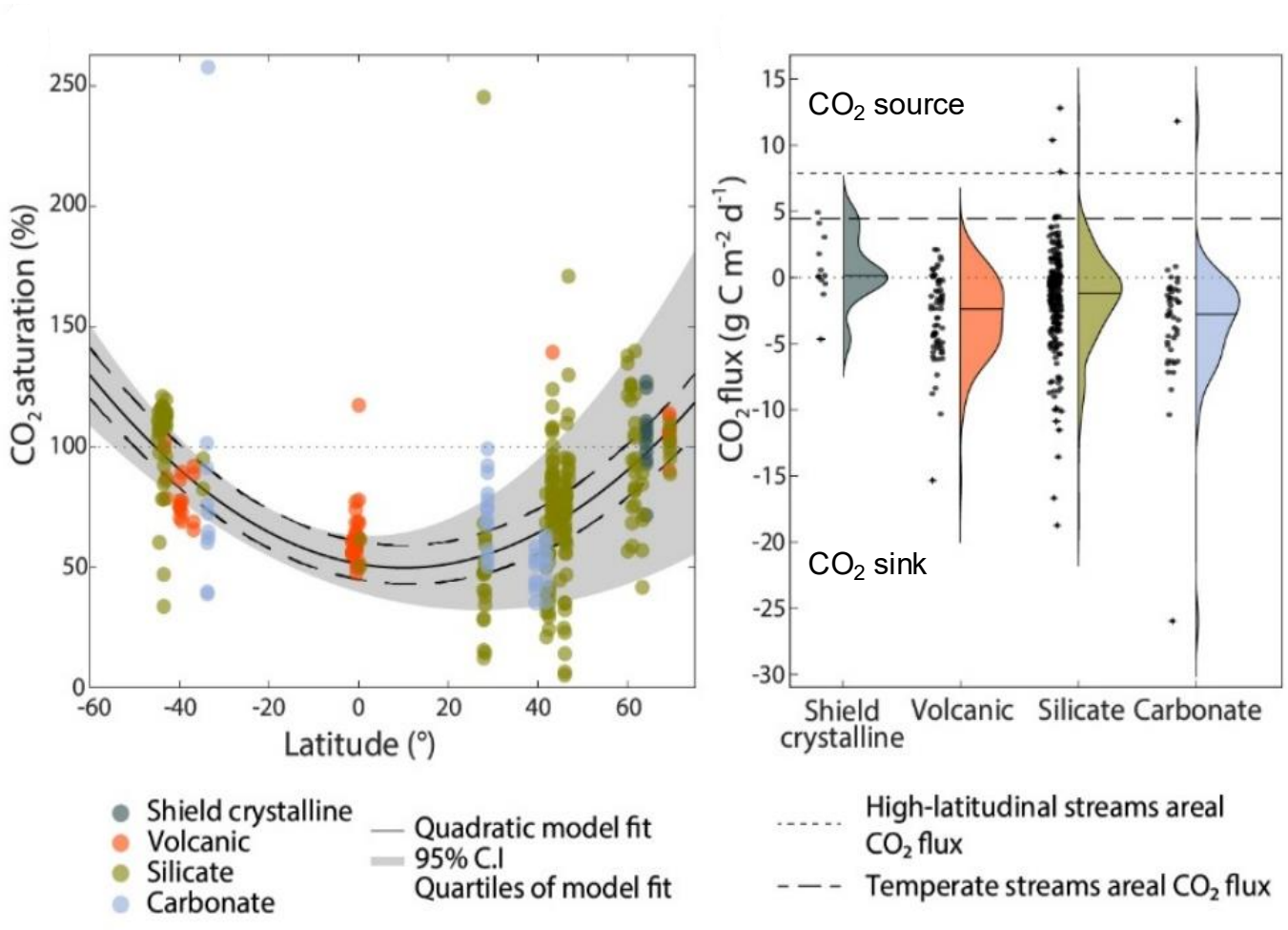


Most streams are CO_2 emittors, but not all!

Glacier-fed streams and lakes

- Glacier-fed streams are CO_2 sinks depending on parent geology
- Chemical weathering consumes CO_2
- Likely in equilibrium with the atmosphere before industrialisation



Styllas et al. in review

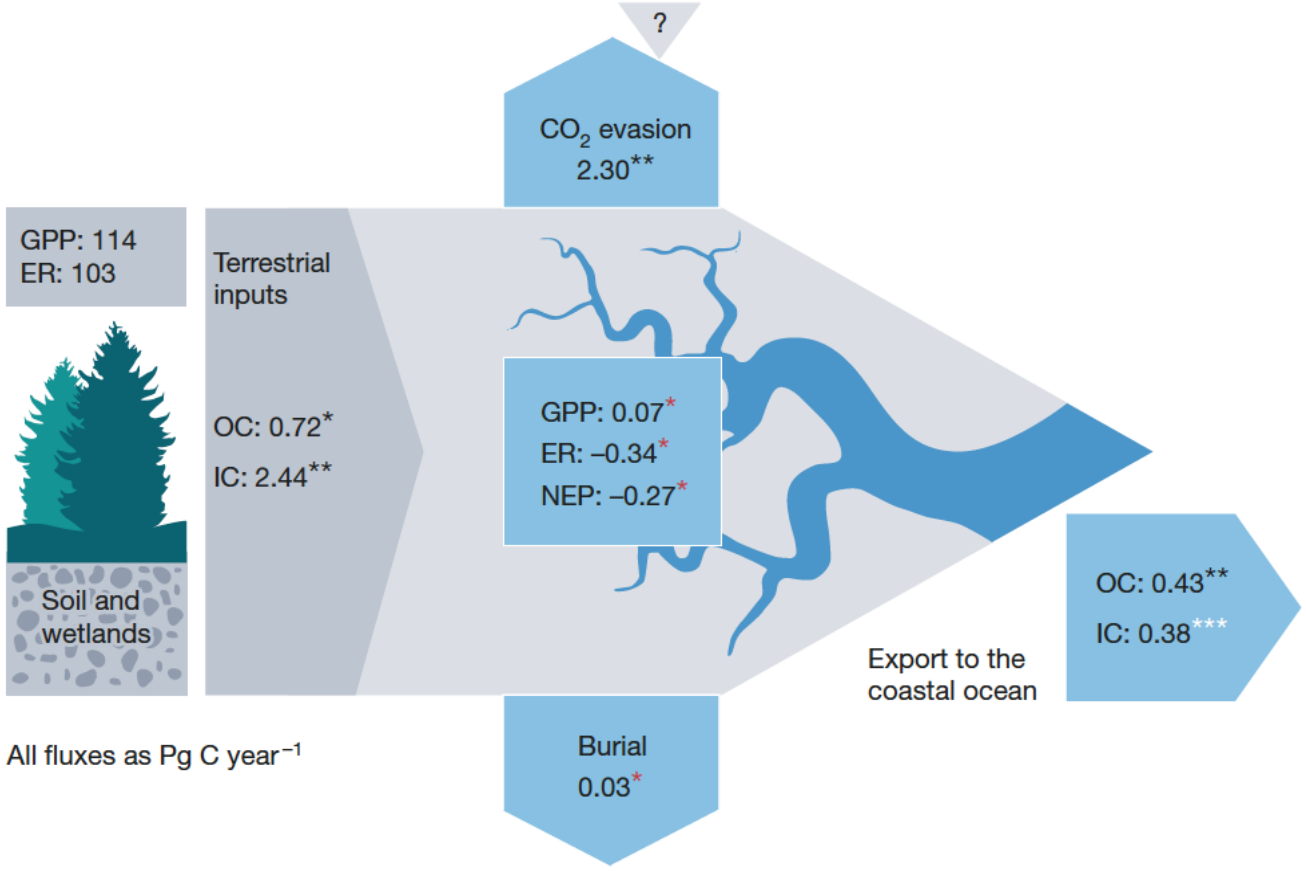
Streams and rivers are major components of the global

Review

River ecosystem metabolism and carbon biogeochemistry in a changing world

https://doi.org/10.1038/s41586-022-05500-8
Received: 12 March 2021
Accepted: 31 October 2022

Tom J. Battin[1✉], Ronny Lauerwald[2], Emily S. Bernhardt[3], Enrico Bertuzzo[4], Lluís Gómez Gener[5], Robert O. Hall Jr[6], Erin R. Hotchkiss[7], Taylor Maavara[8], Tamlin M. Pavelsky[9], Lishan Ran[10,11], Peter Raymond[12], Judith A. Rosentreter[12,13] & Pierre Regnier[14]



- CO_2 emissions from streams and rivers similar to the drawdown fluxes of atmospheric CO_2 by the world's oceans
- Ecosystem metabolism contributes ca.10% to global CO_2 emissions – up to 90% locally.
- Remaining CO_2 from terrestrial primary production and chemical weathering

River networks matter for the global carbon cycle

- Contributions from river NEP to CO_2 evasion from rivers vary widely
- Depend on gas exchange rate, carbonate dissolution, photochemistry etc

LIMNOLOGY and OCEANOGRAPHY

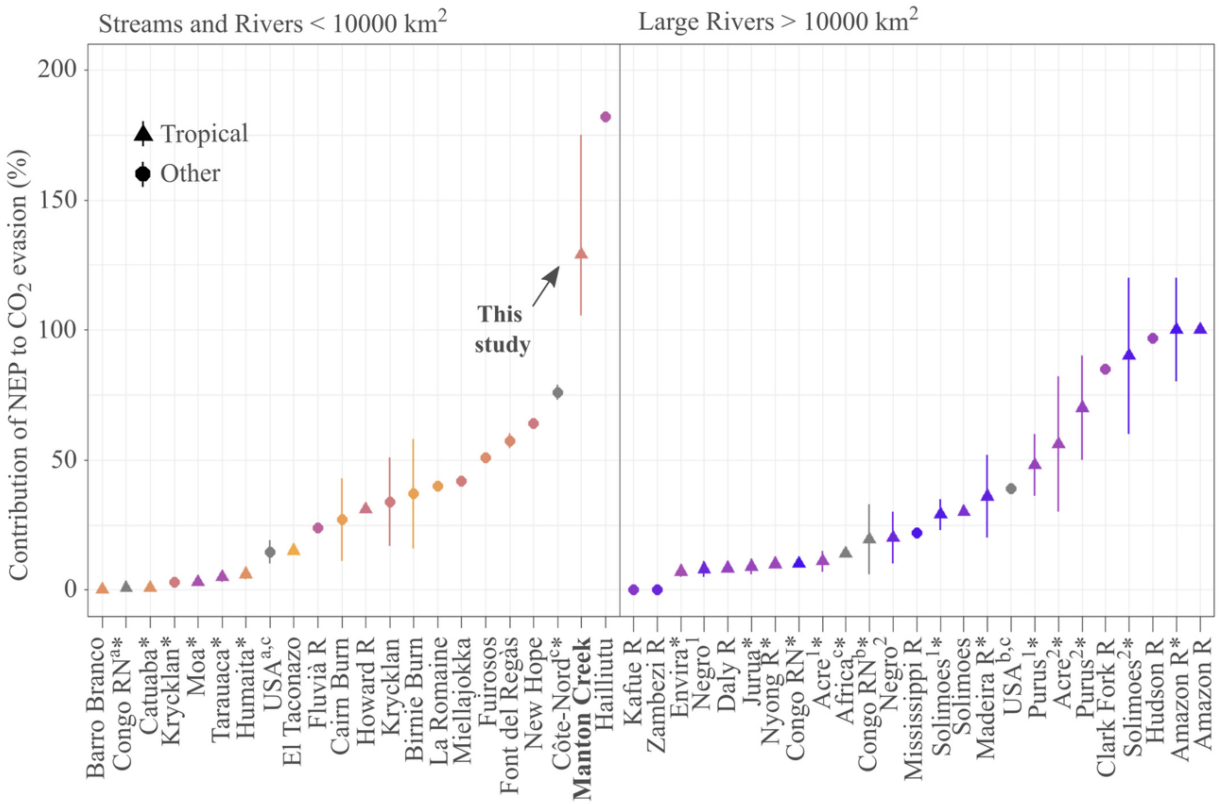
ASLO

Limnol. Oceanogr. 9999, 2023, 1–15

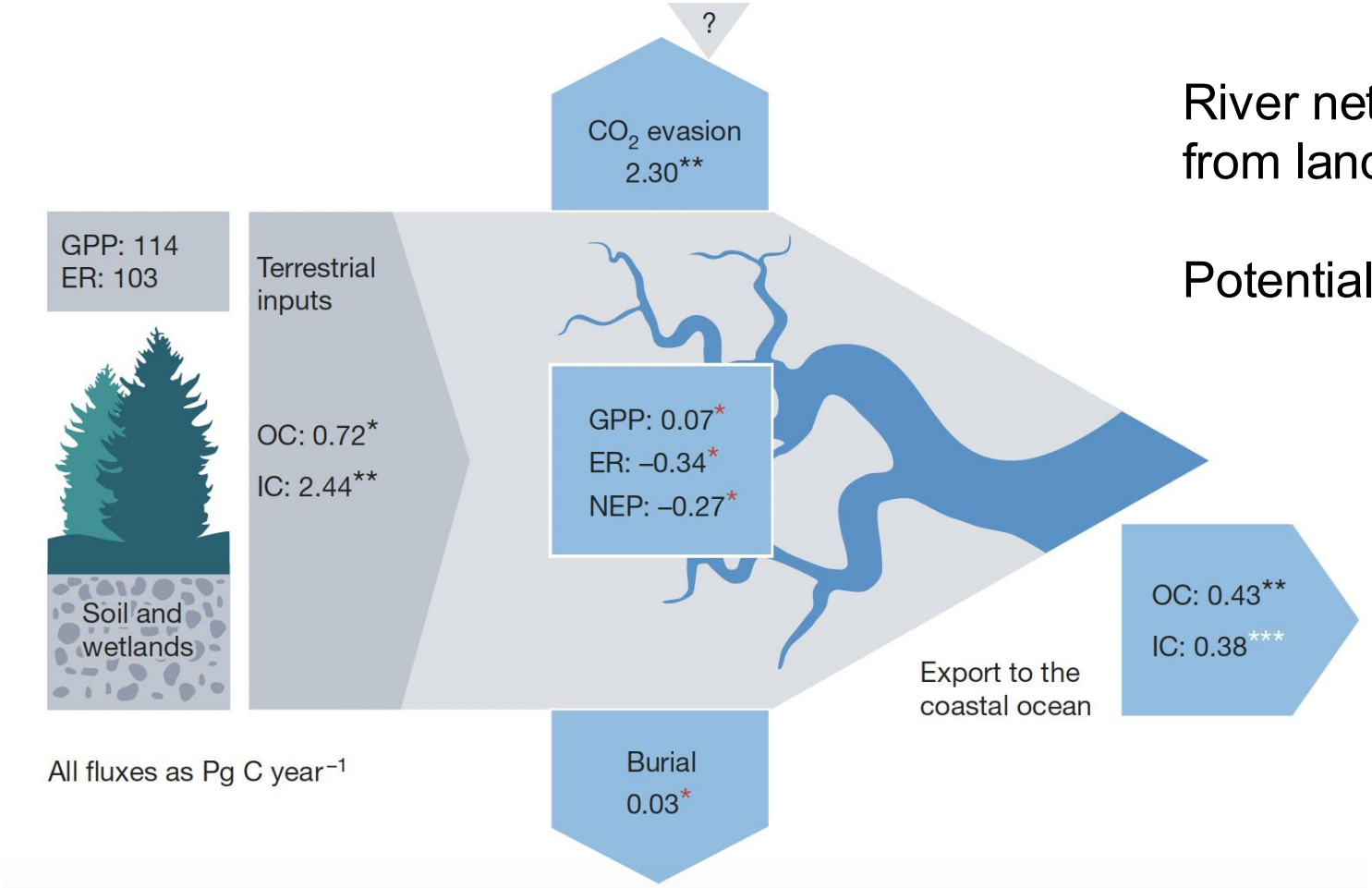
doi: 10.1002/lno.12334

Stream respiration exceeds CO_2 evasion in a low-energy, oligotrophic tropical stream

Vanessa Solano [1*] Clément Duvert [1,2*] Christian Birkel [3,4] Damien T. Maher [5] Erica A. García [1] Lindsay B. Hutley [1]



Streams and rivers are major components of the global carbon cycle



River networks shift the IC:OC ratio en route from land to the ocean

Potential impacts on coastal biogeochemistry

Stream and river networks

The multiple dimensions

Vertical

- Connected to the atmosphere through the turbulent surface
- Conencted to the groundwater

Lateral

- Connected to groundwater, riparian zone and corridor

Longitudinal

- Ample opportunities for downstream processing (see RCC)

Network

- Small streams are mots abundant and tightly connected to the terrestrial environment

Makes streams and rivers so important for carbon fluxes despite their minor contribution by alreal extent