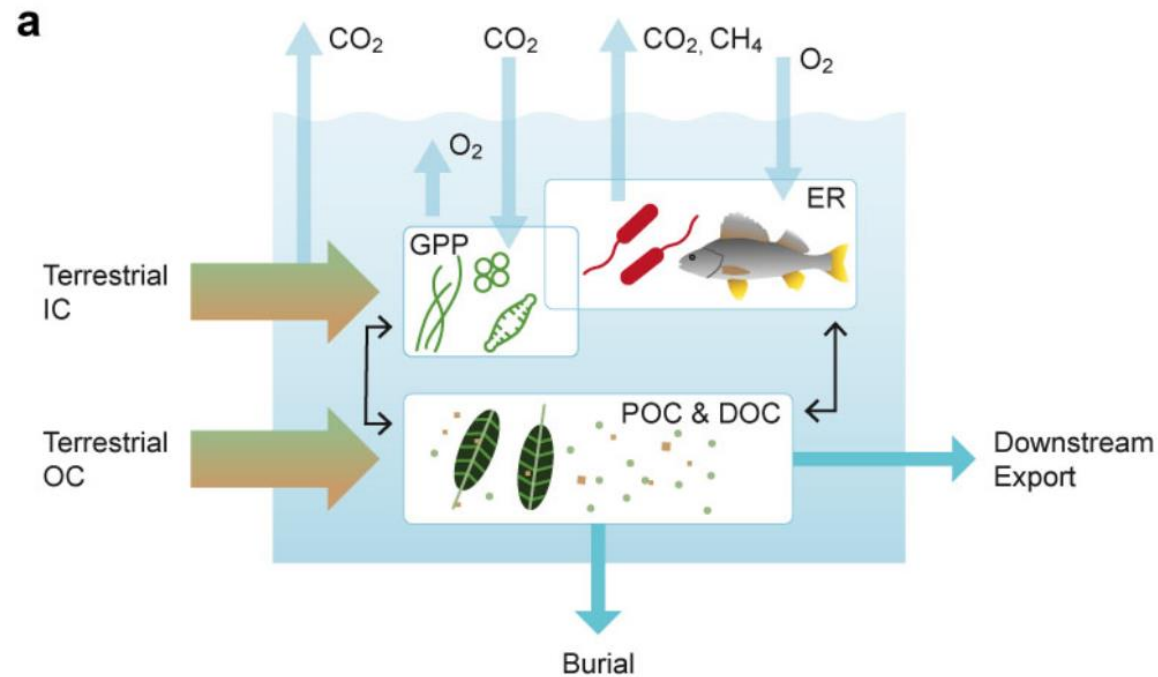


Sample questions

- Storm hydrograph separation: Draw a storm hydrograph and separate its different contributions. Discuss how some of its contributions can induce inundations and how this is influenced by catchment impermeabilisation.
- Explain hysteresis loops between discharge and solute concentrations. Elaborate on how hysteresis loops inform on solute sources and behaviour.
- Explain how streamwater turbidity, nutrient concentrations and grazing can affect ecosystem GPP.
- Explain why small, lowland streams may be particularly prone to hypoxia as streamwater temperature increases?

Ecology

Ecological communities, including diverse representatives from all three domains of life (archaea, bacteria, eukaryotes) are the engines of ecosystem processes and services



Ecology: Understand and predict the interactions within ecological communities and the environment across spatial and temporal scales

From 'biogeochemistry' to ecology

Uptake length $S_w = uh/v_f$



Vertical uptake velocity



Areal uptake flux

$$U = v_f C$$



↑ Mass transfer limitation
↓ because of too thick biomass

- S_w : travel length (m)
- v_f : vertical uptake velocity (m/s)
- U : areal uptake flux (g/m²/s)
- u : flow velocity (m/s)
- h : water depth (m)

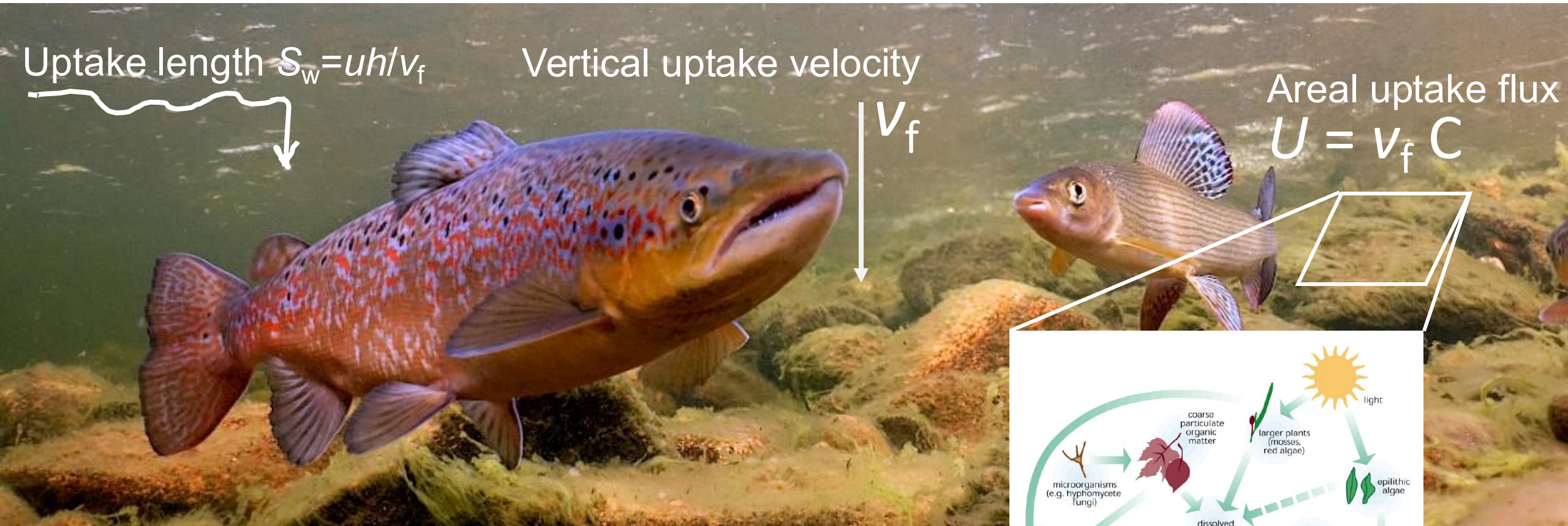
From 'biogeochemistry' to ecology

Uptake length $S_w = uh/v_f$

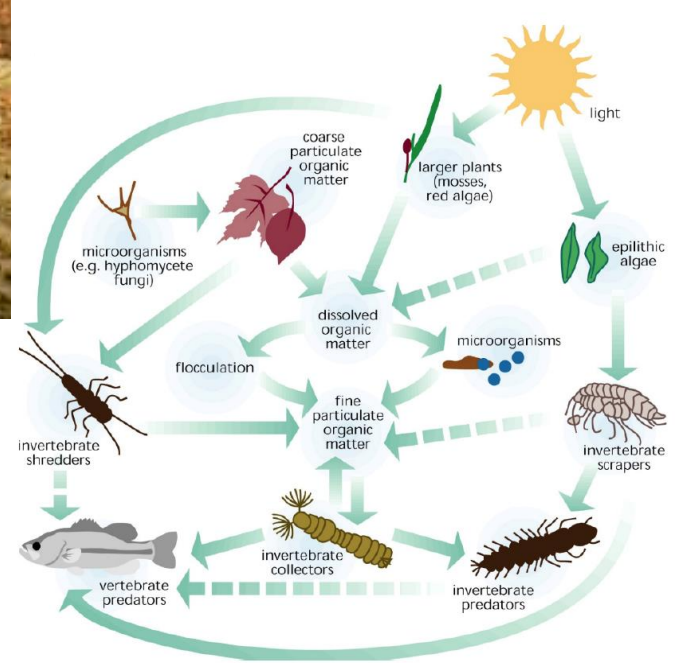
Vertical uptake velocity

Areal uptake flux

$$U = v_f C$$



Biodiversity, food webs etc

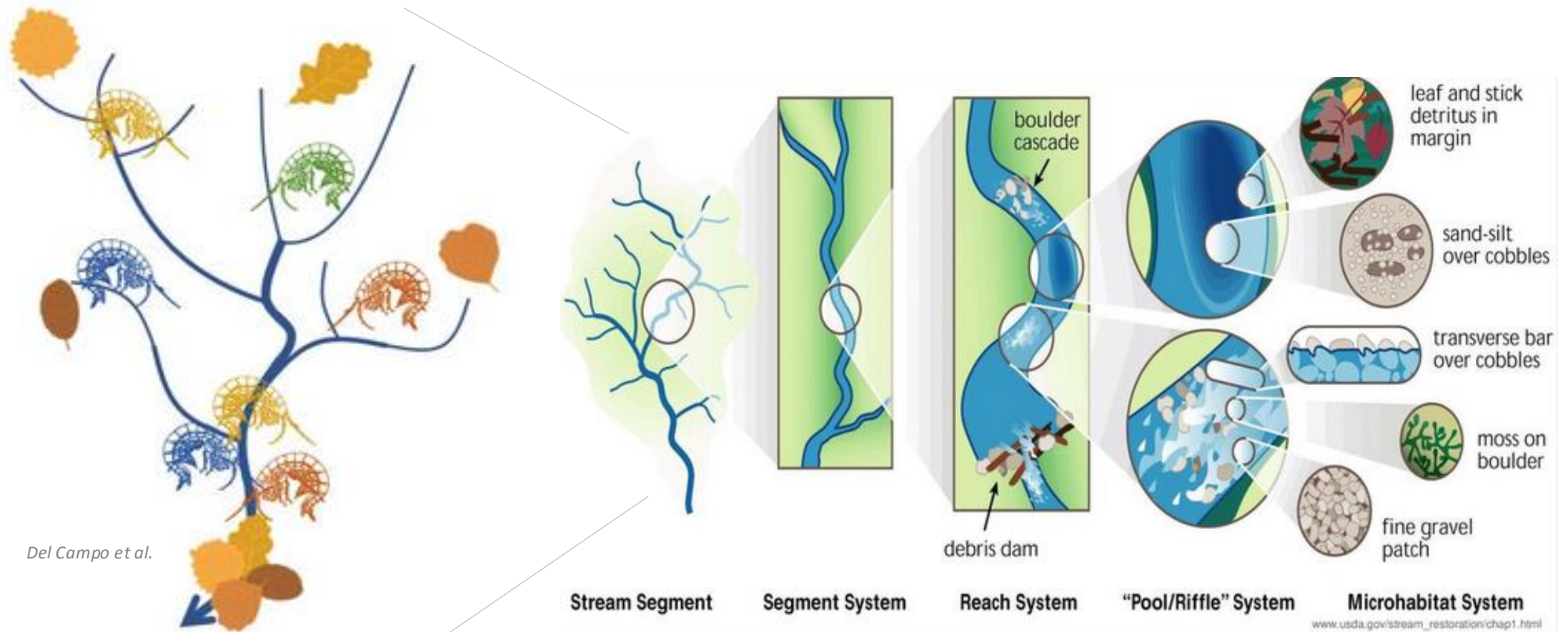


Streams and rivers are among the most biodiverse ecosystems



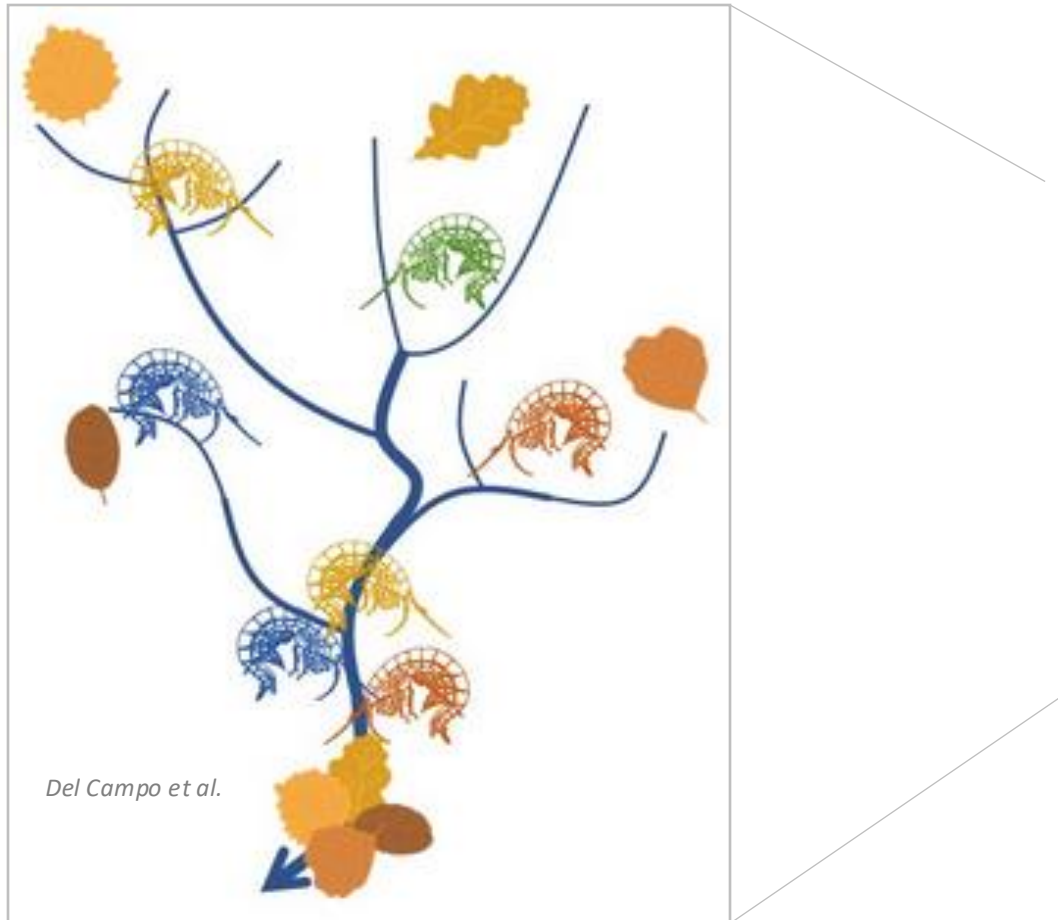
High biodiversity in stream and river ecosystems

- Hierarchical organisation
- Environmental heterogeneity (in space and time)



Hierarchical organisation of stream and river ecosystems

Environmental heterogeneity (in space and time)



- Dendritic network structure
- Spanning catchments and biomes
- Spatial isolation of headwaters
- Reduced connectivity and dispersal

Hierarchical organisation of stream and river ecosystems

Environmental heterogeneity (in space and time)



- Fluvial networks are not static
- Expansion and contraction
- Flow intermittency

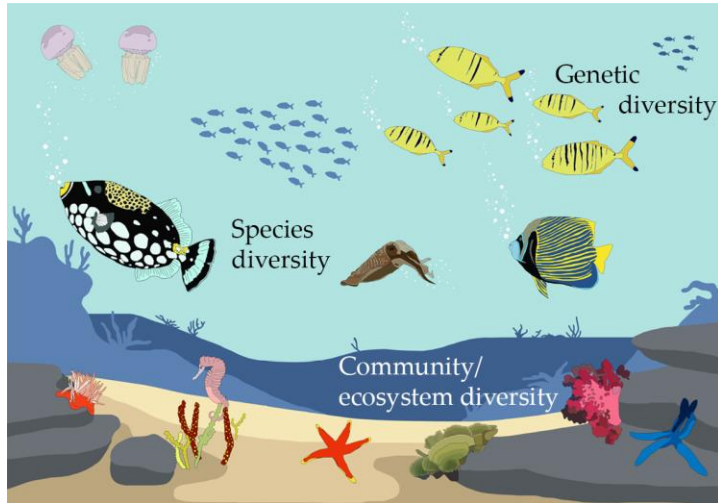
Environmental heterogeneity

What is biodiversity?

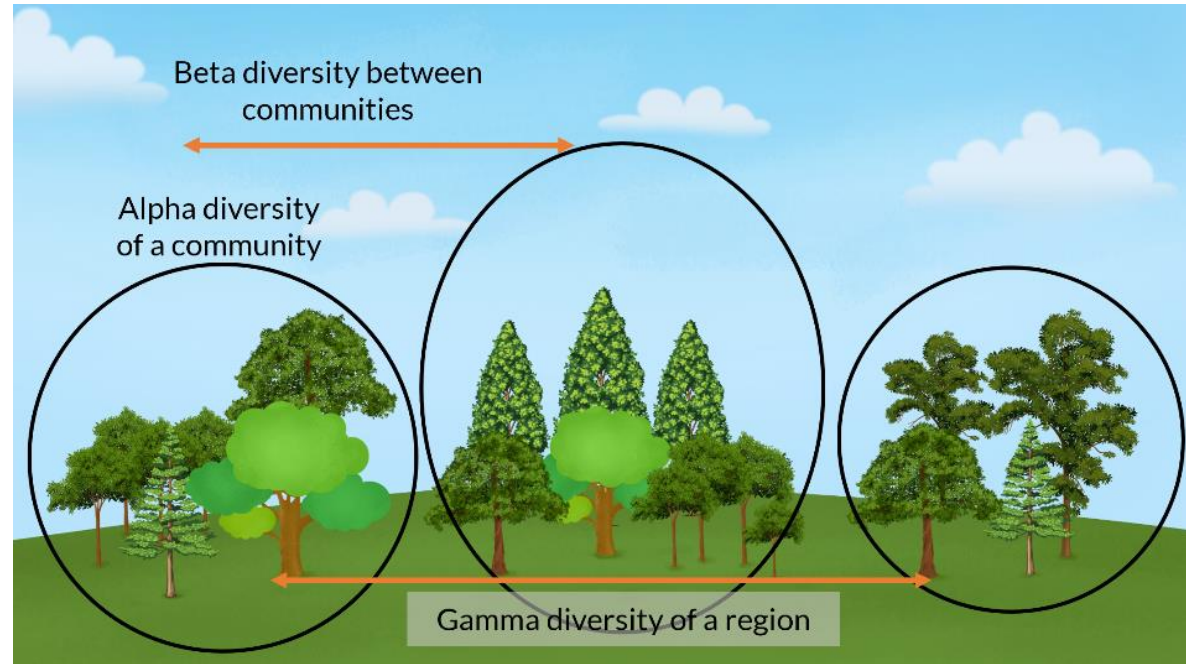
The image displays a grid of 15 educational resources related to biodiversity. Each resource is represented by a thumbnail image and a caption below it. The resources include:

- What is Green Living? What are Different Types of ...**: A circular illustration with the word "Biodiversity" in the center, surrounded by various animals and plants.
- Trellis Group the biodiversity crisis ...**: A globe with a lush green landscape on top, featuring a tree, a giraffe, and a zebra.
- The Guardian The biodiversity crisis in numbers - ...**: A globe with a city skyline on the left and a natural landscape on the right.
- ResearchGate Download Scientific Diagram**: A circular diagram divided into segments, each showing a different ecosystem or species.
- Defenders of Wildlife Biological Diversity ...**: A collage of various animals and plants in their natural habitats.
- EuroKids Biodiversity: Engaging Ways to Teac...**: A globe with a lush green landscape on top, featuring a tree, a giraffe, and a zebra.
- U.S. Environmental Pr... Biodiversity Conserv...**: A circular diagram with "Biodiversity Conservation" in the center, surrounded by various ecosystems and species.
- Exceller Open Biodiversity: Why Every Speci...**: A globe with a camel, a flamingo, and a jellyfish.
- 環境トモシル Co-creation for S... Biodiversity · Ecosystem con...**: A diagram showing "Genetic diversity", "Species diversity", and "Ecosystem diversity" with corresponding illustrations.
- AUSTRALIAN ENVIRONMENTAL EDUCATION Australian Environmental Education**: A landscape with a kangaroo, a koala, and a bird.
- HSE and Fire protection Biodiversity**: A circular illustration with the word "Biodiversity" at the top, surrounded by various animals and plants.
- Oxford Alumni - University of Oxford**: A globe with various animals and plants around it.
- Stockholm International Water Institute**: A landscape with a river, a bear, and a butterfly.
- YouTube What is Biodiversity?**: A video thumbnail with the text "What is Biodiversity?" and various animals and plants.

What is biodiversity?



- Species diversity
- Genetic diversity
- Functional diversity



Three dimensions of biodiversity

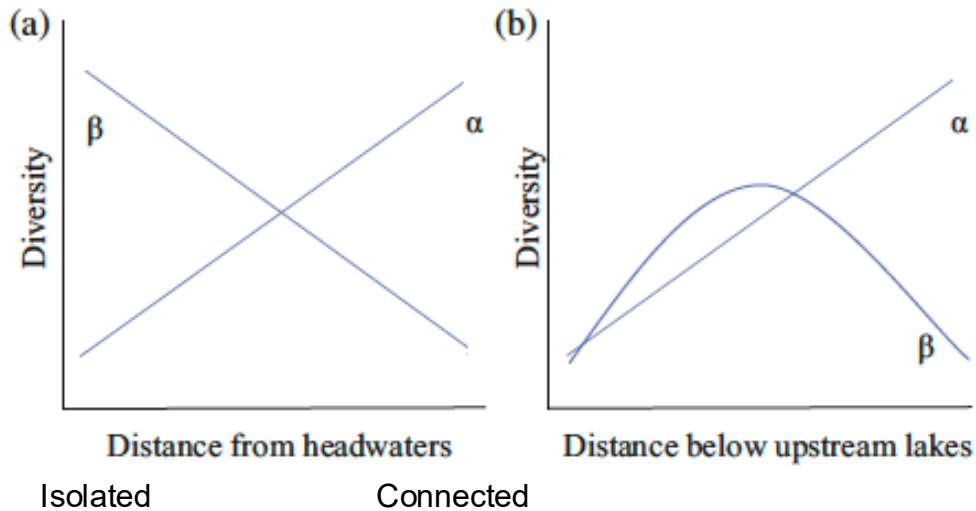
- Alpha-diversity (local species richness)
- Beta-diversity (similarity or dissimilarity between communities)
- Gamma-diversity (total diversity — at regional scale)

[gamma diversity = alpha diversity x beta diversity]

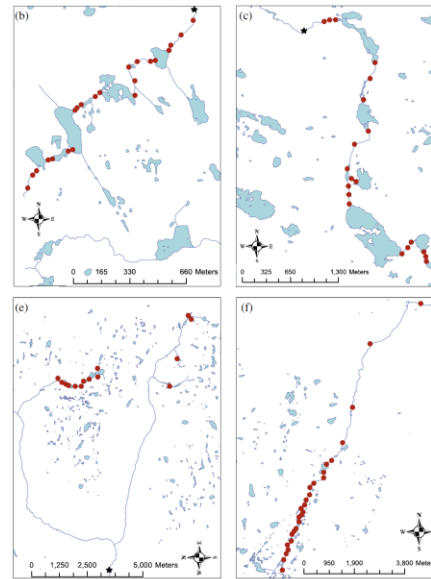
Stream and river biodiversity in space and time

Rethinking biodiversity patterns and processes in stream ecosystems

Matthew D. Green¹ | Kurt E. Anderson¹ | David B. Herbst^{2,3} | Marko J. Spasojevic¹



Mighty headwaters hypothesis: beta diversity is highest in headwaters and decreases moving downstream, showing an inverse relationship with local diversity. Due to the spatially isolated nature of headwaters, high environmental heterogeneity among headwaters, and their abundance relative to the total stream length, headwaters contribute strongly to gamma diversity through high beta diversity.



Alpha- and beta- diversity change inversely downstream across a river network

- Spatial isolation of headwaters at the tips of the river network — high beta diversity
- Little exchange (dispersal) between headwaters
- Downstream systems collect diversity from upstream, hence alpha diversity increases

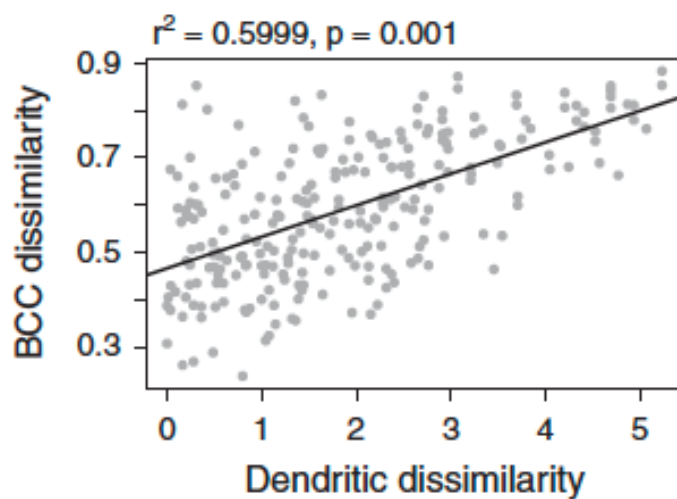
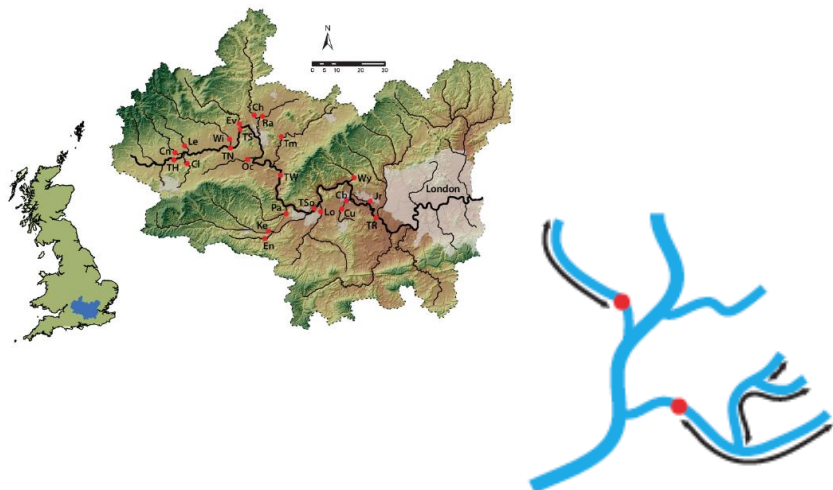
Lakes can interrupt the downstream gradient of beta-diversity

- Homogenisation reduces beta-diversity (elevated similarity)
- Effect decreases downstream

ORIGINAL ARTICLE

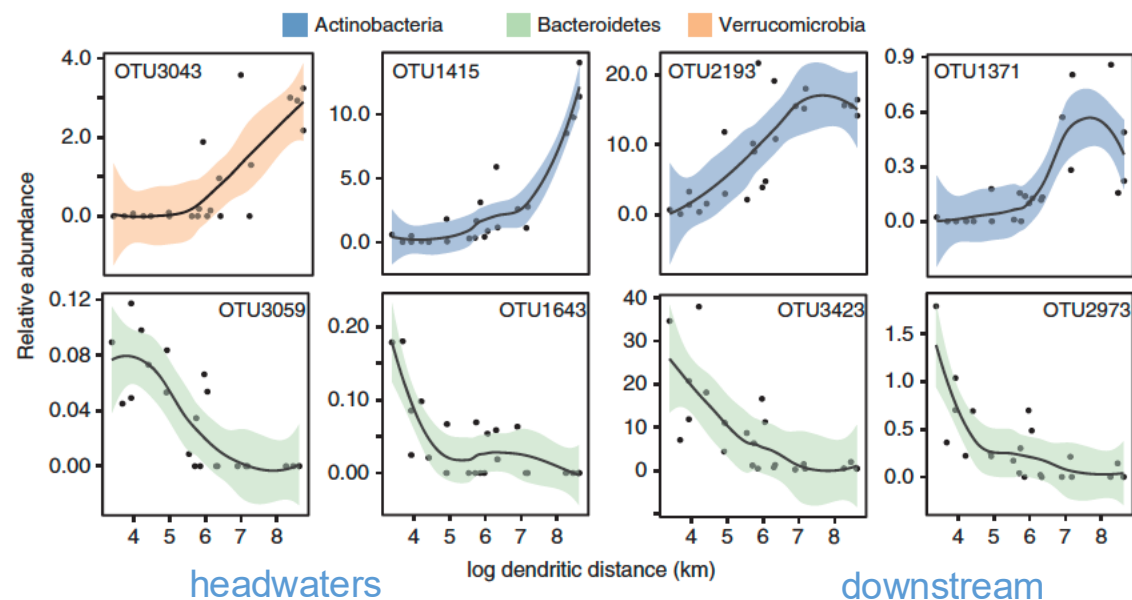
Catchment-scale biogeography of riverine bacterioplankton

Daniel S Read, Hyun S Gweon, Michael J Bowes, Lindsay K Newbold, Dawn Field, Mark J Bailey and Robert I Griffiths
Centre for Ecology & Hydrology, Wallingford, UK



Bacterial diversity is not randomly distributed across river networks

- Beta-diversity: Network structure affects community composition — highest BCC dissimilarity when dissimilarity of upstream channel is highest (environmental heterogeneity)
- Alpha-diversity: Headwaters have overall lower local diversity than downstream reaches (collection effect)
- Downstream turnover of certain bacterial groups – likely linked to lifestyle strategies



Longitudinal dimension of stream biodiversity

The River Continuum Concept¹

ROBIN L. VANNOTE

Stroud Water Research Center, Academy of Natural Sciences of Philadelphia, Avondale, PA 19311, USA

G. WAYNE MINSHALL

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Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331, USA

JAMES R. SEDELL

Weyerhaeuser Corporation, Forestry Research, 505 North Pearl Street, Centralia, WA 98531, USA

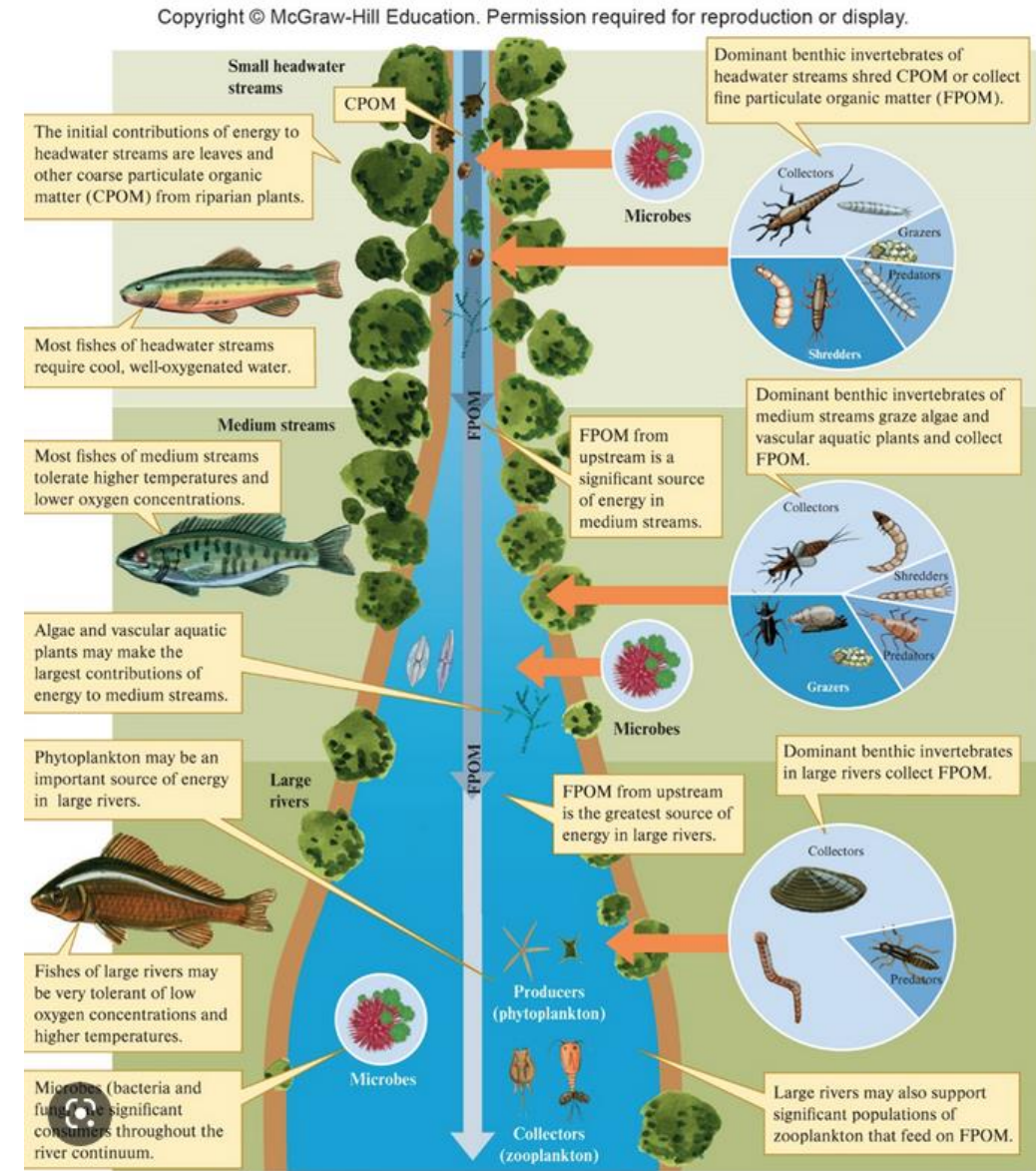
AND COLBERT E. CUSHING

Ecosystems Department, Battelle-Pacific Northwest Laboratories, Richland, WA 99352, USA

VANNOTE, R. L., G. W. MINSHALL, K. W. CUMMINS, J. R. SEDELL, AND C. E. CUSHING. 1980. The river continuum concept. *Can. J. Fish. Aquat. Sci.* 37: 130-137.

The River Continuum Context

- Geomorphology and hydraulics
- Connectivity with land
- Energy subsidies (allochthonous *versus* autochthonous)
- Ecosystem metabolism
- Biodiversity, community composition



Longitudinal dimension of stream biodiversity

The River Continuum Concept¹

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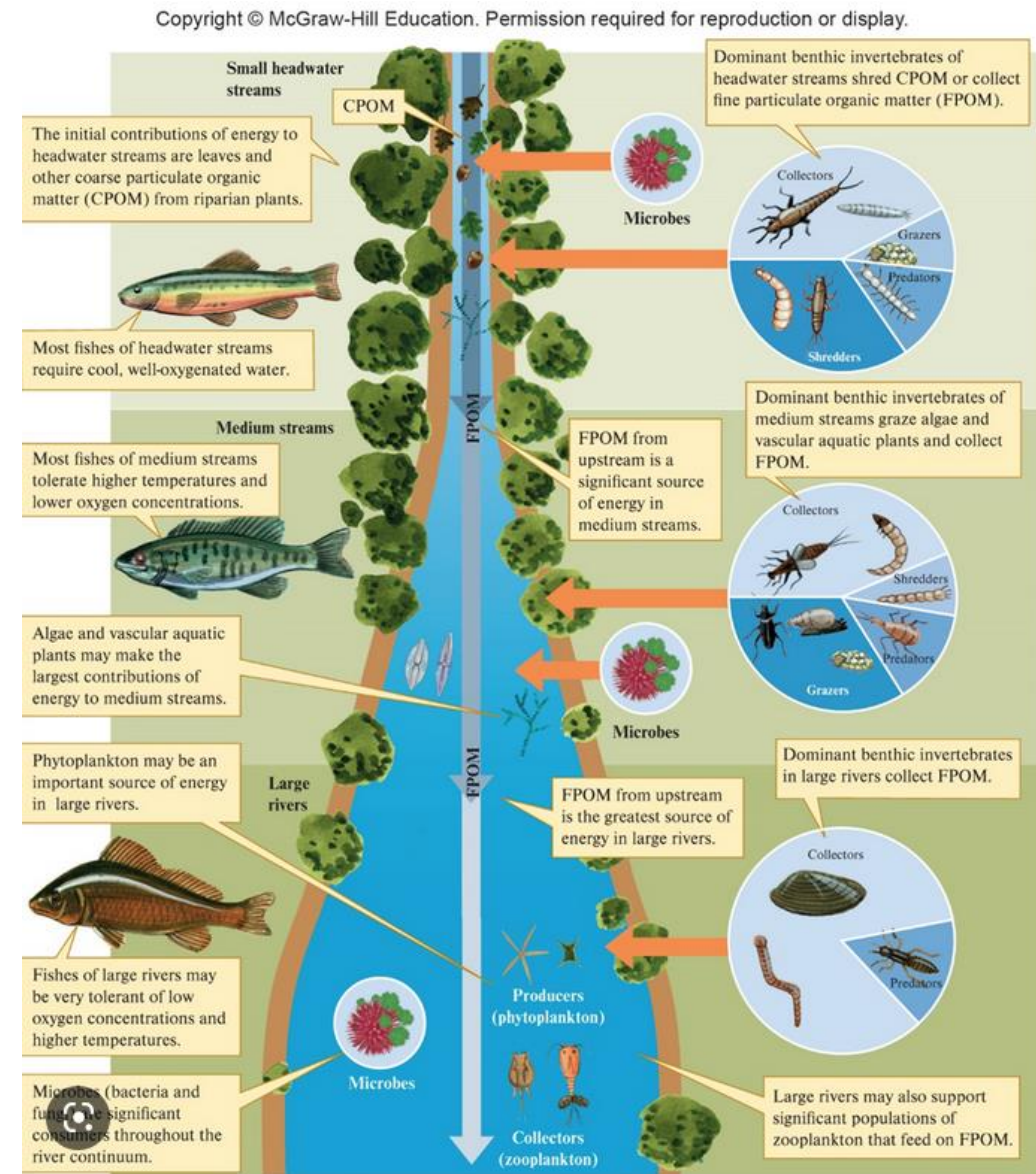
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- Macrozoobenthos communities change downstream as a function of varying resource supply
- Depending on channel geomorphology, light availability and terrestrial subsidies
- Induces changes in functional diversity as shown by functional feeding groups (i.e., grazers, shredders, collectors, filterers, predators)
- Linked to ecosystem processes (e.g., GPP)

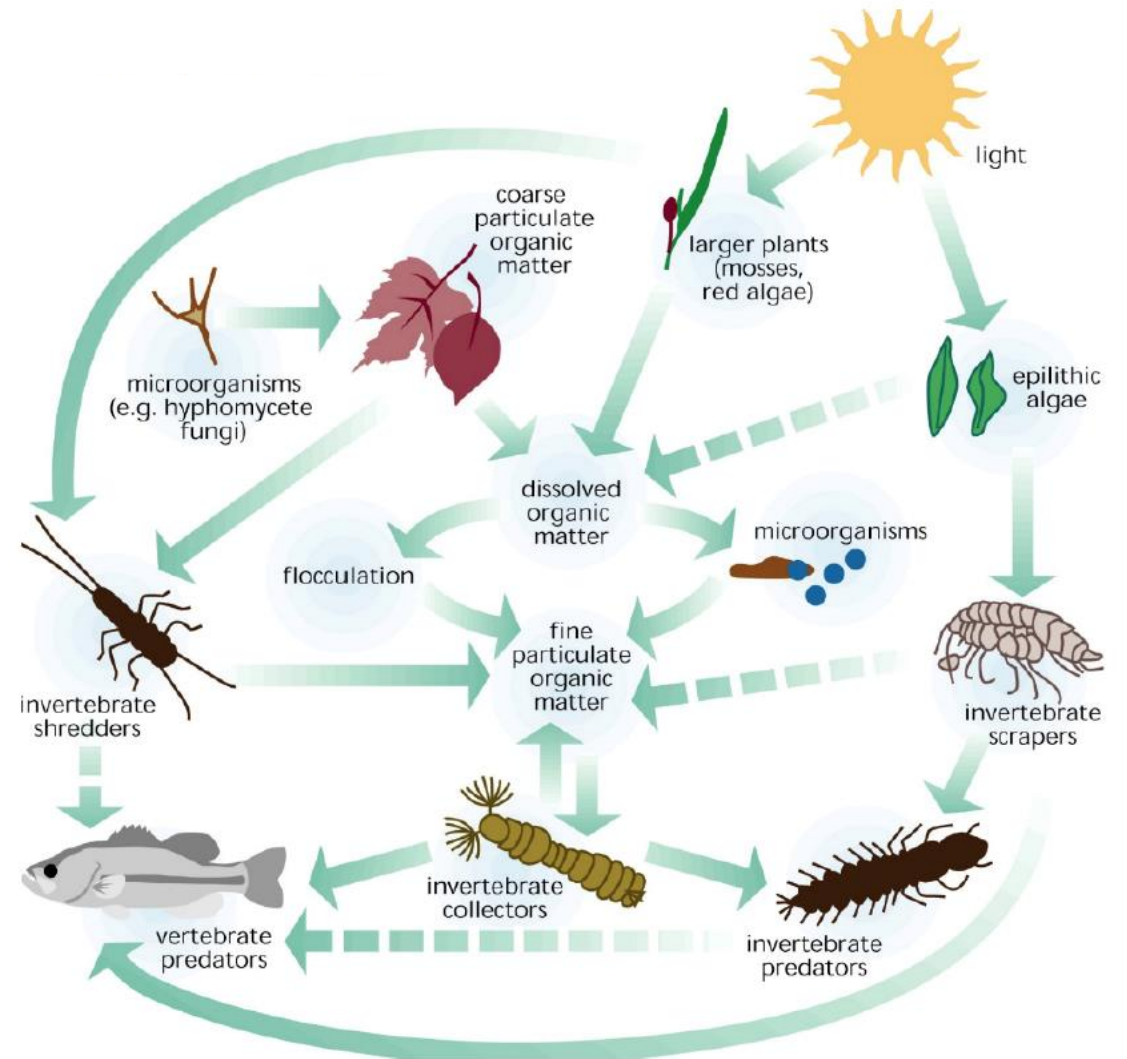


The River Continuum Context

Food web structure and energy flows along the longitudinal continuum

- Sustained by allochthonous and autochthonous energy
- Grazers and scrapers (feed on microbial biofilms/GPP)
- Shredders (feed on plant material; POM)
- Collectors (feed on suspended particles; FPOM)
- Invertebrate predators
- Vertebrate predators (e.g., fish)

Resources change with seasons

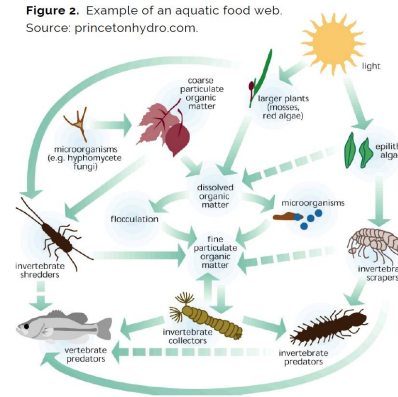


Food web structure and energy flows change with time

CURRENT EVIDENCE

Thinking like a consumer: Linking aquatic basal metabolism and consumer dynamics

Janine Rüegg ^{1,6*}, Caitlin C. Conn ², Elizabeth P. Anderson ³, Tom J. Battin ⁴, Emily S. Bernhardt ⁵, Marta Boix Canadell ⁶,
Sophia M. Bonjour ^{5,6}, Jacob D. Hosen ^{7,8}, Nicholas S. Marzoll ⁹, Charles B. Yackulic ¹⁰



Perturbing stream and river ecosystem phenology

- Climate-induced hydrological extremes (droughts, floods)
- Seasonal shifts (temperature, leaf shedding)
- Altered flow regimes (e.g., damming and hydropeaking)

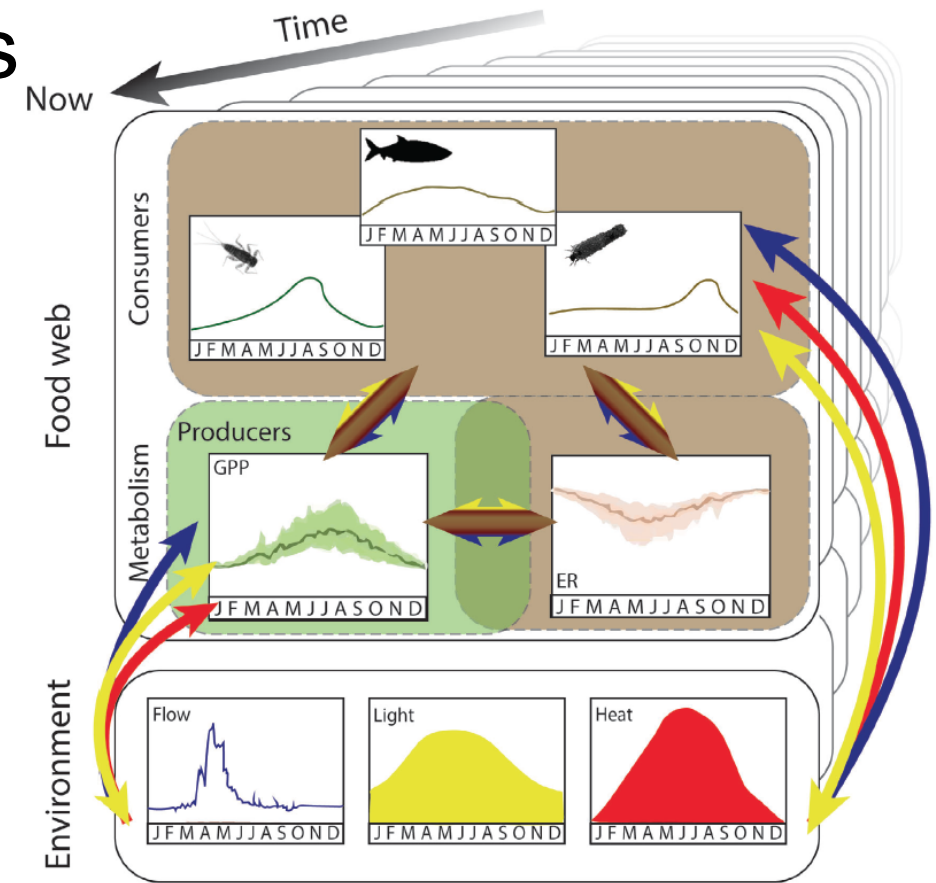
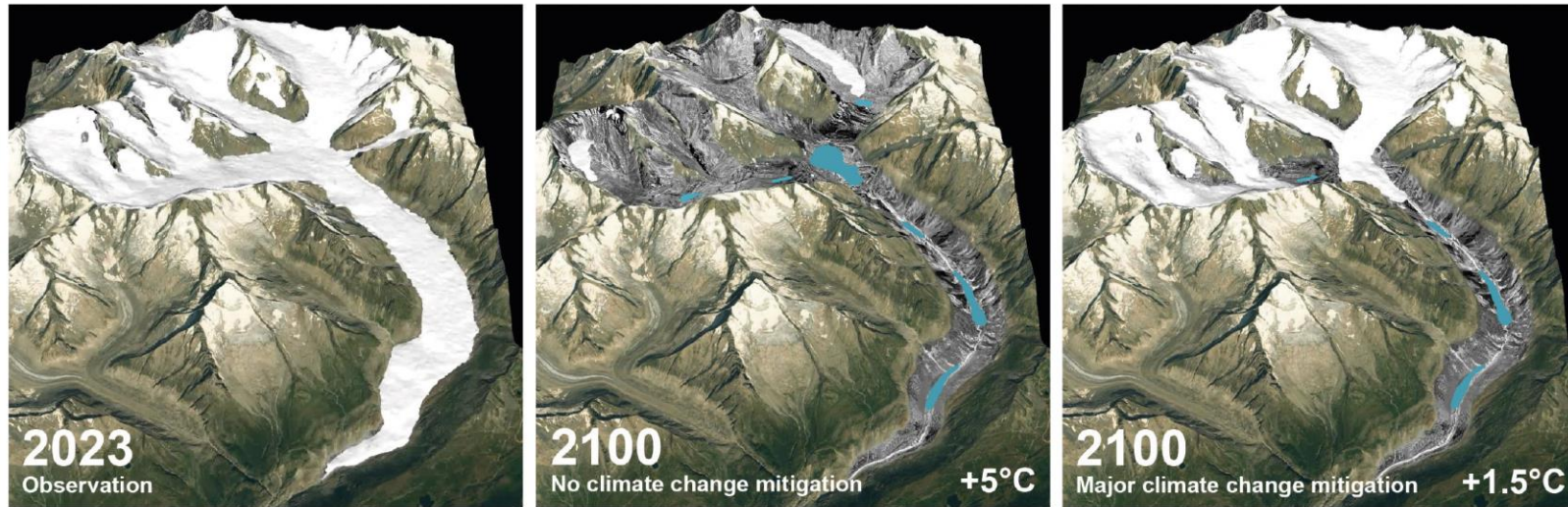


Fig. 2. Our conceptual framework considers metabolism as an emergent property of aquatic food webs. Here, we propose that the links between this emergent property and traditional, organismal-based food web ecology are modulated by the environment. The environment, here depicted as the physical stream environment including flow, light and temperature regimes, affects both the metabolic regimes via influences on GPP (indicated by the shorter blue, yellow and red arrows) and the provision of allochthonous resources, as well as the consumers directly through physiological effects (indicated through the longer blue, yellow and red arrows). Research needs to determine to what degree ER represents macroscopic consumer respiration as opposed to autotrophic or microbial respiration, and whether those ratios are altered by environmental influences (width of arrow between GPP and ER depends on the environment), and if primary production conversion to consumer production and biomass is modulated by the environment (width of arrow between ER/GPP and consumers). Consumer patterns presented here are hypothetical at the moment. The research into current patterns, here expressed on an annual basis, we believe to have developed over time to arrive at the current state of consumer traits and phenology.

Climate change and stream biodiversity



Huss et al.

Aletsch Gletscher

Stream and river biodiversity in time

Homogenisation of stream biodiversity

nature
ecology & evolution

ARTICLES

<https://doi.org/10.1038/s41559-019-1042-8>

A global synthesis of biodiversity responses to glacier retreat

Sophie Cauvy-Fraunié^{1*} and Olivier Dangles²

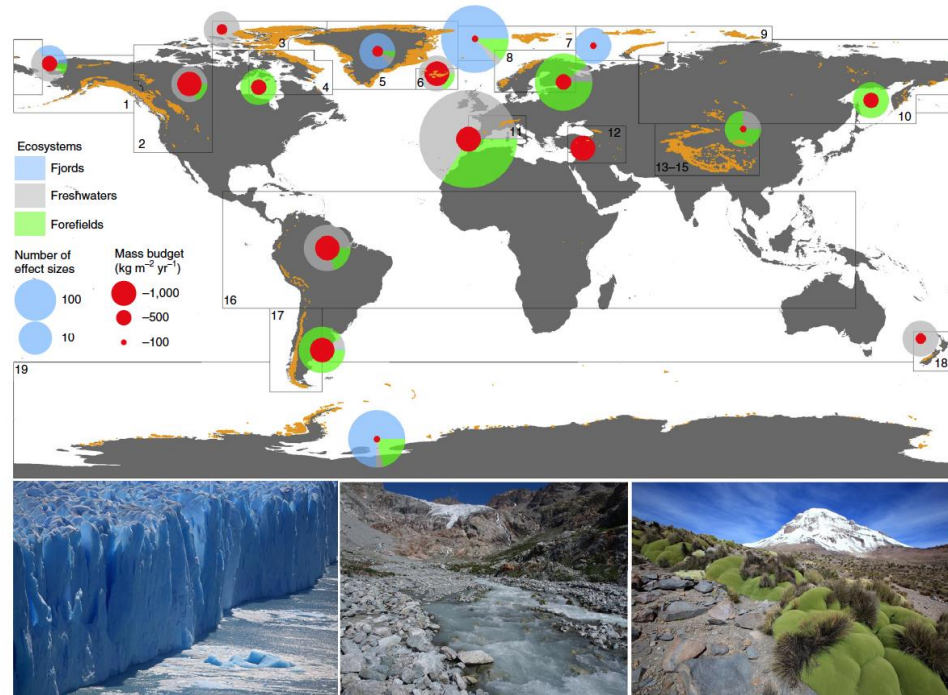
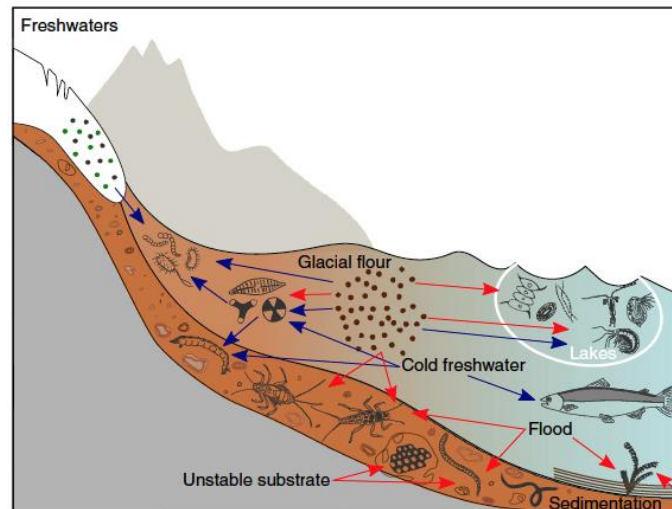


Fig. 1 | Global distribution of the biodiversity surveys analysed in this study. The map indicates the area of glaciers (orange), the rate of glacier retreat (red discs) and the number of effect sizes for abundance and richness (pie charts) for glacier-influenced fjord (blue), freshwater (grey) and forefield systems (green). Fjords are deep estuaries, carved by glaciers, that form important boundary zones between the cryosphere and the ocean. Freshwaters include streams and lakes influenced by periodic glacier melting. Glacier forefields are the leading edge of glaciers and moraines. We used the Randolph Glacier Inventory^{262,263}, which defines 17 regions with different ice mass budget ($\text{kg m}^{-2} \text{yr}^{-1}$)²⁵⁴. Photographs show (left to right) a fjord, freshwater, and forefield systems: O.D. and S.C.-F.

Glacier shrinkage impacts downstream ecosystems

- Temperature
- Turbidity and light availability
- Channel stability
- Resource availability



Stream and river biodiversity in time

Homogenisation of stream biodiversity

nature
climate change

LETTERS

PUBLISHED ONLINE: 11 MARCH 2012 | DOI:10.1038/NCLIMATE1435

Biodiversity under threat in glacier-fed river systems

Dean Jacobsen^{1*}, Alexander M. Milner^{2,3}, Lee E. Brown⁴ and Olivier Dangles^{5,6,7*}

Glacier shrinkage impacts downstream macrozoobenthos biodiversity patterns

- Overall loss and homogenisation owing to increasing similarity across communities (that is, from one to the next glacier)
- Increasing local (alpha) diversity attributed to upstream migration
- Increasing regional (gamma) diversity

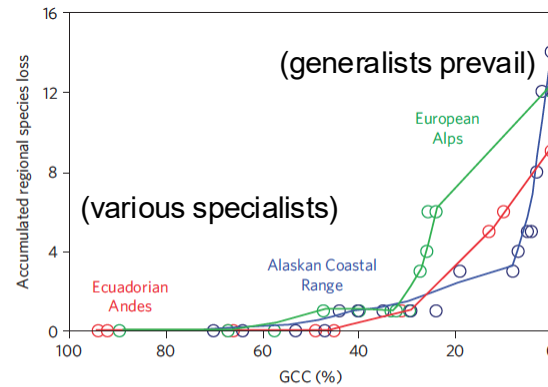


Figure 1 | Accumulated loss of regional species richness (γ diversity) as a function of glacial cover. Obligate glacial river macroinvertebrates begin to disappear from assemblages when glacial cover in the catchment drops below approximately 50%. Each data point represents a river site and lines are Lowess fits.

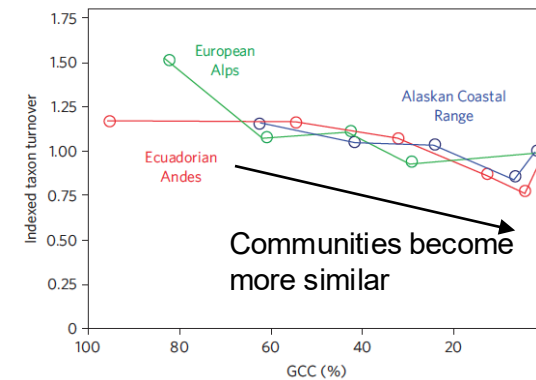


Figure 2 | Taxon turnover (β diversity) as a function of glacial cover. The data shown are for species turnover (Alaska) and family turnover (Ecuador and Alps). Assemblages at river sites close to glaciers are more spatially variable than those at sites with less glacial influence. Data are indexed to 1 at non-glacial sites (0% glacial cover). Each data point represents a river site and lines are Lowess fits.

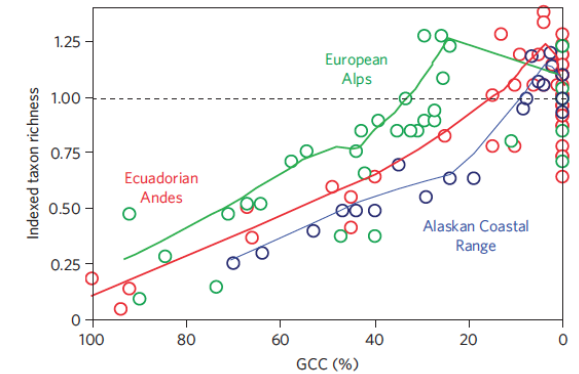
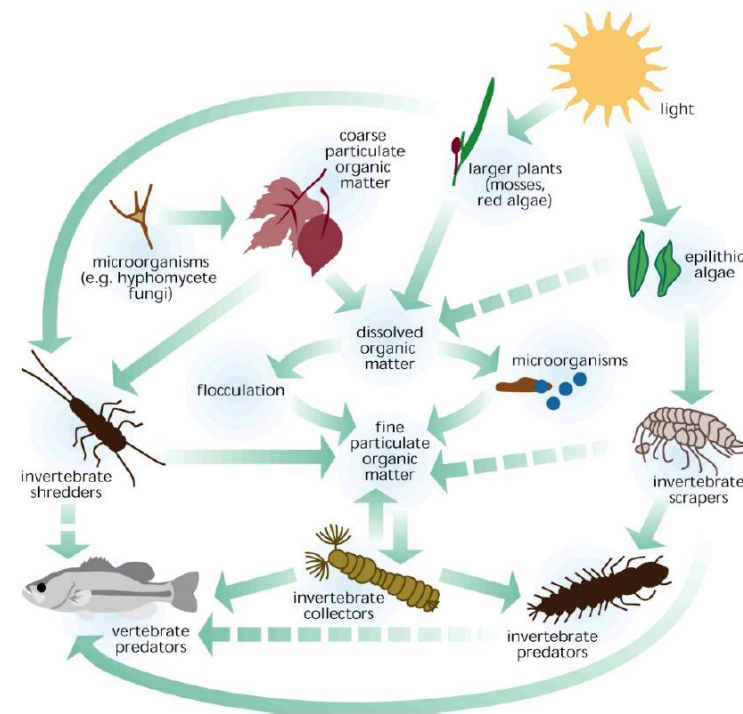


Figure 3 | Local richness (α diversity) as a function of glacial cover. The data shown are for species richness (Alaska) and family richness (Ecuador and Alps). Local taxon richness peaks at 5–30% GCC. Data are indexed to 1, indicated by the horizontal dashed line, at non-glacial sites (0% glacial cover). Each data point represents a river site and lines are Lowess fits.

GCC (glacier catchment coverage)

Direct human alterations of stream ecosystems

Pharmaceuticals and food webs



Ecosystem degradation and biodiversity loss

Loss of accumulation of pharmaceuticals



ARTICLE
 DOI: 10.1038/s41467-018-06822-w OPEN
 A diverse suite of pharmaceuticals contaminates stream and riparian food webs
 Erinn K. Richmond¹, Emma J. Rosi², David M. Walters^{3,8}, Jerker Fick⁴, Stephen K. Hamilton^{2,5}, Tomas Brodin^{6,7}, Anna Sundelin⁴ & Michael R. Grace¹

- Over 60 pharmaceutical compounds detected in aquatic invertebrates and riparian spiders in streams near Melbourne.
- Antidepressants and antibiotics!
- Anthropogenic imprint on aquatic food webs
- Impacts poorly understood – antibiotic resistance!

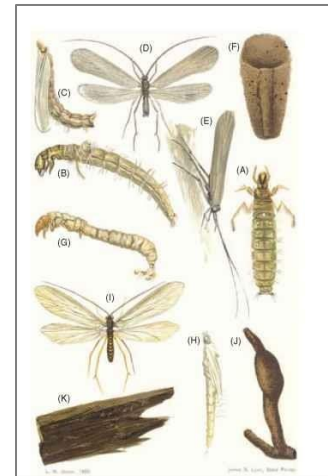
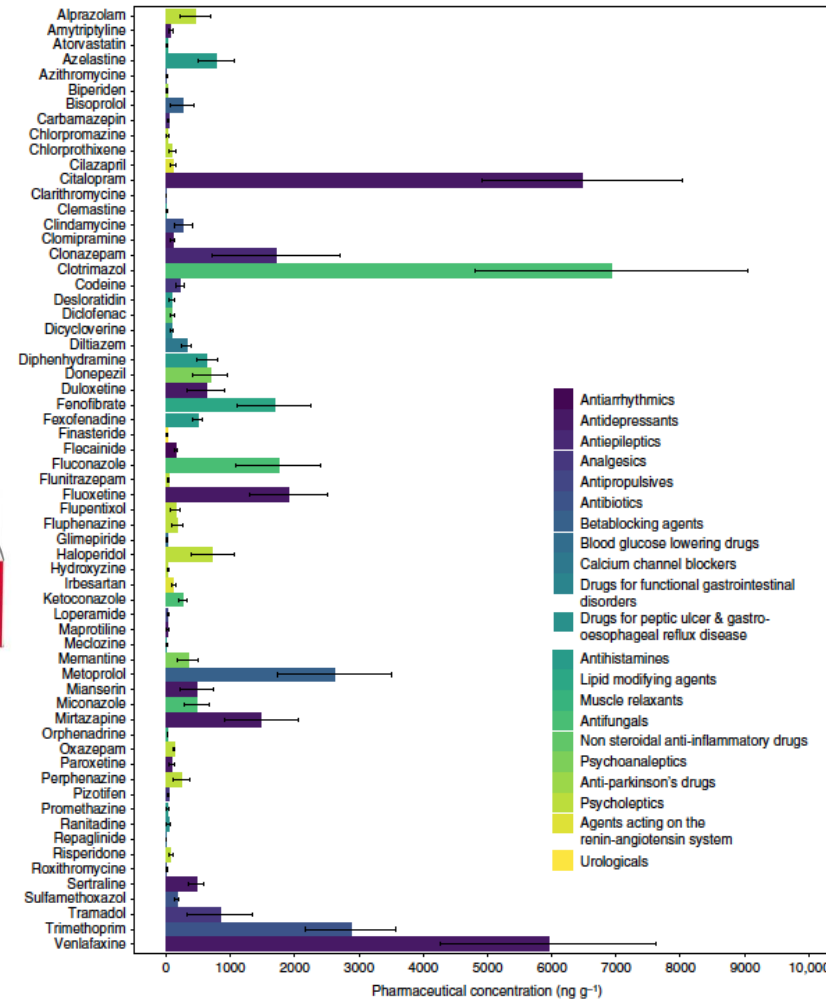


Fig. 1 Pharmaceutical concentrations in caddisfly larvae. Mean pharmaceutical concentrations (ng g⁻¹ dry weight ±1 SE) in caddisfly larvae (Hydropsychidae) (n = 6) at wastewater-influenced Brushy Creek. Each bar represents the mean concentration of a pharmaceutical compound in the six individuals collected over two sampling dates. Colours represent therapeutic drug classes

Ecosystem degradation and biodiversity

Loss of accumulation of pharmaceuticals



ARTICLE

DOI: 10.1038/s41467-018-06822-w OPEN

A diverse suite of pharmaceuticals contaminates stream and riparian food webs

Erinn K. Richmond¹, Emma J. Rosi², David M. Walters^{3,8}, Jerker Fick⁴, Stephen K. Hamilton^{2,5}, Tomas Brodin^{6,7}, Anna Sundelin⁴ & Michael R. Grace¹

- Over 60 pharmaceutical compounds detected in aquatic invertebrates and riparian spiders in six streams near Melbourne.
- Similar concentrations in aquatic invertebrate larvae and riparian predators suggest direct trophic transfer via emerging adult insects to riparian predators that consume them.
- Transfer from used waters to aquatic biomass to terrestrial predators...
- What is the next step?

Aquatic prey Terrestrial predator

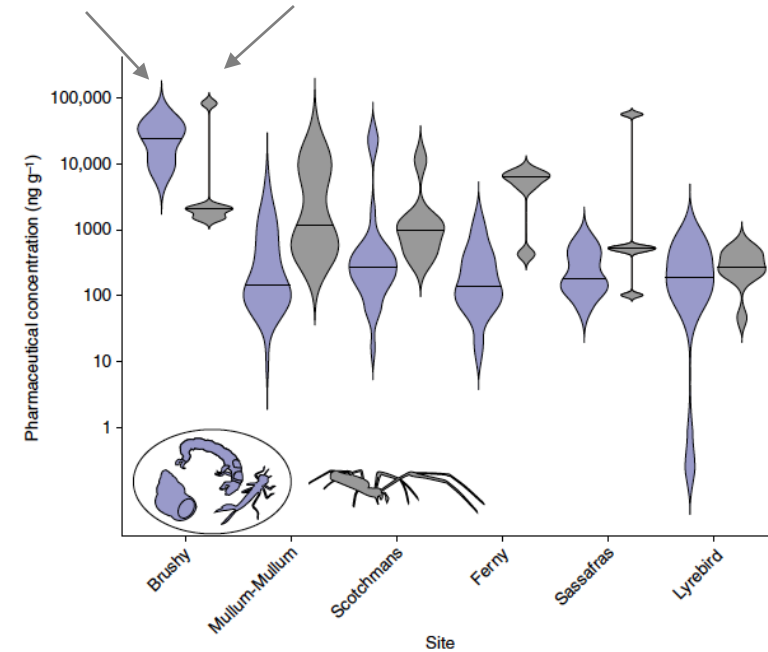


Fig. 2 Pharmaceutical concentrations in benthic aquatic invertebrates and riparian spiders. Total pharmaceutical concentration (ng g⁻¹ dry weight) in aquatic invertebrates (purple) and riparian web-building spiders (dark grey) for each study site, arranged in decreasing wastewater influence (indicated by $\delta^{15}\text{N}$ in biofilms; Table 1). Violin plots illustrate kernel probability density and horizontal lines within each plot indicate median concentrations (see Methods for additional details on violin plots). The caddisfly image in this figure was adapted from Walters, D.M., M.A. Ford, and R.E. Zuellig. 2017. An open-source digital reference collection for aquatic macroinvertebrates of North America. *Freshwater Science* 36(4):693–697. DOI: 10.1086/694539. The spider image was adapted from a photo by Ryan R. Otter (Middle Tennessee State University)

A diverse suite of pharmaceuticals contaminates stream and riparian food webs

Erinn K. Richmond¹, Emma J. Rosi², David M. Walters^{3,8}, Jerker Fick⁴, Stephen K. Hamilton^{2,5}, Tomas Brodin^{6,7}, Anna Sundelin⁴ & Michael R. Grace¹

- As representative vertebrate predators feeding on aquatic invertebrates, platypus and brown trout could consume some drug classes such as antidepressants at as much as one-half of a recommended therapeutic dose for humans based on their estimated prey consumption rates
- Yet the consequences for fish and wildlife of this chronic exposure are unknown
- Who eats trout?

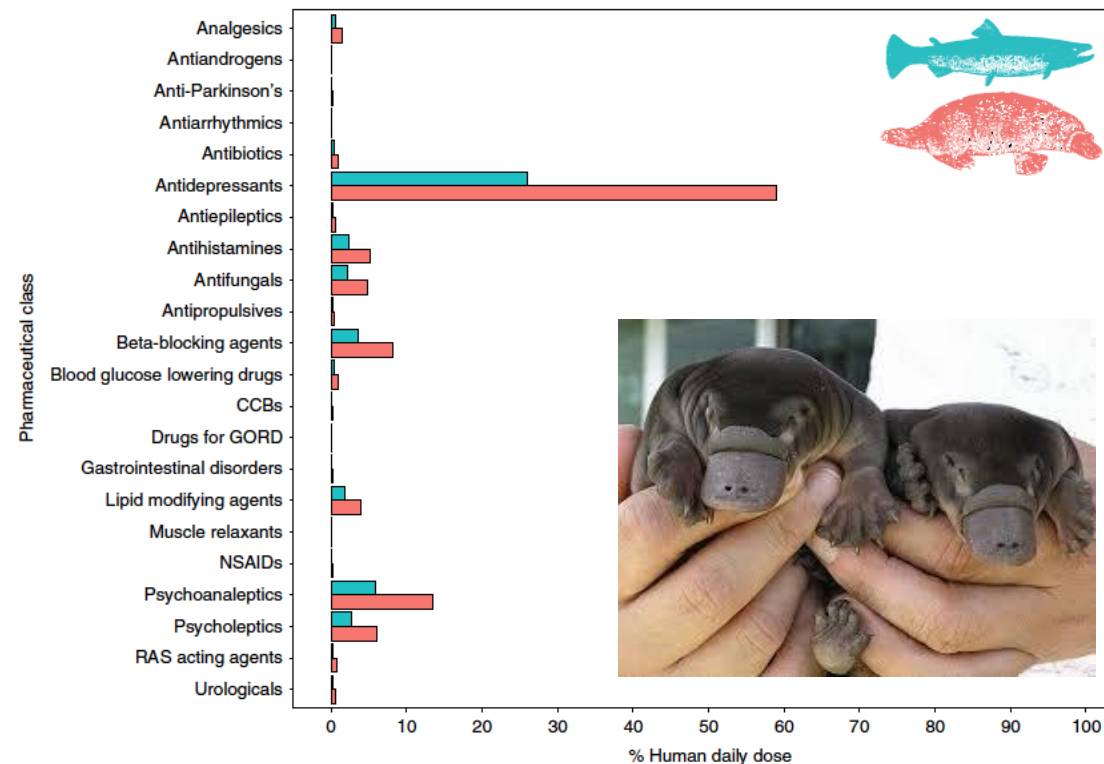
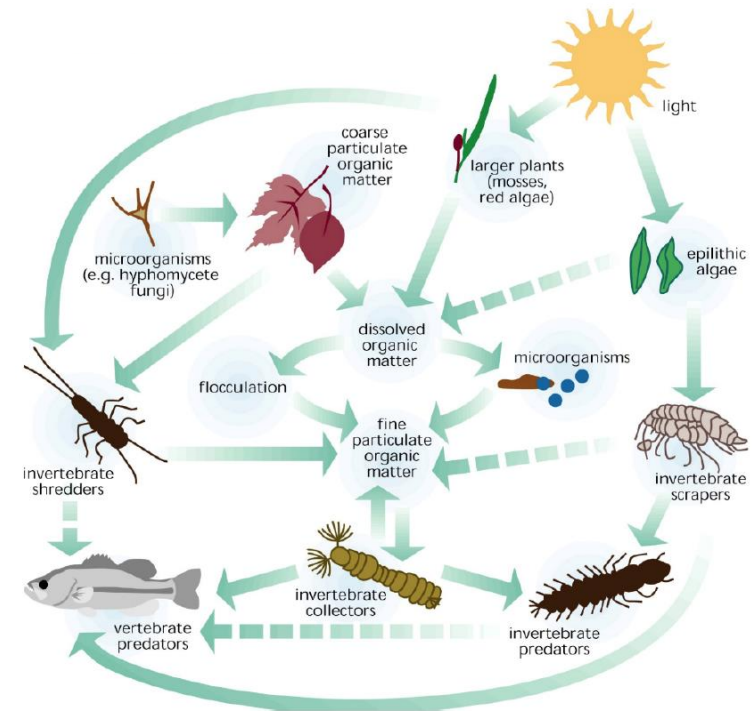


Fig. 4 Estimated dietary intake of pharmaceuticals by two representative invertebrate predators compared to recommended human pharmaceutical doses. Dietary intake rates as a percentage of recommended human pharmaceutical daily doses by therapeutic class for platypus (pink) and brown trout (blue) in Brushy Creek. (CCBs calcium channel blockers, GORD gastroesophageal reflux disease, NSAID non-steroidal anti-inflammatory drugs, RAS renin angiotensin system). Calculations appear in Methods section (equations 2-5). The trout and platypus images in this figure were adapted from Harter, Jim. 'Animals 1419 copyright-free illustrations of mammals, birds, fish, insects, etc. A pictorial archive from Nineteenth century sources' Mineola, New York. Copyright Dover Publication Inc. (1979). All rights reserved

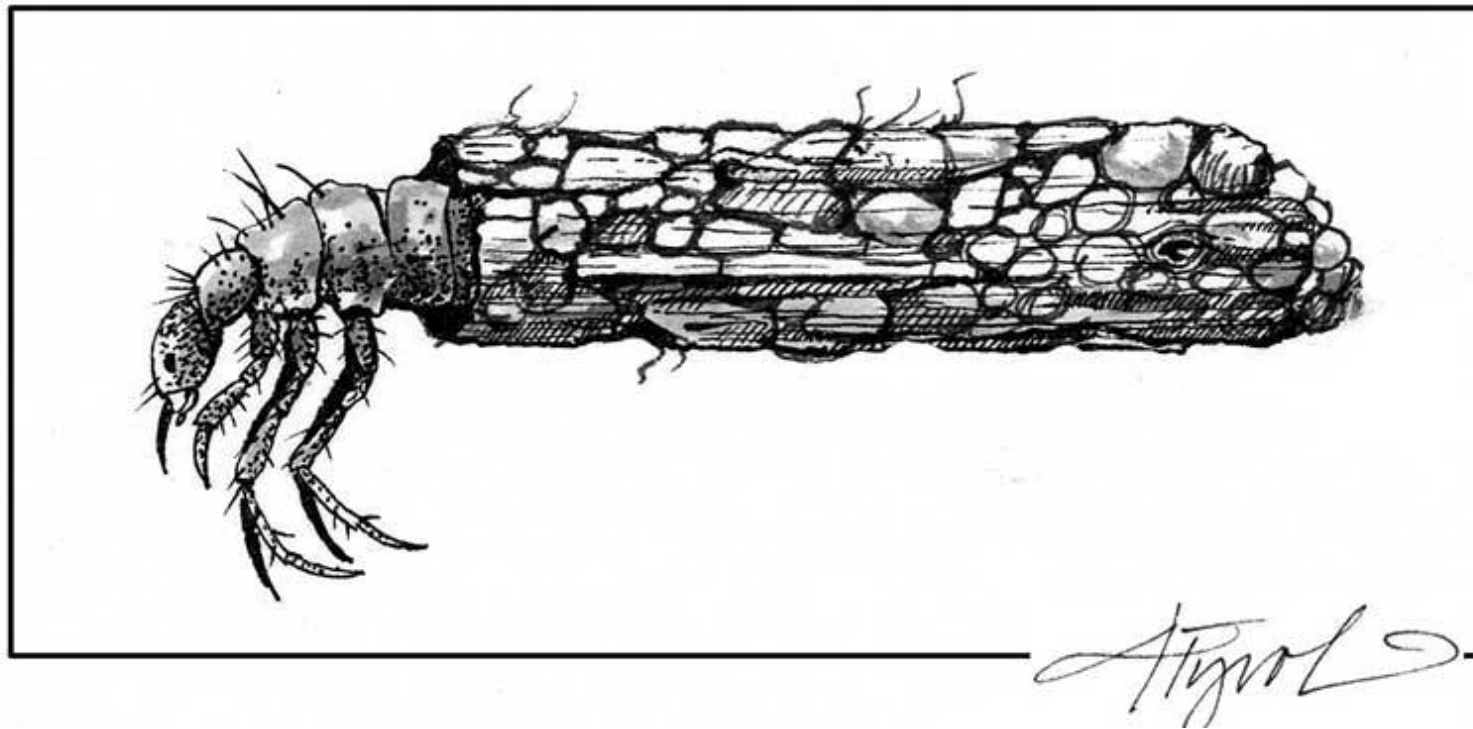
Direct human alterations of stream ecosystems

Hydropower and food webs



The beauty of the life in streams and rivers

Caddisfly larvae with case



The beauty of the life in streams and rivers

Caddisfly larvae (Trichoptera)



- Filter and gather particles from the water
- Exposed to the flow
- Trade-off between hydraulic stress and resource supply

Ecohydraulics and the adaptive traits of benthic organisms in streams

Benthic organisms experience complex flow fields around their bodies

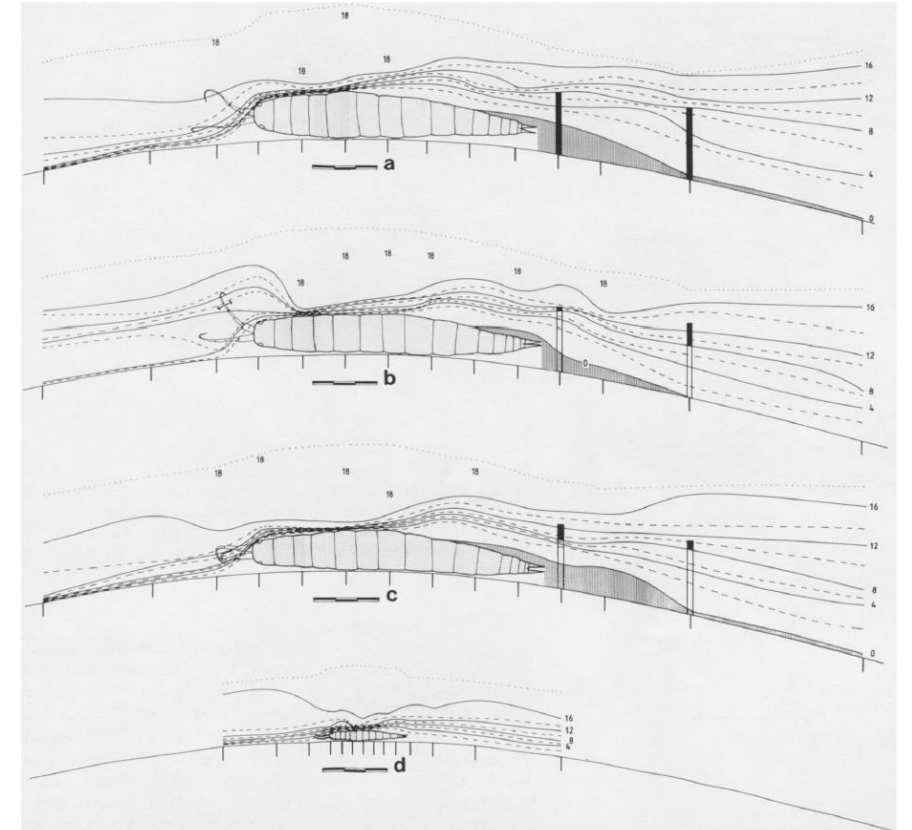
Hydraulic constraints on life in streams

Trade-offs between

- Diffusive transport of gases and solutes through boundary layer
- Erosion through lift forces

Biota have developed adaptive traits to respond to hydraulic constraints

- Compressed body shape to remain within the laminar flow
- Various anchoring mechanisms



Hydraulic niches contribute to the high biodiversity in stream ecosystems



- Different species occupy and exploit different hydraulic niches in streams
- Promotes taxonomic and functional diversity
- Impacts for ecosystem processes (i.e., OM degradation)

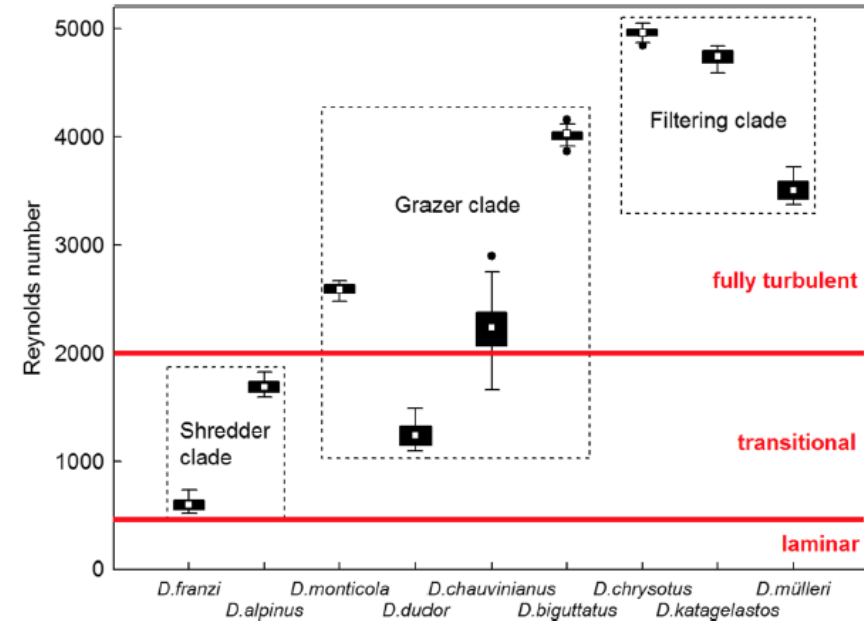


Fig. 4 Box plots of organismic Reynolds numbers acting on fifth instar larvae of nine Drusinae species (= 68 specimens), heads directed upstream. Red bars indicate thresholds between laminar, transitional and fully turbulent regimes. The two species of the shredder clade and *D. dudor* were well in the transitional range ($R = 500\text{--}2000$), the rest of the grazer clade and the filtering clade species were in the fully turbulent

range of R , with *D. chauvinianus* taking an intermediate position between transitional and fully turbulent. White rectangles = means, black bars = 25/75% quartiles, whiskers = range without outliers, black dots = outliers. The differences between the three clades were very highly significant ($p = 0.000$; Kruskal-Wallis ANOVA)

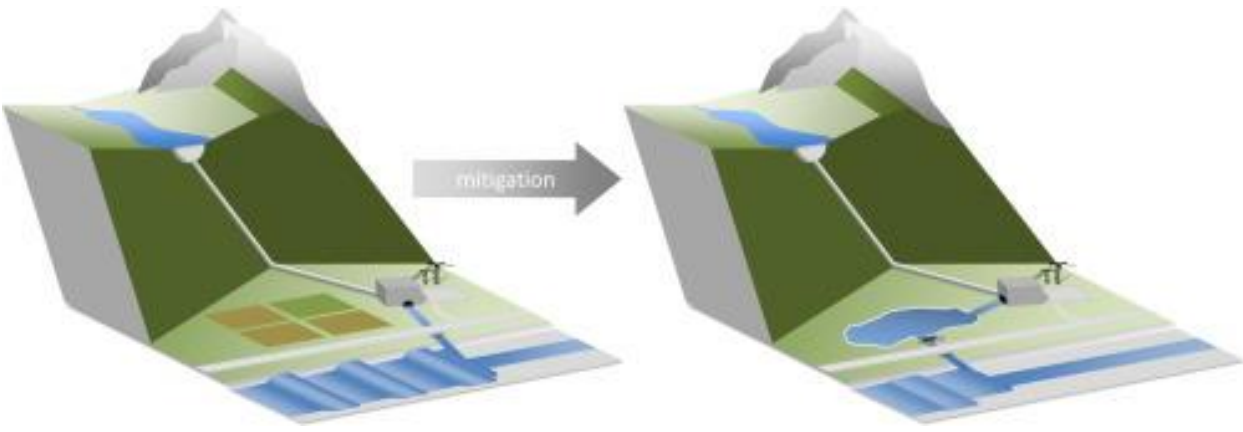
Biologia (2021) 76:1465–1473
<https://doi.org/10.2478/s11756-020-00648-y>

ORIGINAL ARTICLE

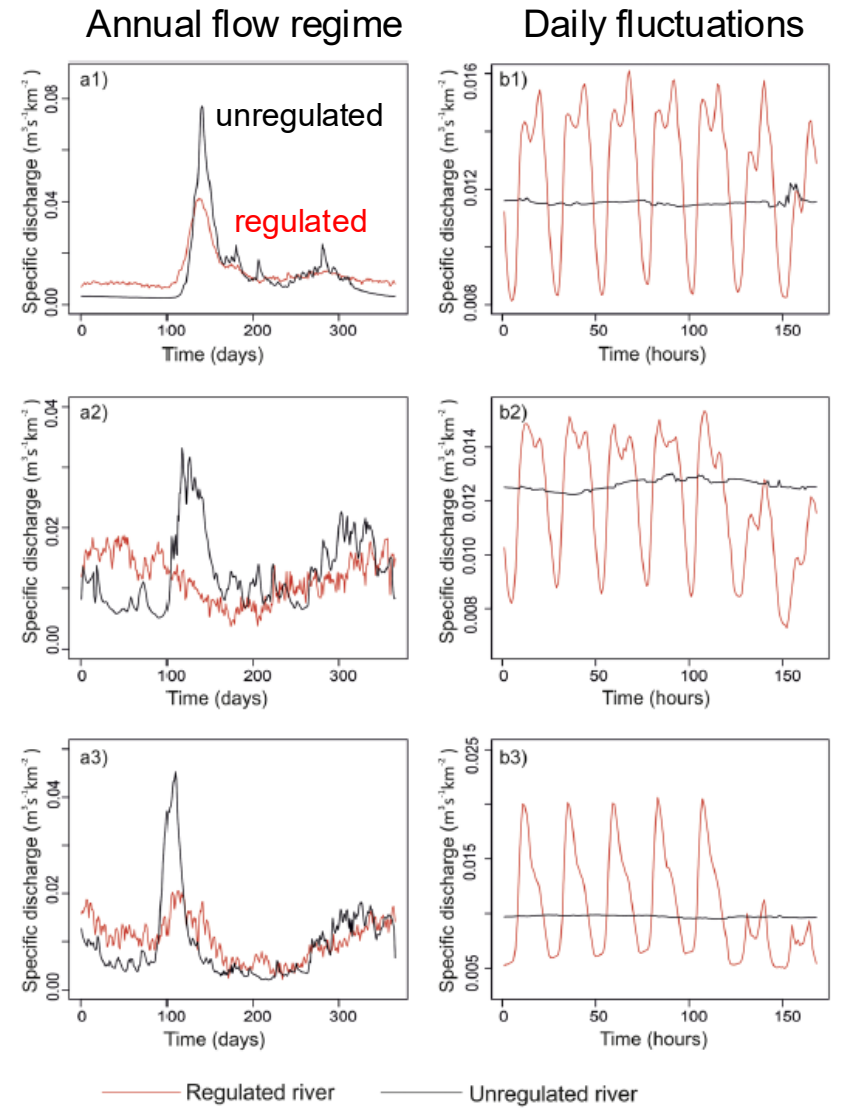
Hydraulic niche utilization by larvae of the three Drusinae clades (Insecta: Trichoptera)

Johann Waringer¹ · Simon Vitecek² · Jan Martini¹ · Carina Zitra¹ · Stephan Handschuh³ · Ariane Vieira⁴ · Hendrik C. Kuhlmann⁴

Hydropeaking affects hydraulics and invertebrate communities



Possible mitigation measures:
Buffering volume

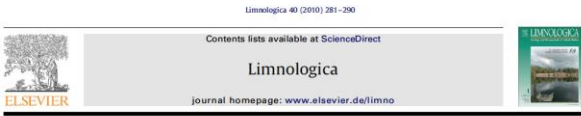
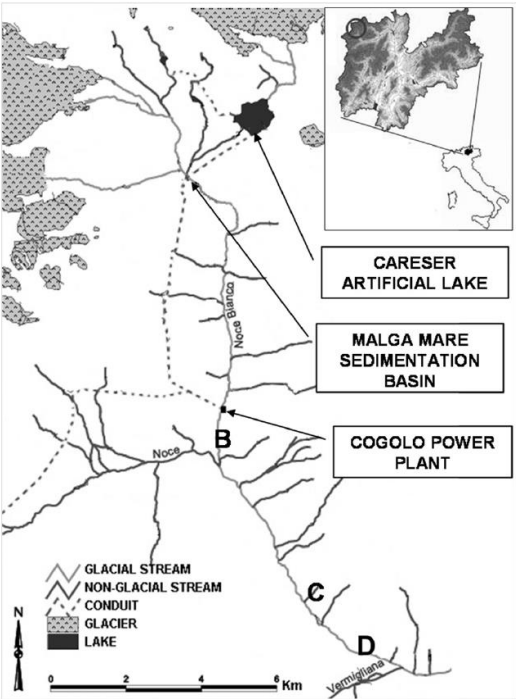


Changes in short term river flow regulation and hydropeaking in Nordic rivers

Faisal Bin Ashraf¹, Ali Torabi Haghighi², Joakim Rim³, Knut Alfreidson⁴, Jarkko J. Koskela⁵, Bjørn Kløve⁶ & Hannu Marttilä¹

Figure 5. Aggregated mean long term regulation (a) and aggregated mean short term regulation (b) pattern in terms of specific discharge on large (1) medium (2) and small river (3) and that of comparable unregulated rivers. Taivalkoski (regulated), Ounasjoki at kongas (unregulated) on daily scale (a1) and hourly scale (b1). Iontta (regulated), Sanginjoki (unregulated) on daily scale (a2) and hourly scale (b2). Kyrösoski (regulated), Akkola (unregulated) on daily scale (a3) and hourly scale (b3). The x-axis shows (a1–a3) show days of the year and (b1–b3) hours of the day.

Hydropeaking affects hydraulics and invertebrate communities



Short time-scale impacts of hydropeaking on benthic invertebrates in an Alpine stream (Trentino, Italy)
 Maria Cristina Bruno*, Bruno Maiolini, Mauro Carolli, Luana Silveri

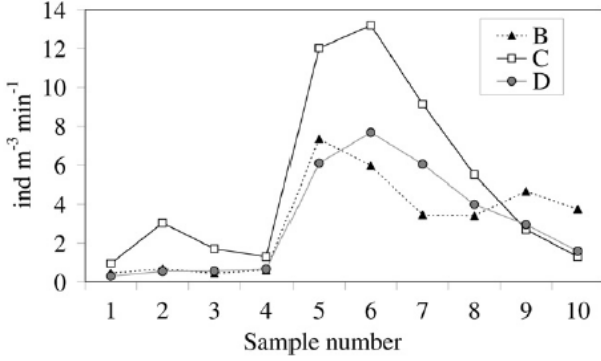


Fig. 6. Loss from bed of drifting aquatic invertebrates (ind m⁻³ min⁻¹) in each station for each drift sample in the Noce Bianco Stream, Trentino, Italy, calculated by averaging three replicates for each sample. For sampling station locations, see Fig. 1.

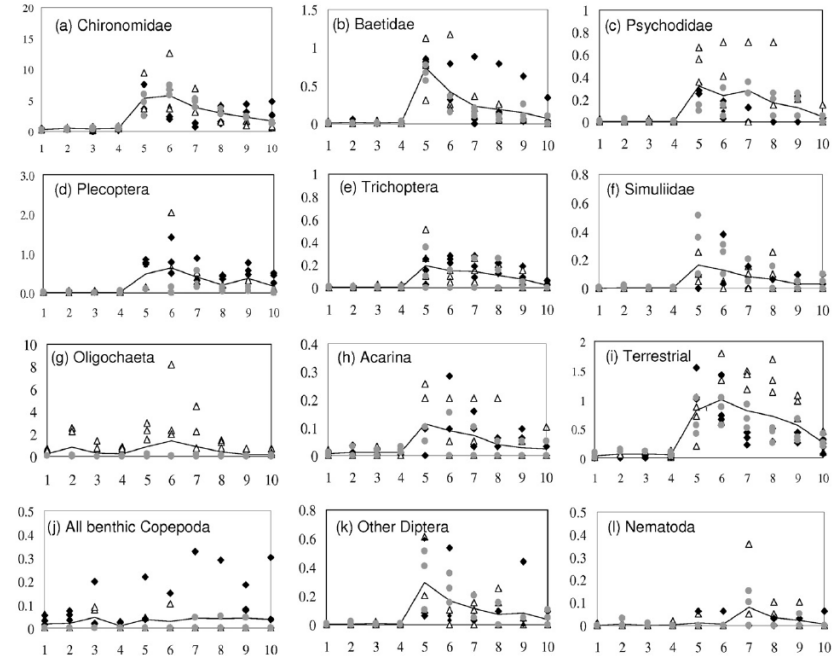


Fig. 5. Mean loss from bed of drifting aquatic invertebrates (ind m⁻³ min⁻¹) in each station for each time sample in the Noce Bianco Stream, Trentino, Italy. Taxa in figure are those that contributed most to the dissimilarities between all three stations (see Table 2). All terrestrial taxa, Nematoda, and all Copepoda are added because they represent the impact on riparian habitat, and on the benthic/hyporheic interface, respectively. Black rhombs: station B; white triangles: station C; grey circles: station D; continuous line: mean of all samples. For sampling station locations, see Fig. 1.

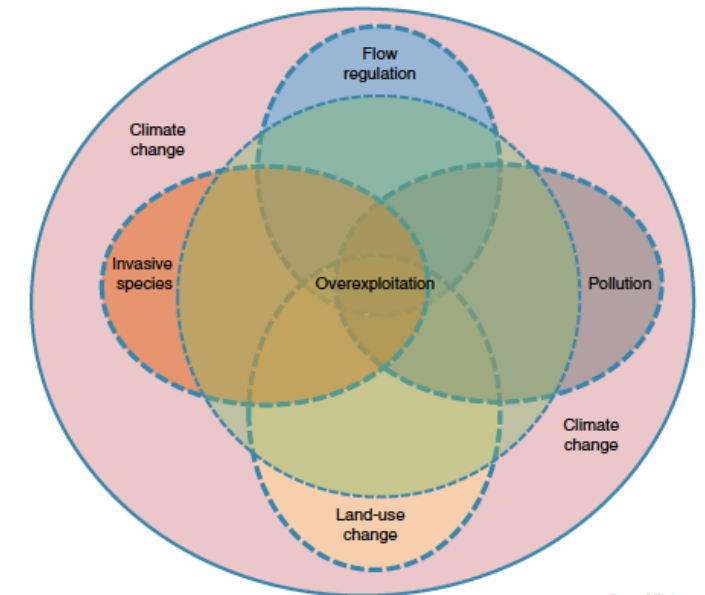
- Downstream export of biomass
- Reduction in biodiversity

Streams and rivers are among the most biodiverse ecosystems

Essay

Multiple threats imperil freshwater biodiversity in the Anthropocene

David Dudgeon



Current Biology

Figure 1. A conceptual diagram of global threats to freshwater ecosystems. The total planetary operating space is equivalent to the climate-change ellipse, and individual freshwater bodies can be positioned within this space according to the combination of threat categories that they experience. Overexploitation occupies the centre of the space because this is the earliest and sometimes the only threat to freshwater biodiversity in remote or sparsely populated localities. Most fresh waters are located within spaces where three or more threat categories overlap.

ENVIRONMENTAL STUDIES

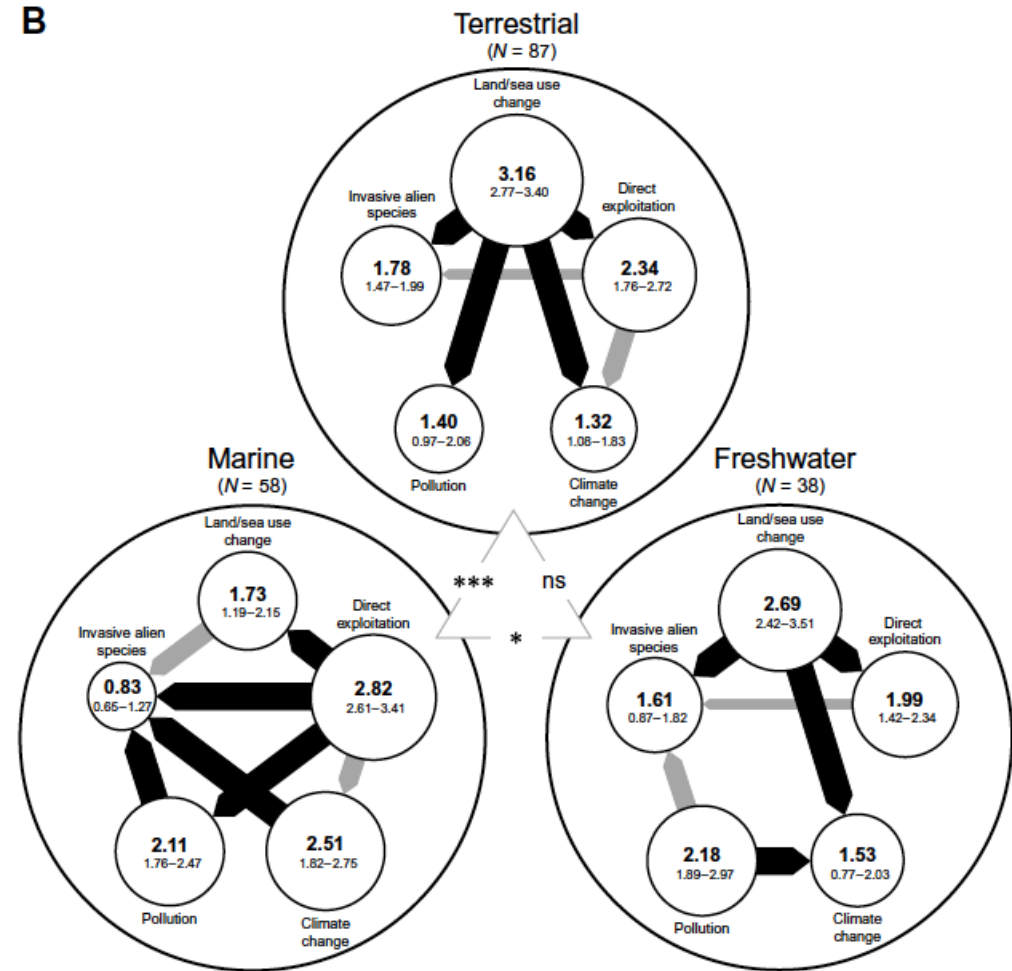
The direct drivers of recent global anthropogenic biodiversity loss

Pedro Jaureguiberry^{1†}, Nicolas Titeux^{2,3,4†}, Martin Wiemers^{2,5}, Diana E. Bowler^{3,6,7}, Luca Coscieme⁸, Abigail S. Golden^{9,10}, Carlos A. Guerra^{3,11}, Ute Jacob^{12,13}, Yasuo Takahashi¹⁴, Josef Settele^{2,3,15}, Sandra Díaz¹, Zsolt Molnár¹⁶, Andy Purvis^{17,18*}

Land use change is the dominant direct driver of recent biodiversity loss worldwide.

Pollution ranks second, direct exploitation third; climate change and invasive alien species have been significantly less important than the top two drivers.

However, ecosystems and their biodiversity are increasingly exposed to multiple stressors

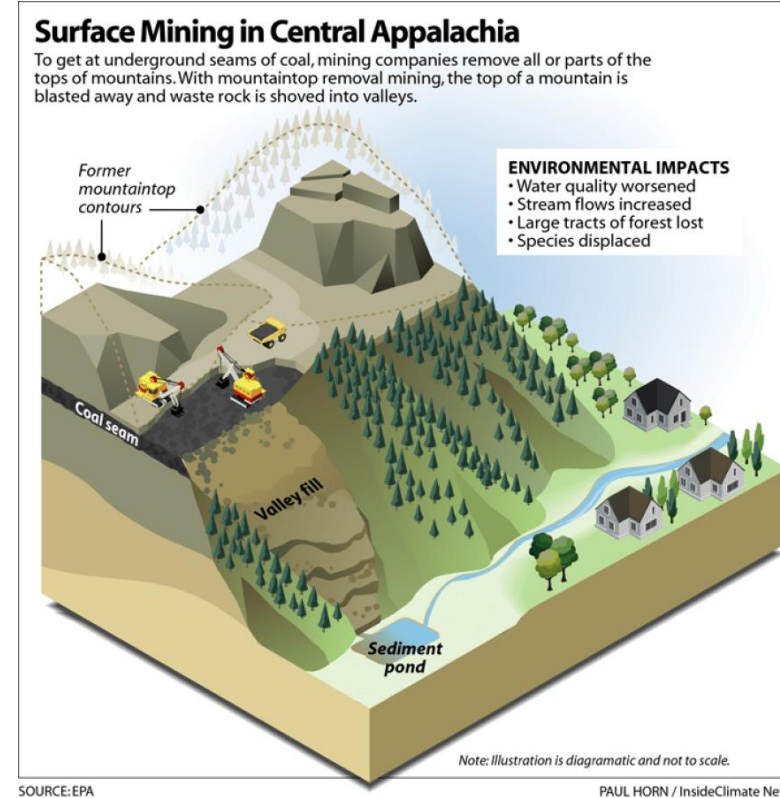


A catchment perspective of fluvial ecosystems



Land use change

- Urbanisation
- Deforestation
- Mountain top mining and valley filling



Global threats to human water security and river biodiversity

C. J. Vörösmarty^{1*}, P. B. McIntyre^{2,†}, M. O. Gessner³, D. Dudgeon⁴, A. Prusevich⁵, P. Green¹, S. Glidden⁵, S. E. Bunn⁶, C. A. Sullivan⁷, C. Reidy Liermann⁸ & P. M. Davies⁹

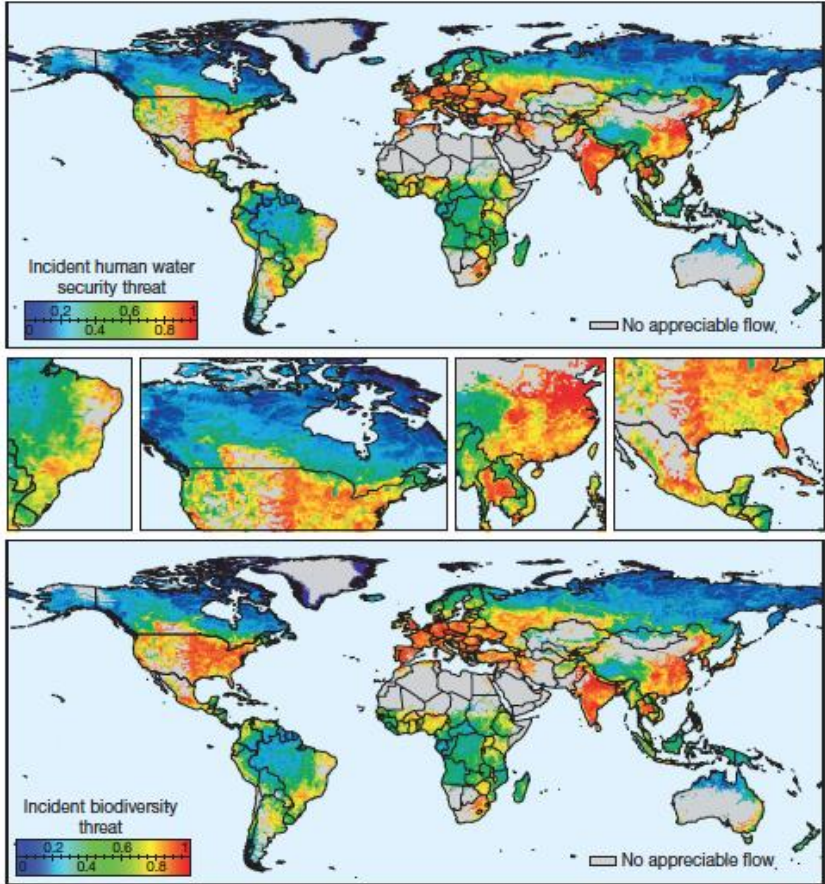


Figure 1 | Global geography of incident threat to human water security and biodiversity. The maps demonstrate pandemic impacts on both human water security and biodiversity and are highly coherent, although not identical (biodiversity threat = 0.964 × human water security threat + 0.018; $r = 0.97$, $P < 0.001$). Spatial correlations among input drivers (stressors) varied, but were

generally moderate (mean $|r| = 0.34$; $n = 253$ comparisons). Regional maps exemplify main classes of human water security threat (see main text and Supplementary Fig. 4). Spatial patterns proved robust in a variety of sensitivity tests (Supplementary Methods and Supplementary Discussion). Threat indices are relative and normalized over discharging landmass.

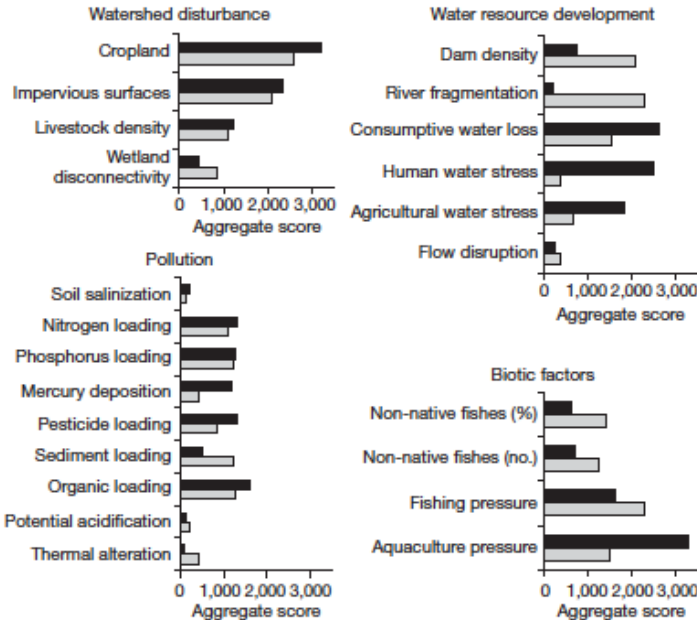
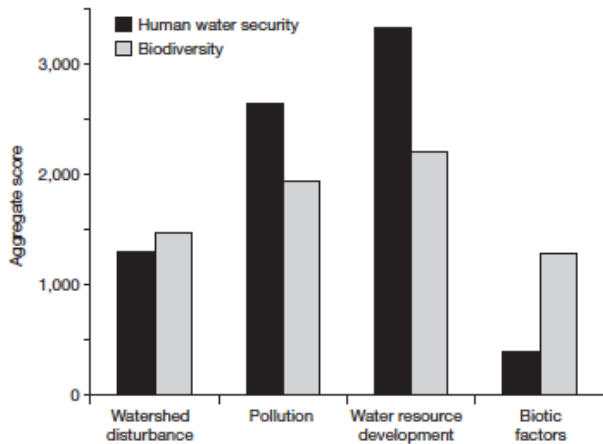


Figure 3 | Theme and driver contributions in areas where incident threat exceeds the 75th percentile. High incident threat typically arises from the spatial coincidence of multiple themes and/or drivers of stress acting in concert. Each aggregate score represents the number of grid cells exceeding the 75th percentile for each individual theme or driver over the high incident threat areas. Influence of each of the four themes (left) is relative to its contribution to overall incident threat. For the individual drivers (right), scores are relative to other drivers in the same theme. Bars summarize results over the entire discharging landmass.