River Microbial Ecology

Microbial Life cross Scales

Hannes Peter
EPFL River Ecosystems Laboratory

River Ecosystems Laboratory

recap

The superlatives of rivers

Largest biogeochemical nexus between land, the oceans and atmosphere

Span multiple catchments and biomes

High biodiversity

Provide critical ecosystem services (e.g., drinking water, proteins, hydropower)

The microbe is so very small,
you cannot make him out at all,
but many sanguine people
hope to see him through
the microscope . . .”
(Hilaire Belloc)

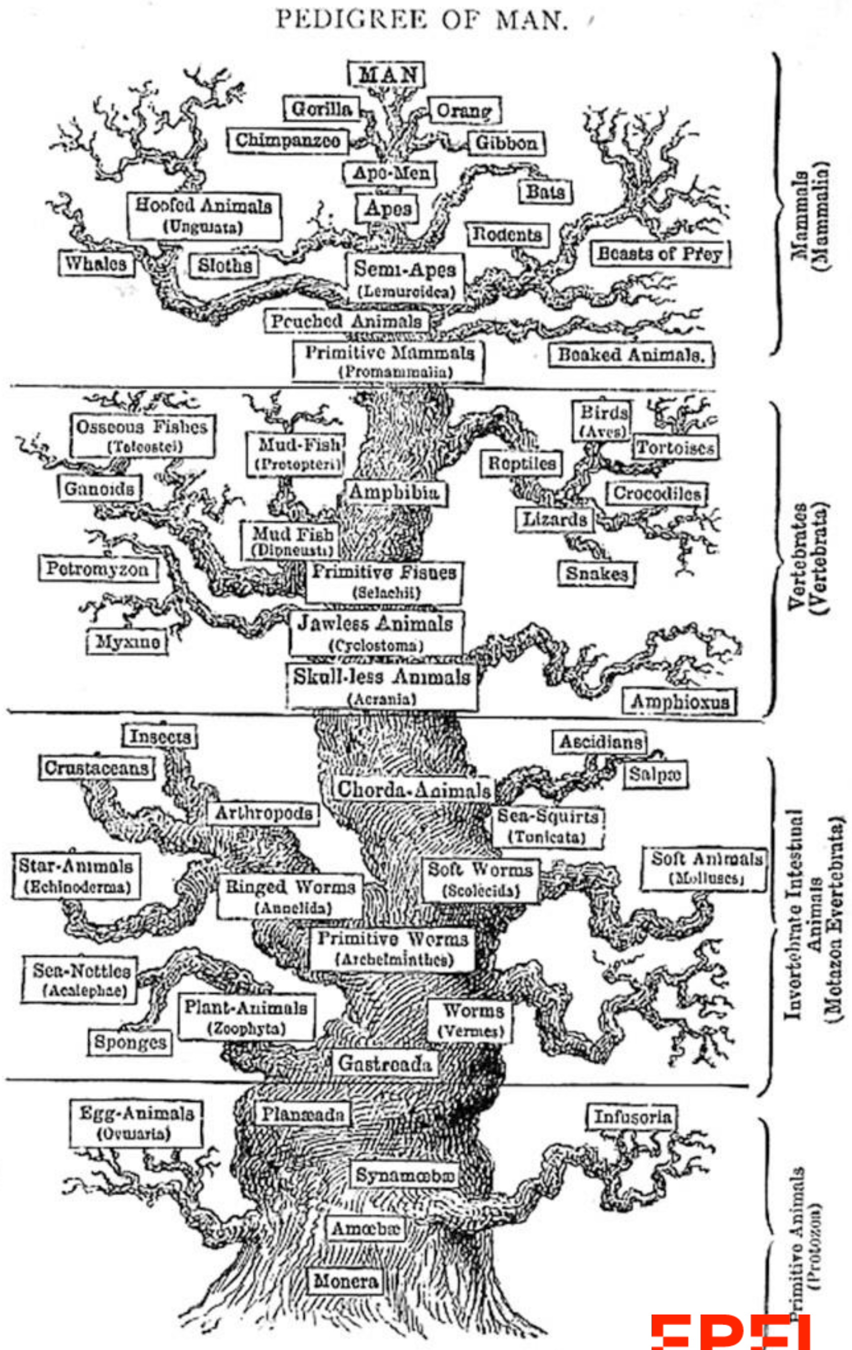
Antoni van Leeuwenhoek
(1632-1723)

Louis Pasteur
(1822–1895)

Robert Koch
(1843–1910)

Sergei Winogradsky
(1856-1953)

microbiology of natural biotopes



EPFL

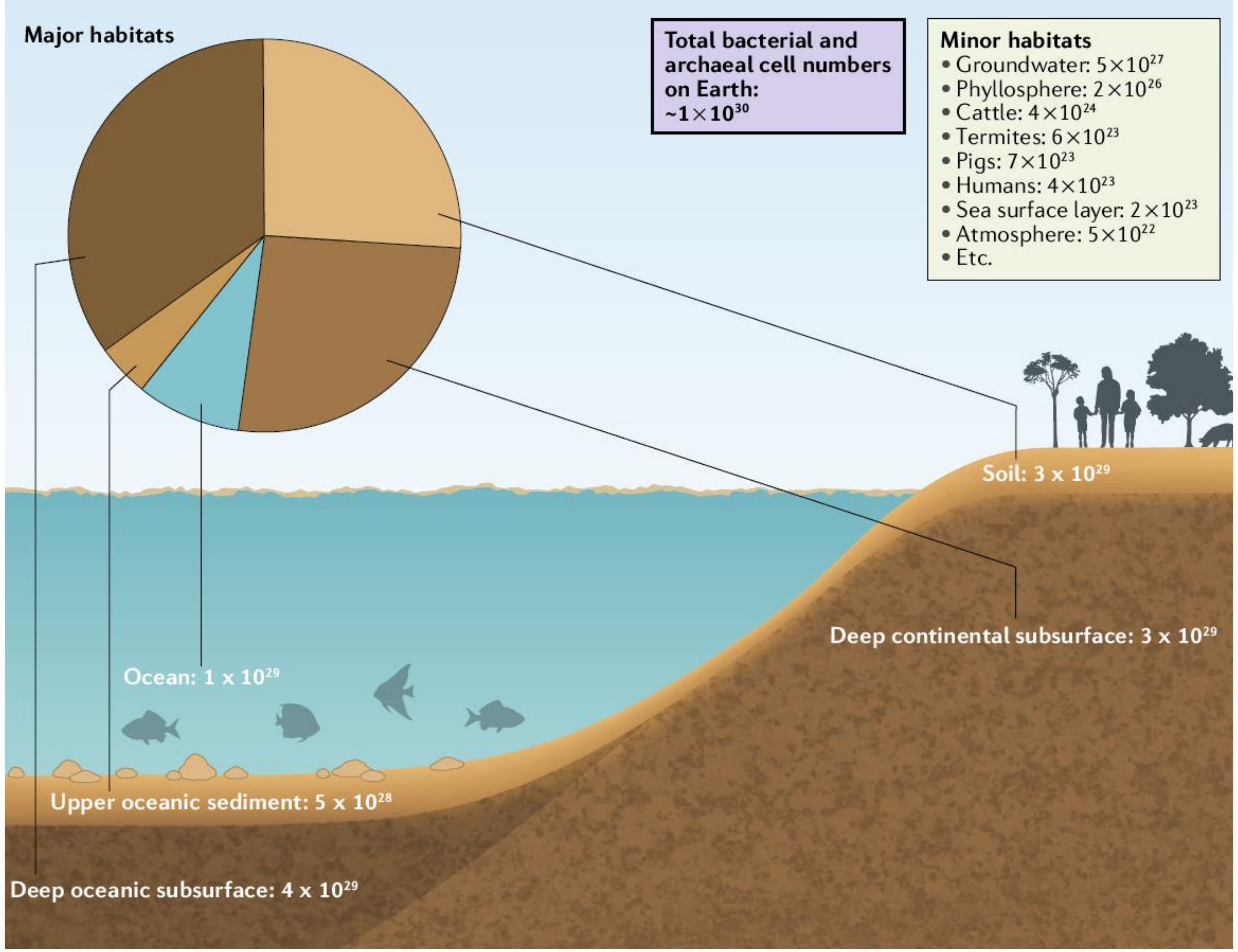
Most microbes life attached to surfaces!

MICROBIAL BIOFILMS

Bacteria and archaea on Earth and their abundance in biofilms

Hans-Curt Flemming[1,2]* and Stefan Wuertz[1,3]*

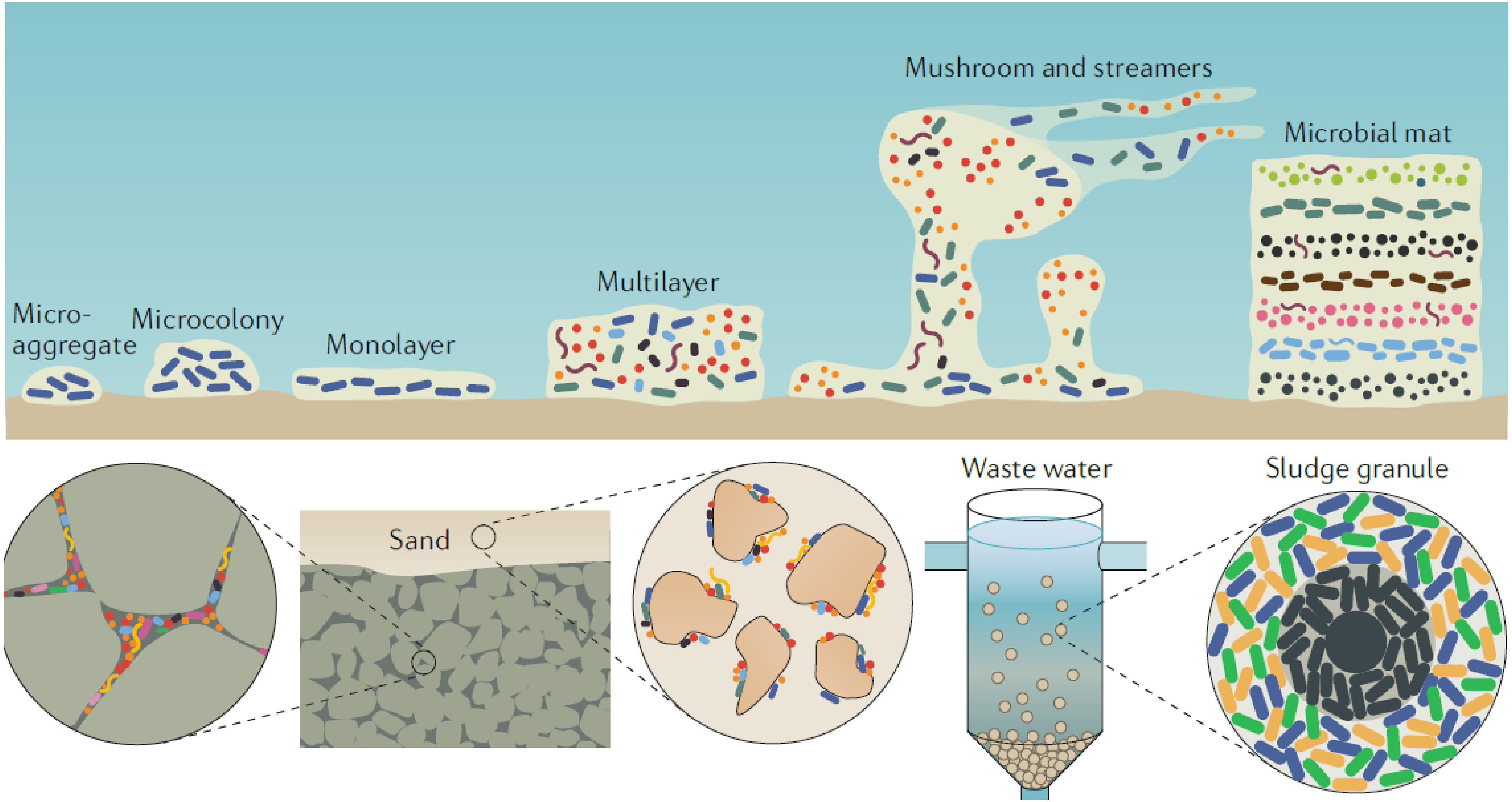
Habitat	Estimated total (bacterial and archaeal) cell number[a]	Estimated cell number in biofilms[b]
Total Earth	1.2×10^{30}	On surface of Earth: 3.5×10^{29}; deep subsurface: large but as yet unknown, ranging from 4.9×10^{29} to 9.1×10^{29}
Deep oceanic subsurface[c]	4×10^{29}	Most cells attached, either single or in clusters; 20–80% in biofilms based on microscopic and biogeochemical evidence
Deep continental subsurface[d]	3×10^{29}	Most cells attached, single and microclusters; 20–80% in biofilms based on microscopic and biogeochemical evidence
Top 10–50 cm of oceanic sediment[e]	5×10^{28}	5×10^{28}
Soil	3×10^{29}	3×10^{29}
Open ocean	1×10^{29}	Large planktonic fraction, unknown numbers in marine snow, transparent exopolymer particles, gels, on mineral and debris particles, microplastics, plants and animals
Groundwater	5×10^{27}	Unattached
Atmosphere[f]	5×10^{22}	Unknown but unlikely



EPFL

Bacteria and archaea on Earth and their abundance in biofilms

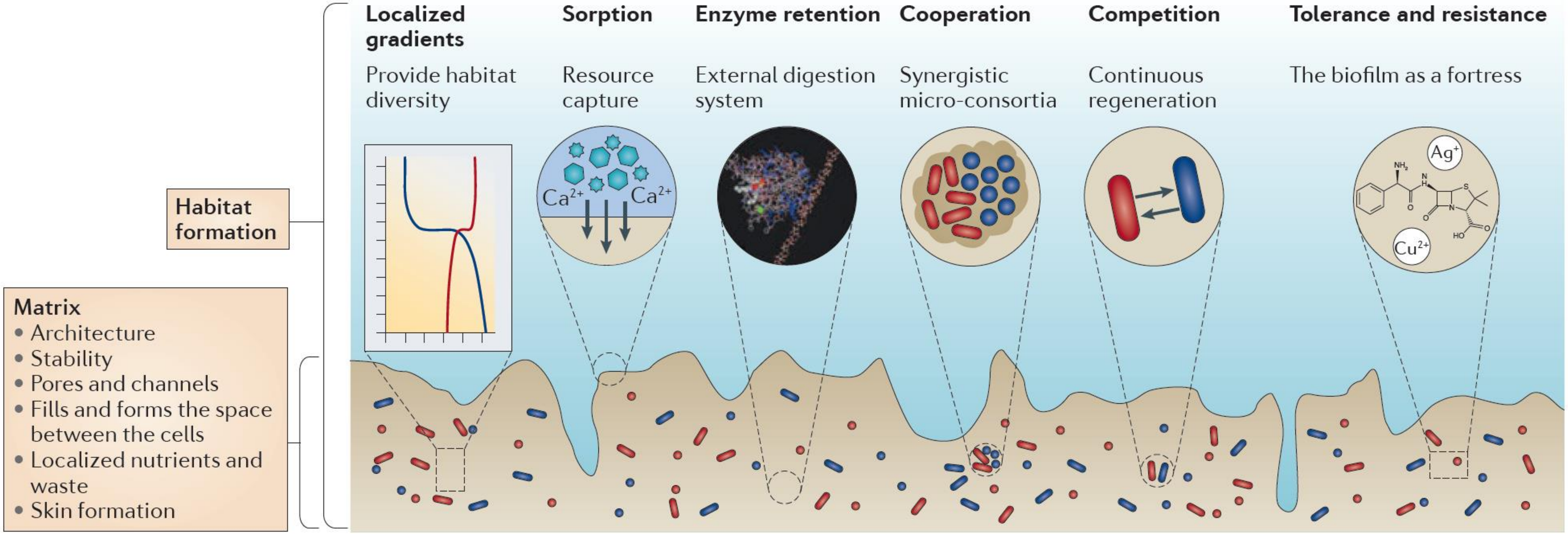
Hans-Curt Flemming[1,2]* and Stefan Wuertz[1,3]*



EPFL

Biofilms: an emergent form of bacterial life

Hans-Curt Flemming[1], Jost Wingender[1], Ulrich Szewzyk[2], Peter Steinberg[3], Scott A. Rice[4] and Staffan Kjelleberg[4]

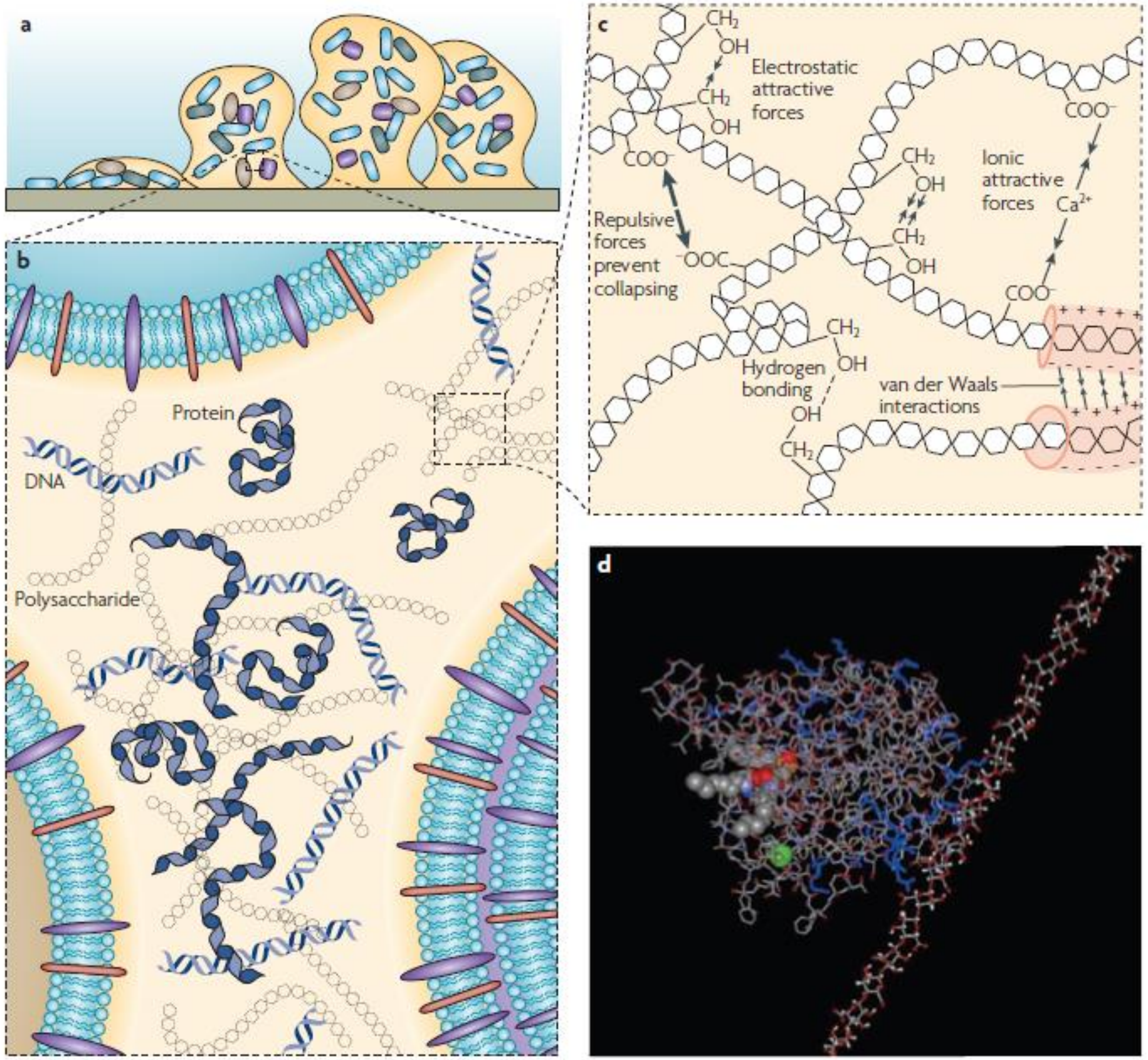


REVIEWS

The biofilm matrix

Hans-Curt Flemming and Jost Wingender

Function	Relevance for biofilms	EPS components involved
Adhesion	Allows the initial steps in the colonization of abiotic and biotic surfaces by planktonic cells, and the long-term attachment of whole biofilms to surfaces	Polysaccharides, proteins, DNA and amphiphilic molecules
Aggregation of bacterial cells	Enables bridging between cells, the temporary immobilization of bacterial populations, the development of high cell densities and cell–cell recognition	Polysaccharides, proteins and DNA
Cohesion of biofilms	Forms a hydrated polymer network (the biofilm matrix), mediating the mechanical stability of biofilms (often in conjunction with multivalent cations) and, through the EPS structure (capsule, slime or sheath), determining biofilm architecture, as well as allowing cell–cell communication	Neutral and charged polysaccharides, proteins (such as amyloids and lectins), and DNA
Retention of water	Maintains a highly hydrated microenvironment around biofilm organisms, leading to their tolerance of dessication in water-deficient environments	Hydrophilic polysaccharides and, possibly, proteins
Protective barrier	Confers resistance to nonspecific and specific host defences during infection, and confers tolerance to various antimicrobial agents (for example, disinfectants and antibiotics), as well as protecting cyanobacterial nitrogenase from the harmful effects of oxygen and protecting against some grazing protoza	Polysaccharides and proteins
Sorption of organic compounds	Allows the accumulation of nutrients from the environment and the sorption of xenobiotics (thus contributing to environmental detoxification)	Charged or hydrophobic polysaccharides and proteins
Sorption of inorganic ions	Promotes polysaccharide gel formation, ion exchange, mineral formation and the accumulation of toxic metal ions (thus contributing to environmental detoxification)	Charged polysaccharides and proteins, including inorganic substituents such as phosphate and sulphate
Enzymatic activity	Enables the digestion of exogenous macromolecules for nutrient acquisition and the degradation of structural EPS, allowing the release of cells from biofilms	Proteins
Nutrient source	Provides a source of carbon-, nitrogen- and phosphorus-containing compounds for utilization by the biofilm community	Potentially all EPS components
Exchange of genetic information	Faciliates horizontal gene transfer between biofilm cells	DNA
Electron donor or acceptor	Permits redox activity in the biofilm matrix	Proteins (for example, those forming pili and nanowires) and, possibly, humic substances
Export of cell components	Releases cellular material as a result of metabolic turnover	Membrane vesicles containing nucleic acids, enzymes, lipopolysaccharides and phospholipids
Sink for excess energy	Stores excess carbon under unbalanced carbon to nitrogen ratios	Polysaccharides
Binding of enzymes	Results in the accumulation, retention and stabilization of enzymes through their interaction with polysaccharides	Polysaccharides and enzymes



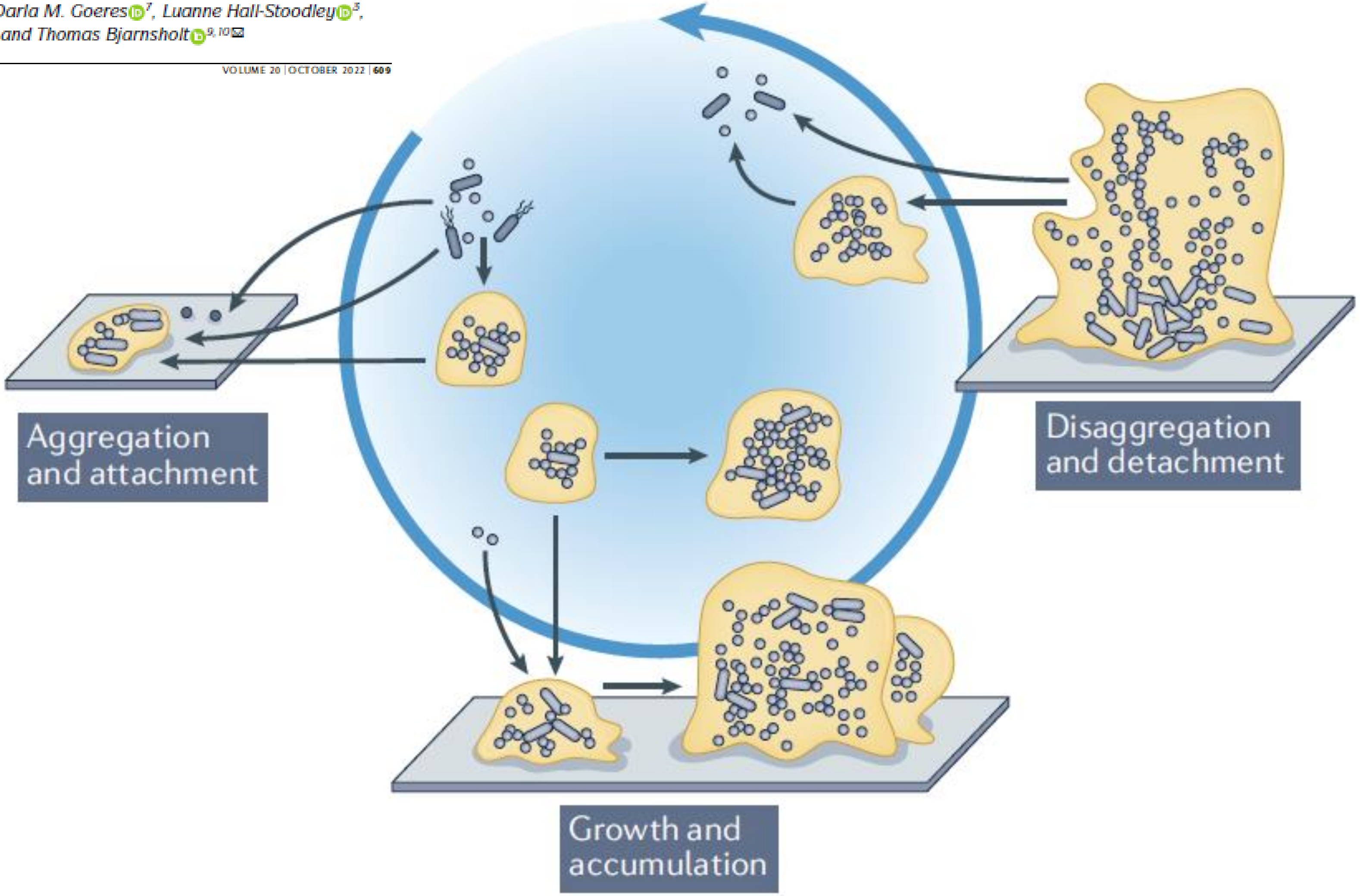
EPFL

Check for updates

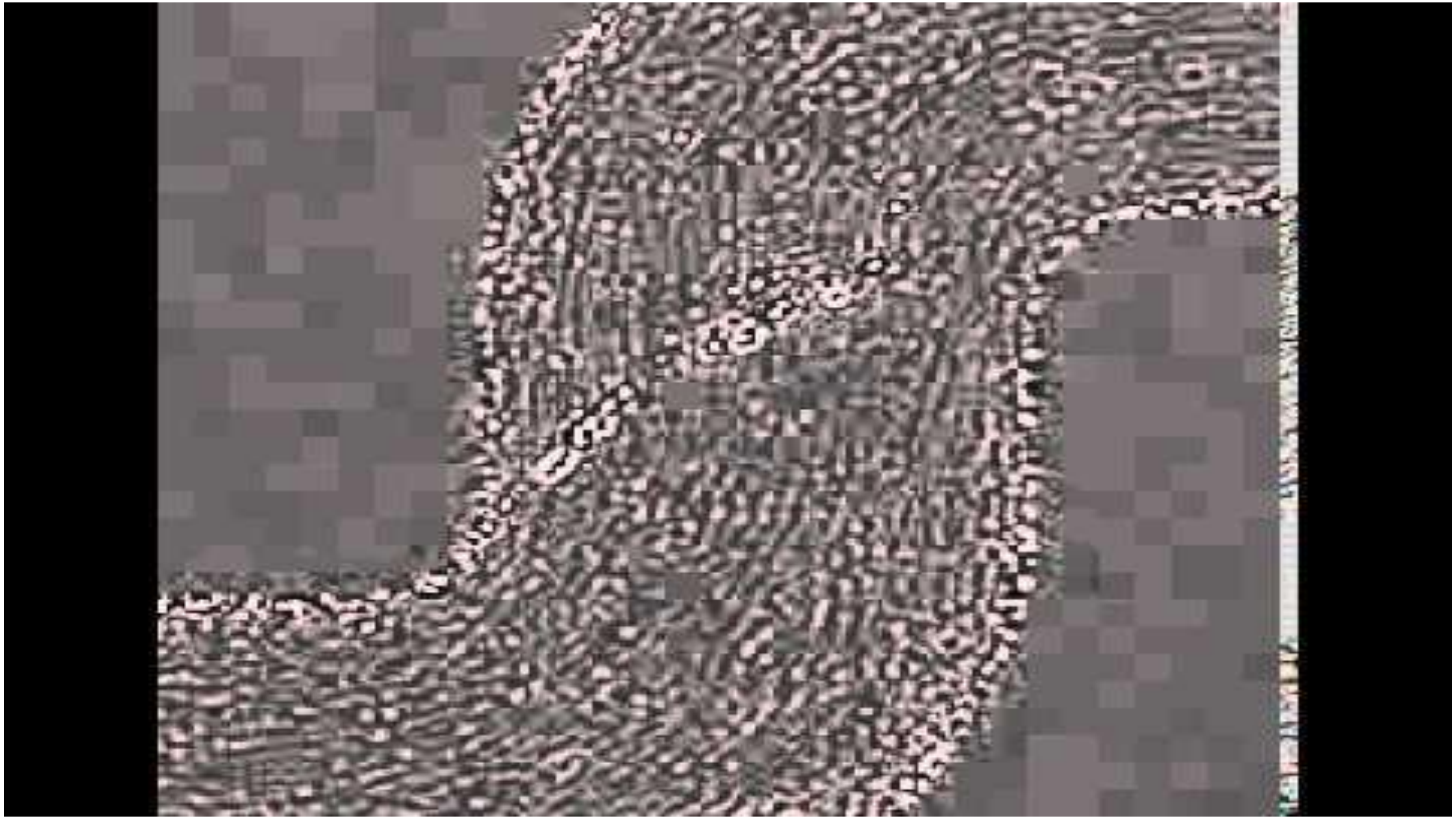
The biofilm life cycle: expanding the conceptual model of biofilm formation

Karin Sauer[1,2], Paul Stoodley[3,4,5,6], Darla M. Goeres[7], Luanne Hall-Stoodley[3], Mette Burmølle[8], Philip S. Stewart[7] and Thomas Bjarnsholt[9,10]✉

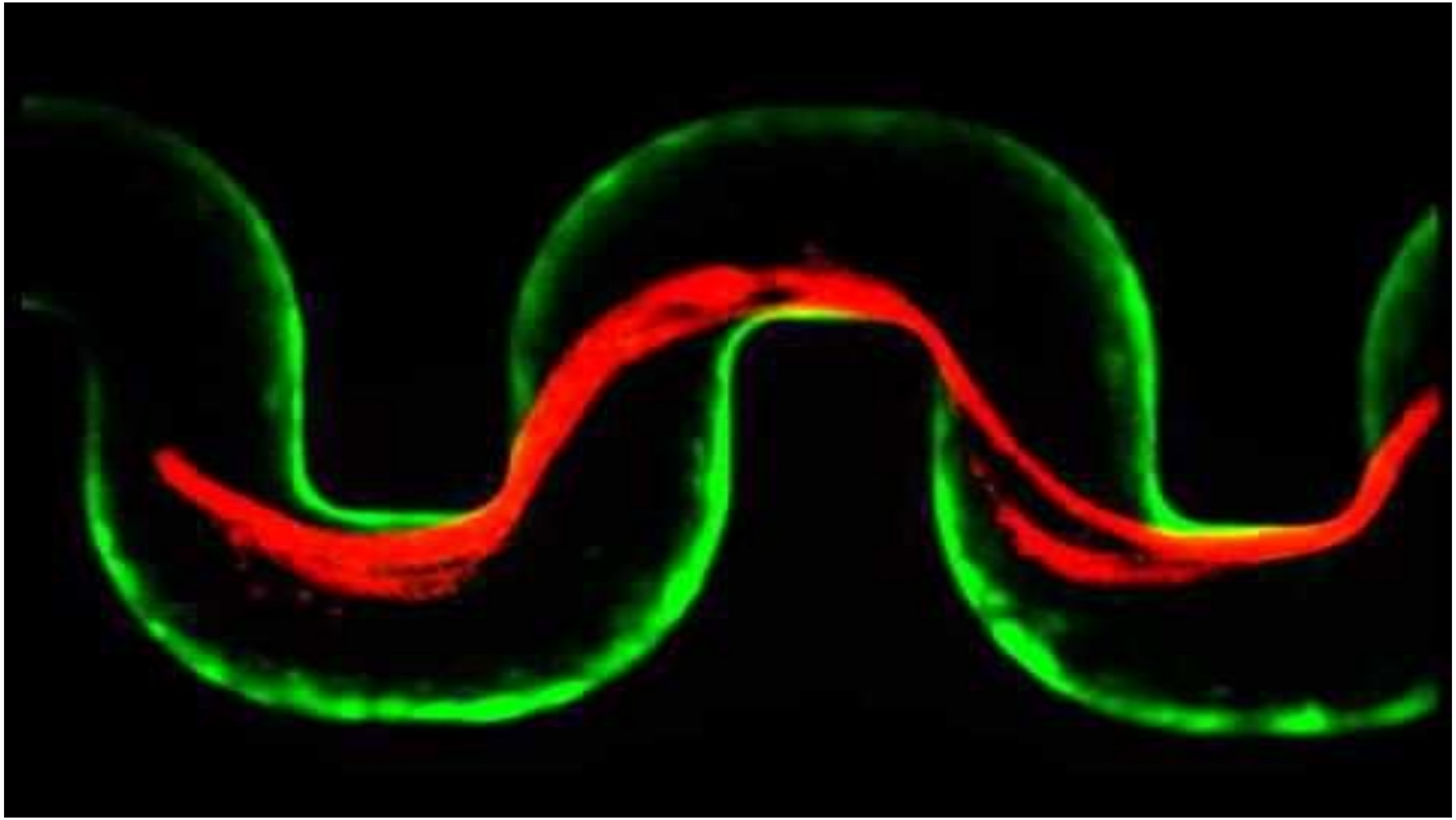
NATURE REVIEWS | MICROBIOLOGY VOLUME 20 | OCTOBER 2022 | 609



EPFL



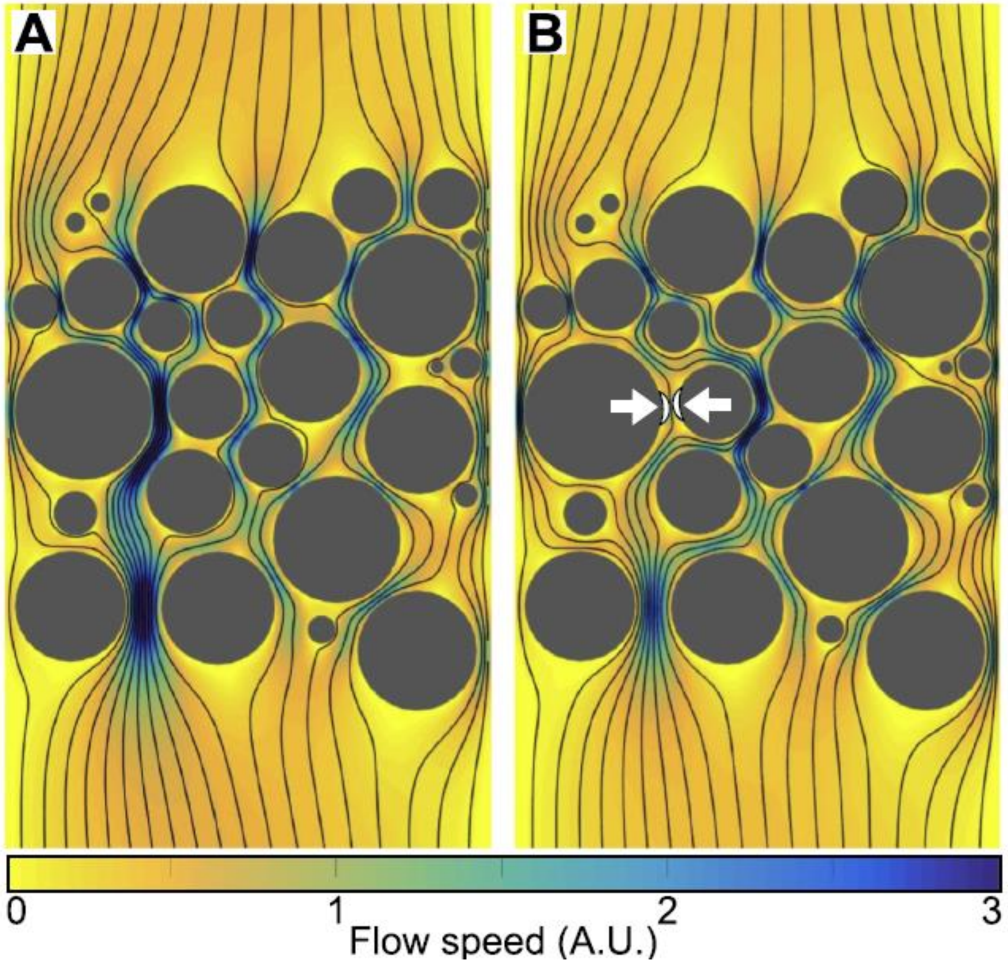
Drescher et al. 2013 PNAS

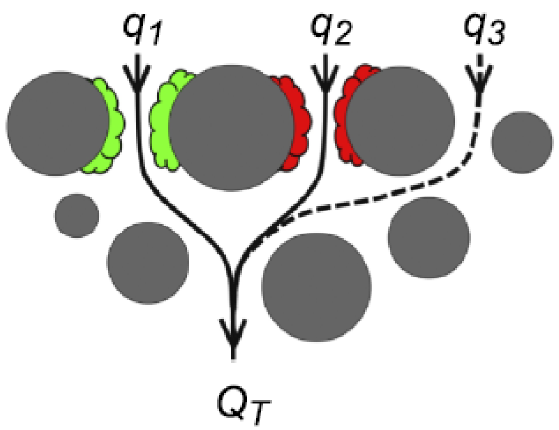


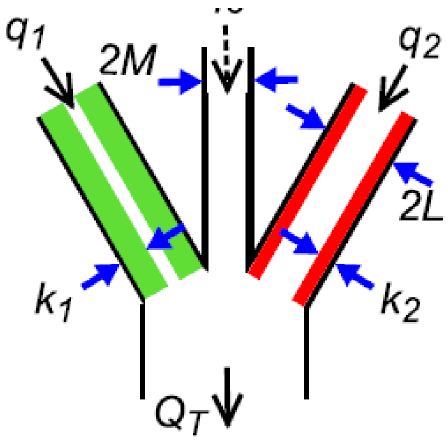
Drescher et al. 2013 PNAS

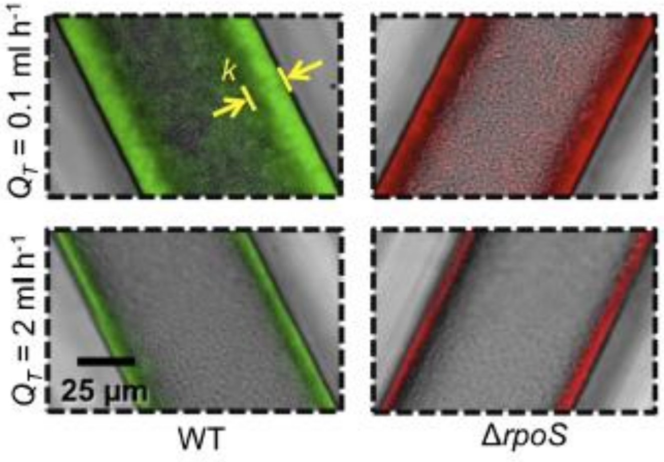
EPFL

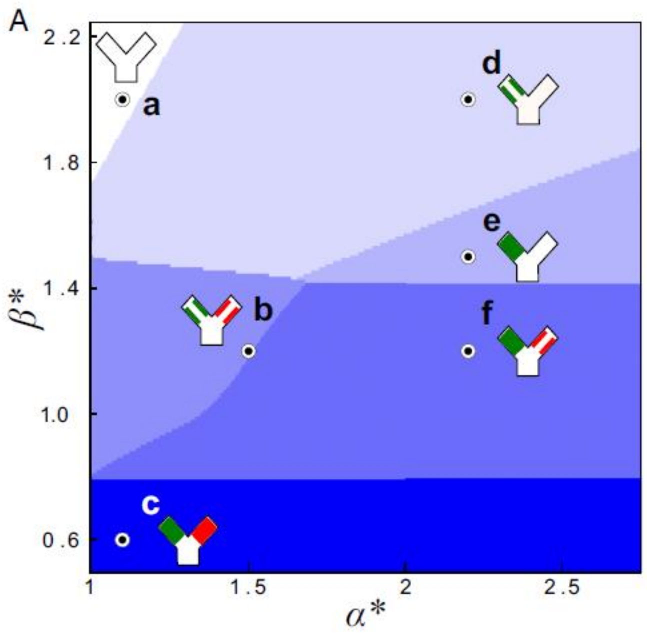
cooperation and competition shape biofilm structure



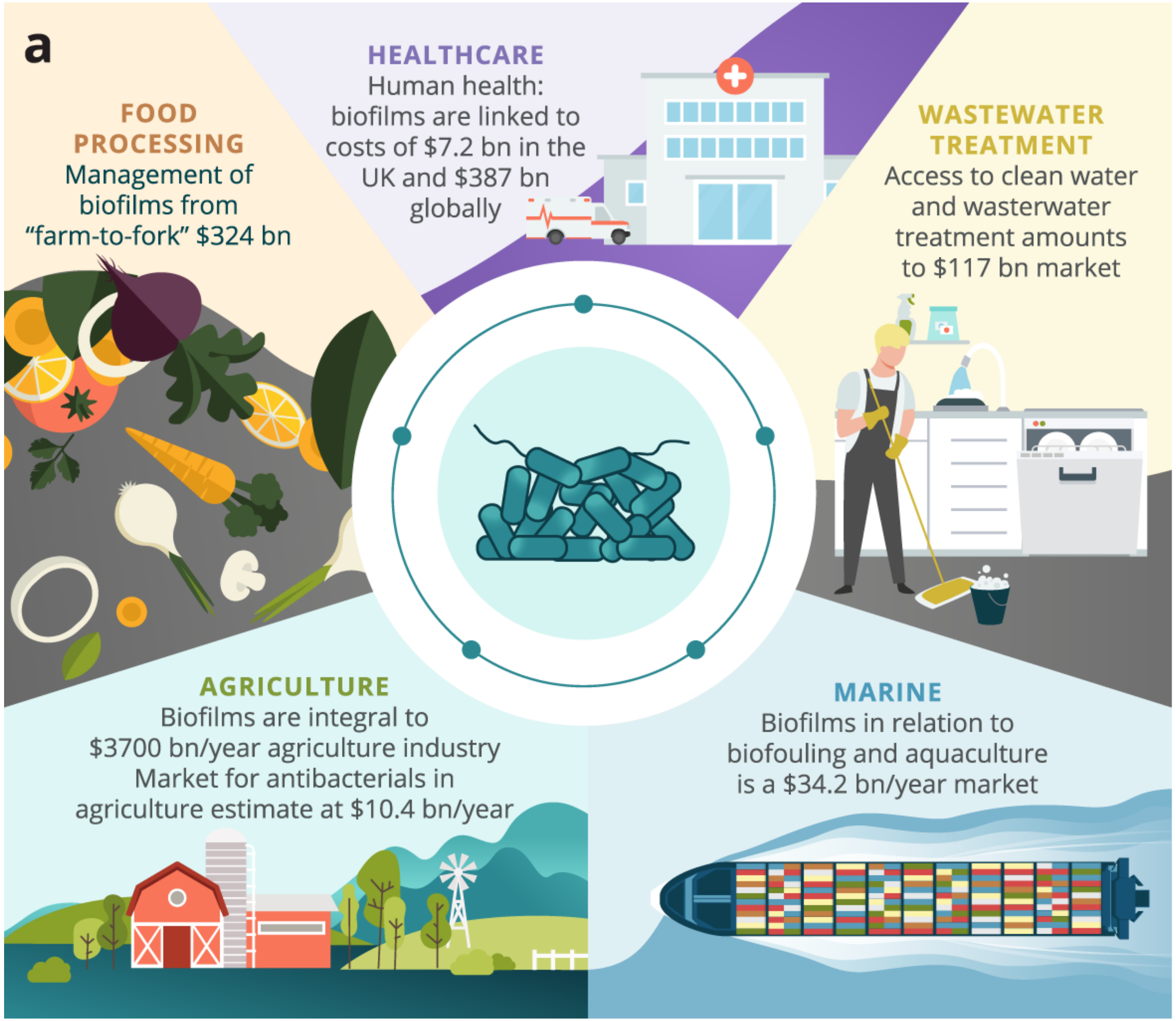








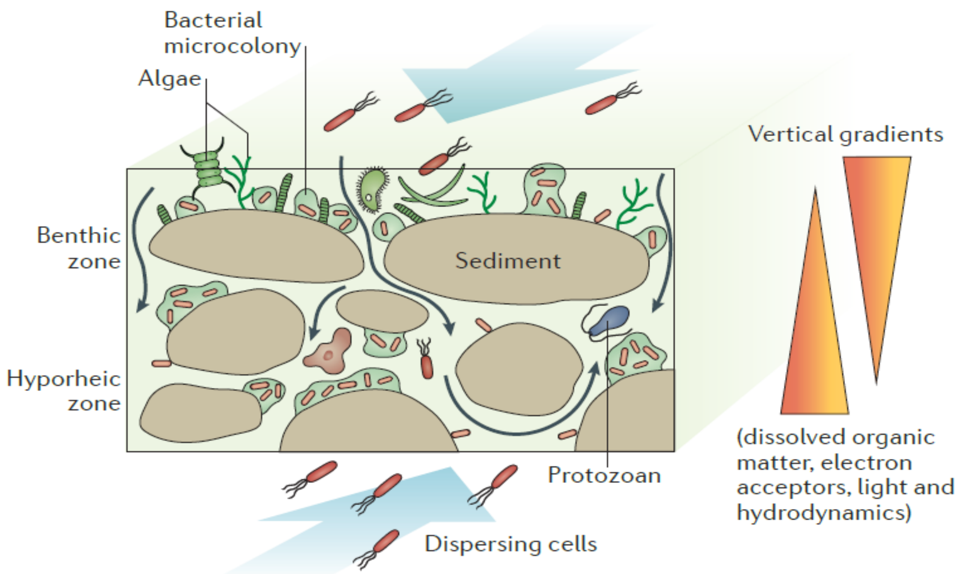
Coyte et al. 2016 PNAS

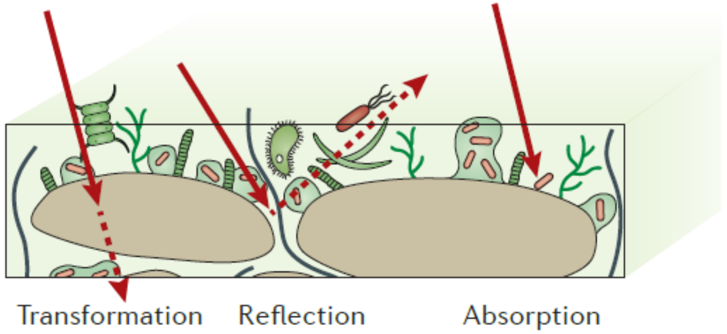


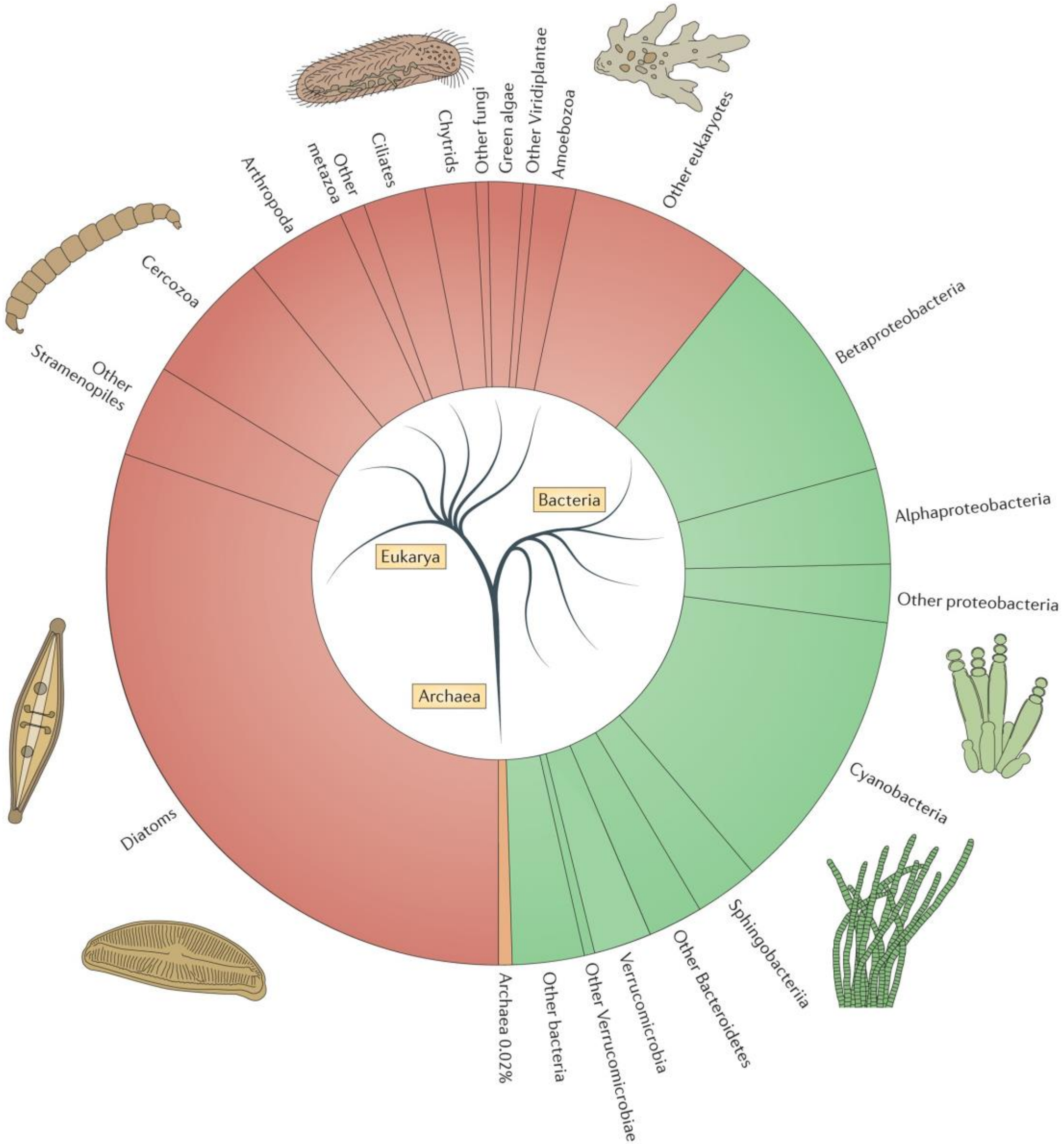
Highmore et al. 2022

The ecology and biogeochemistry of stream biofilms

Tom J. Battin[1], Katharina Besemer[2], Mia M. Bengtsson[3], Anna M. Romani[4] and Aaron I. Packmann[5]





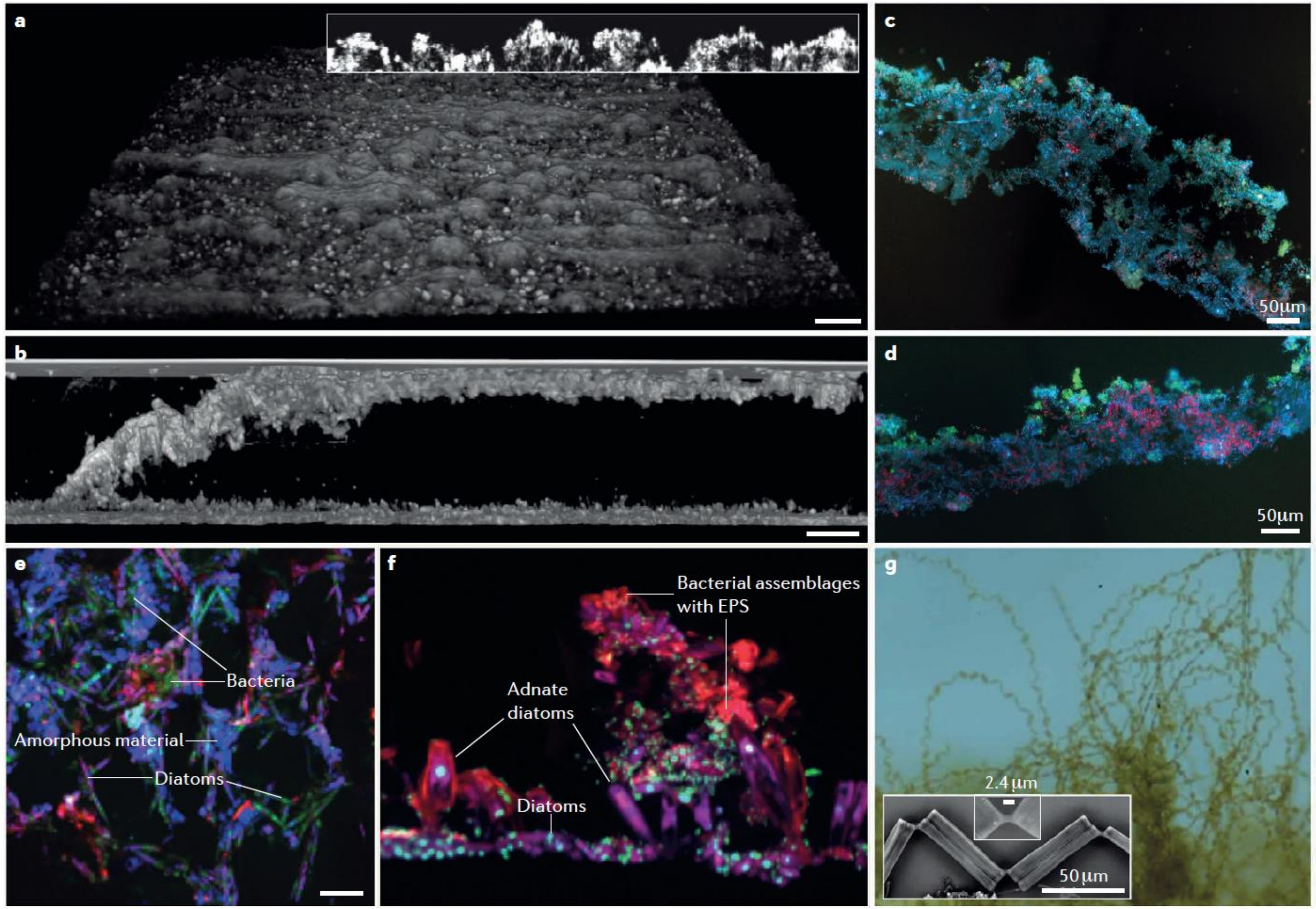


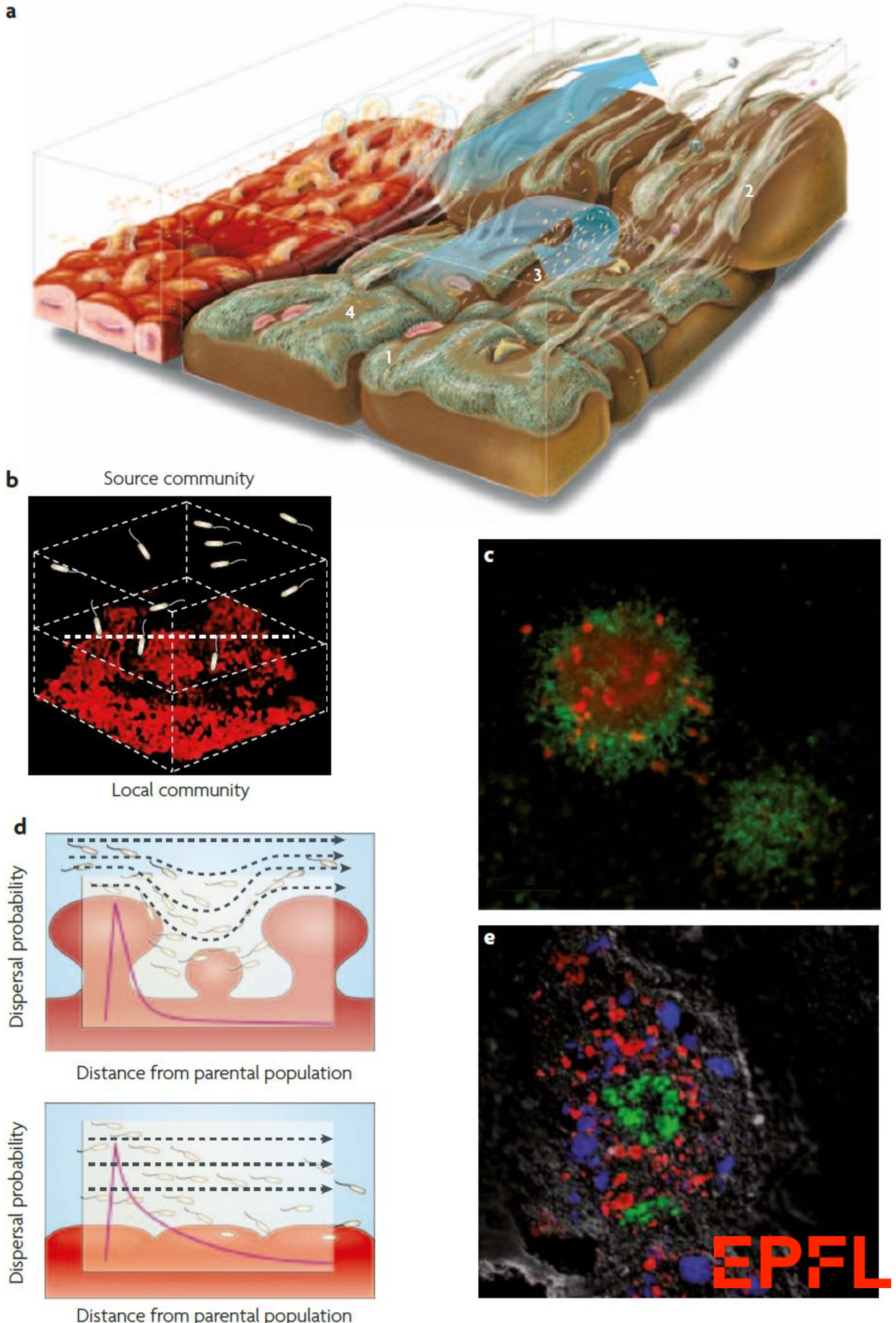
In streams and rivers, biofilm communities are highly complex /diverse and perform important ecosystem functions (e.g. metabolism, water purification, retention of nutrients, cylcing of elements, …

OPINION

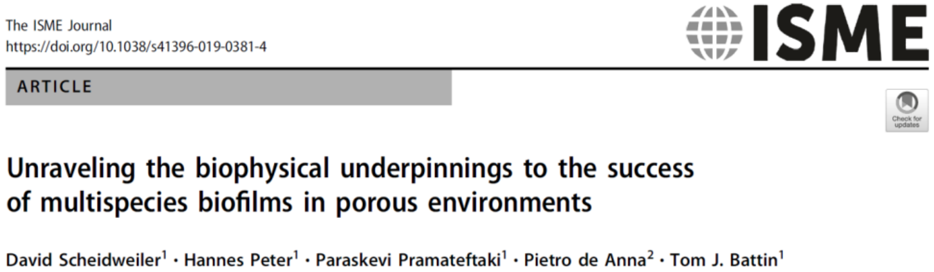
Microbial landscapes: new paths to biofilm research

Tom J. Battin, William T. Sloan, Staffan Kjelleberg, Holger Daims, Ian M. Head, Tom P. Curtis and Leo Eberl



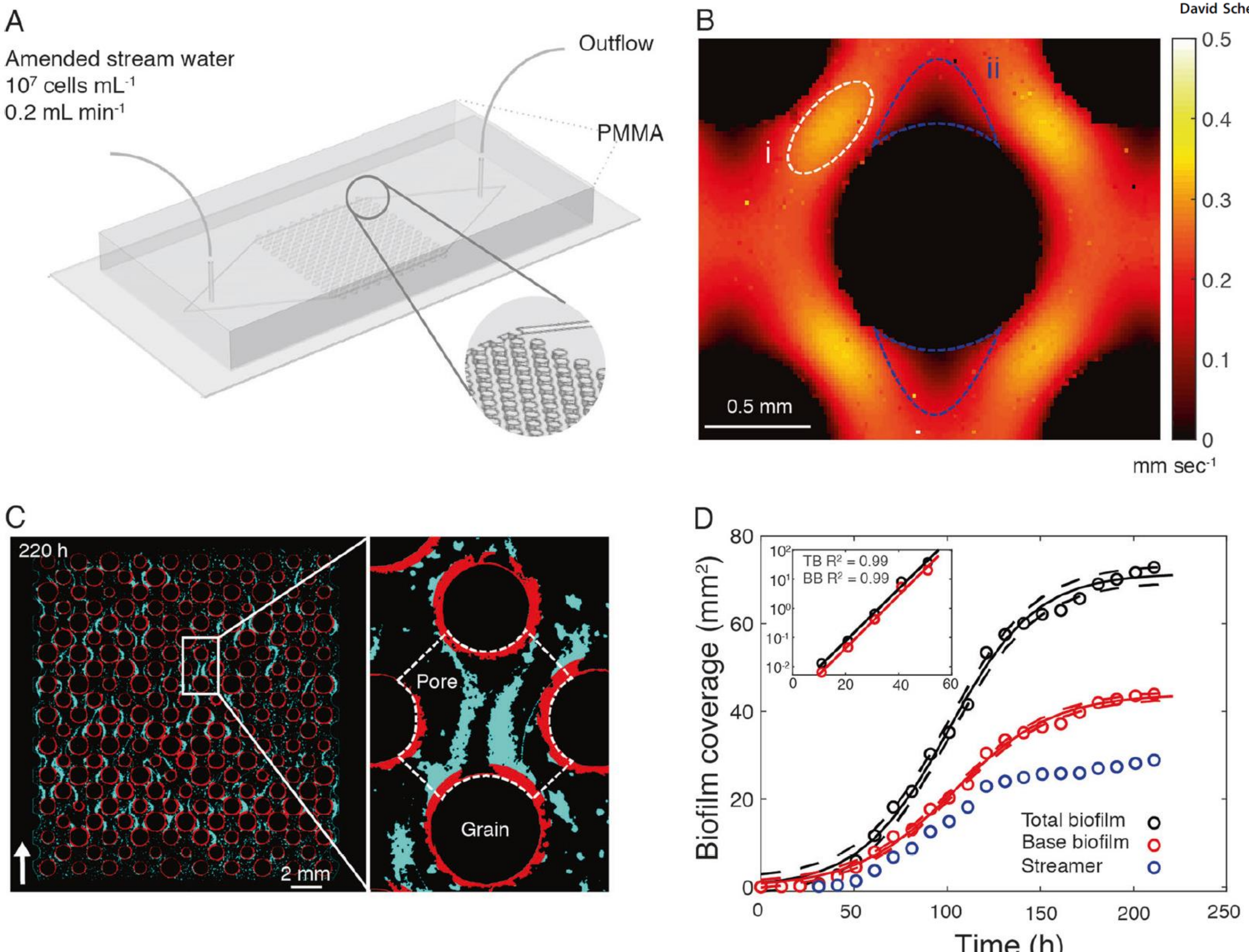


the small scale…


The ISME Journal
https://doi.org/10.1038/s41396-019-0381-4
ISME
ARTICLE

Unraveling the biophysical underpinnings to the success of multispecies biofilms in porous environments

David Scheidweiler[1] · Hannes Peter[1] · Paraskevi Pramateftaki[1] · Pietro de Anna[2] · Tom J. Battin[1]

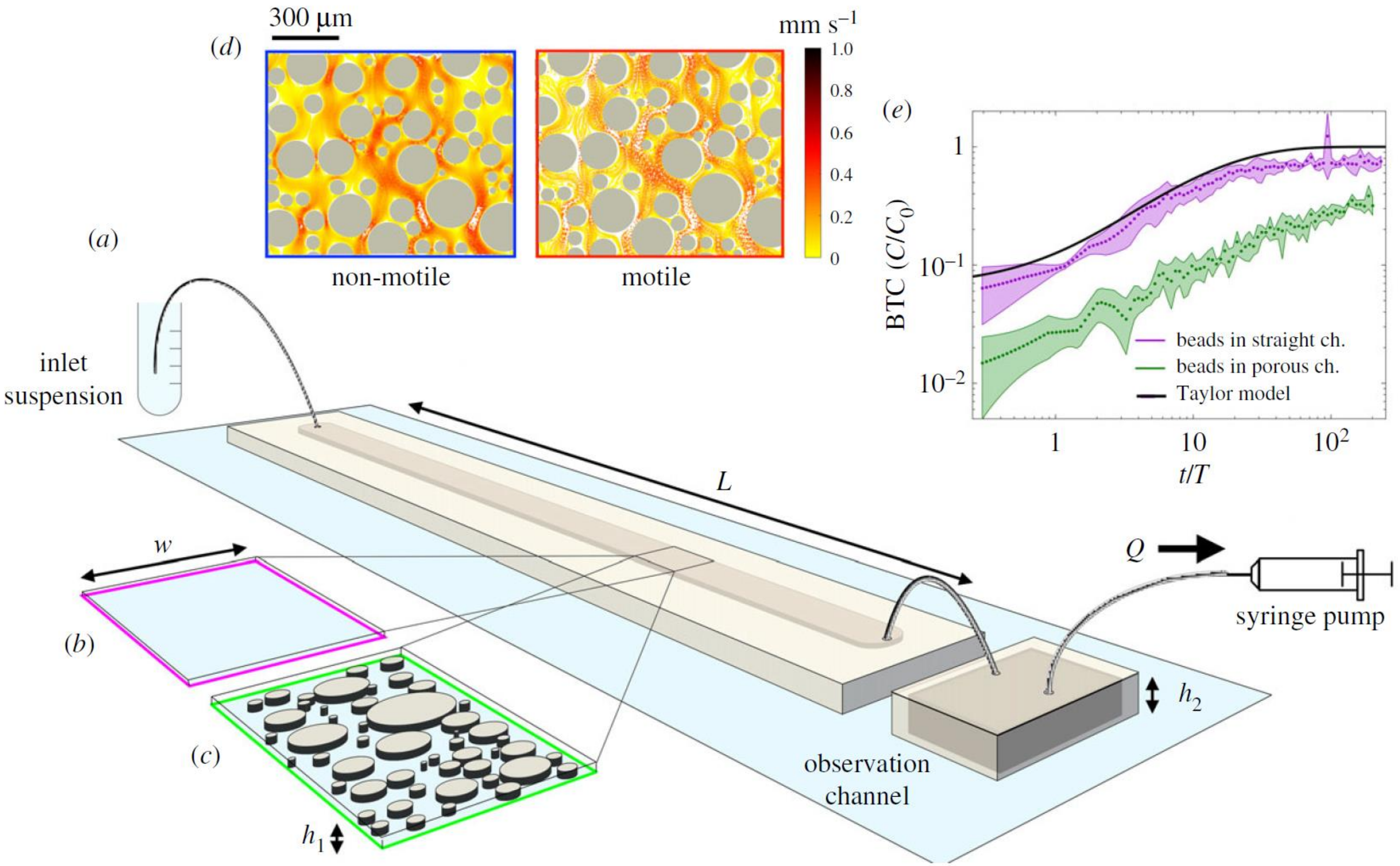


Microfluidics is a powerful tool to study biofilms under controlled conditions.

Biofilm structure (e.g. streamer formation) can help microbes colonize porous substrates.

Architectural plasticity allows a maximization of carrying capacity.

EPFL



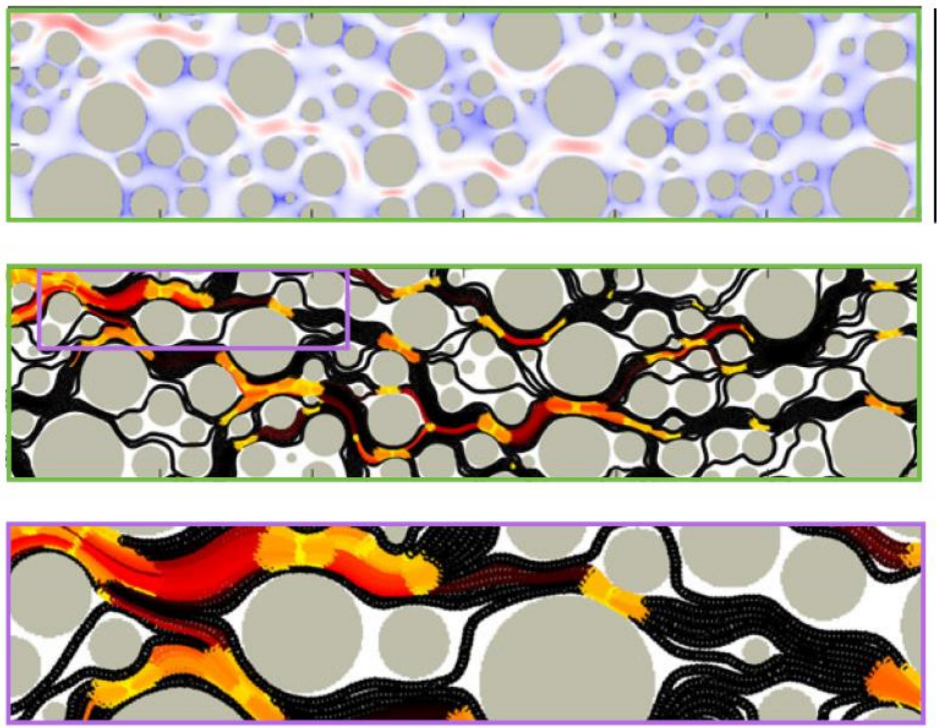
INTERFACE

royalsocietypublishing.org/journal/rsif

Research

Trait-specific dispersal of bacteria in heterogeneous porous environments: from pore to porous medium scale

David Scheidweiler[1,2], Filippo Miele[2], Hannes Peter[1], Tom J. Battin[1] and Pietro de Anna[2]



Biofilm colonization can enhance/lead to the formation of preferential flow paths in porous environments.

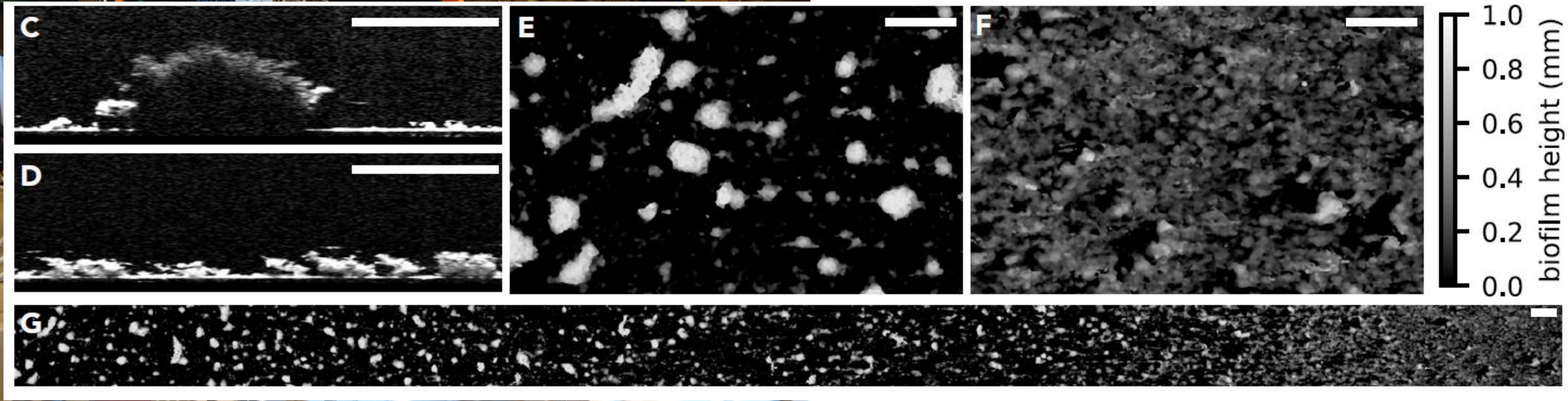
Motile bacteria can escape these trajectories

iScience

CellPress
OPEN ACCESS

Article

Morphogenesis and oxygen dynamics in phototrophic biofilms growing across a gradient of hydraulic conditions



Interactions between biofilm structure and small-scale hydraulics lead to different biofilm morphologies

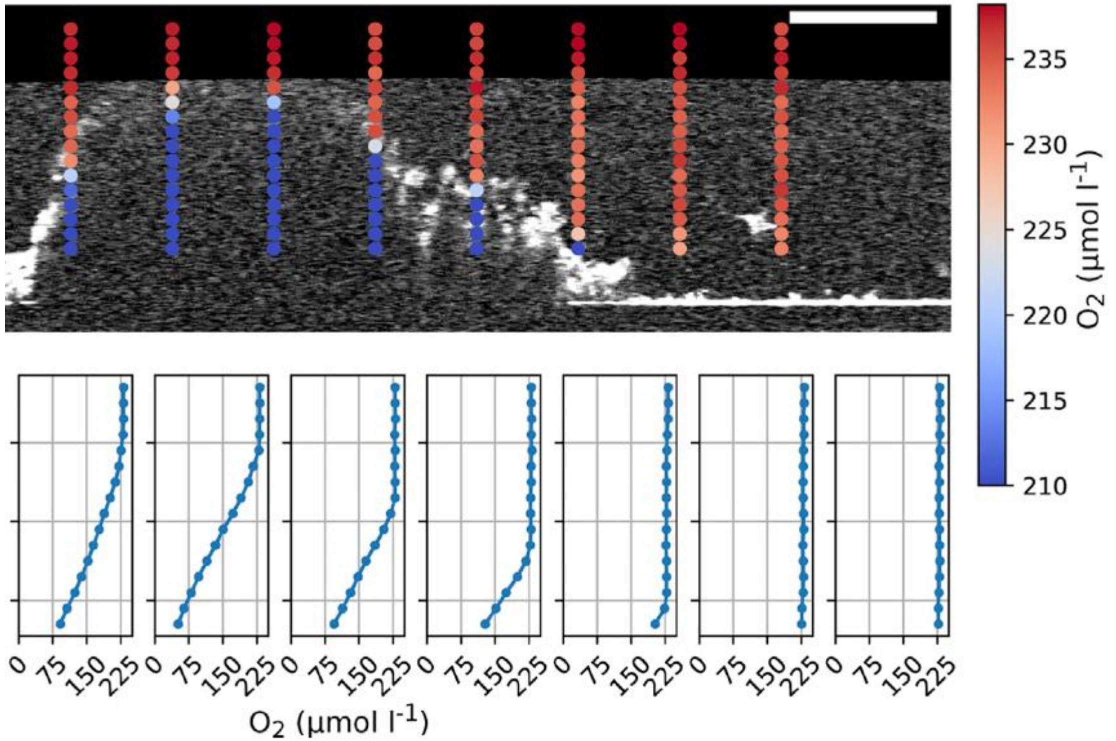
npj Biofilms and Microbiomes www.nature.com/npjbiofilms

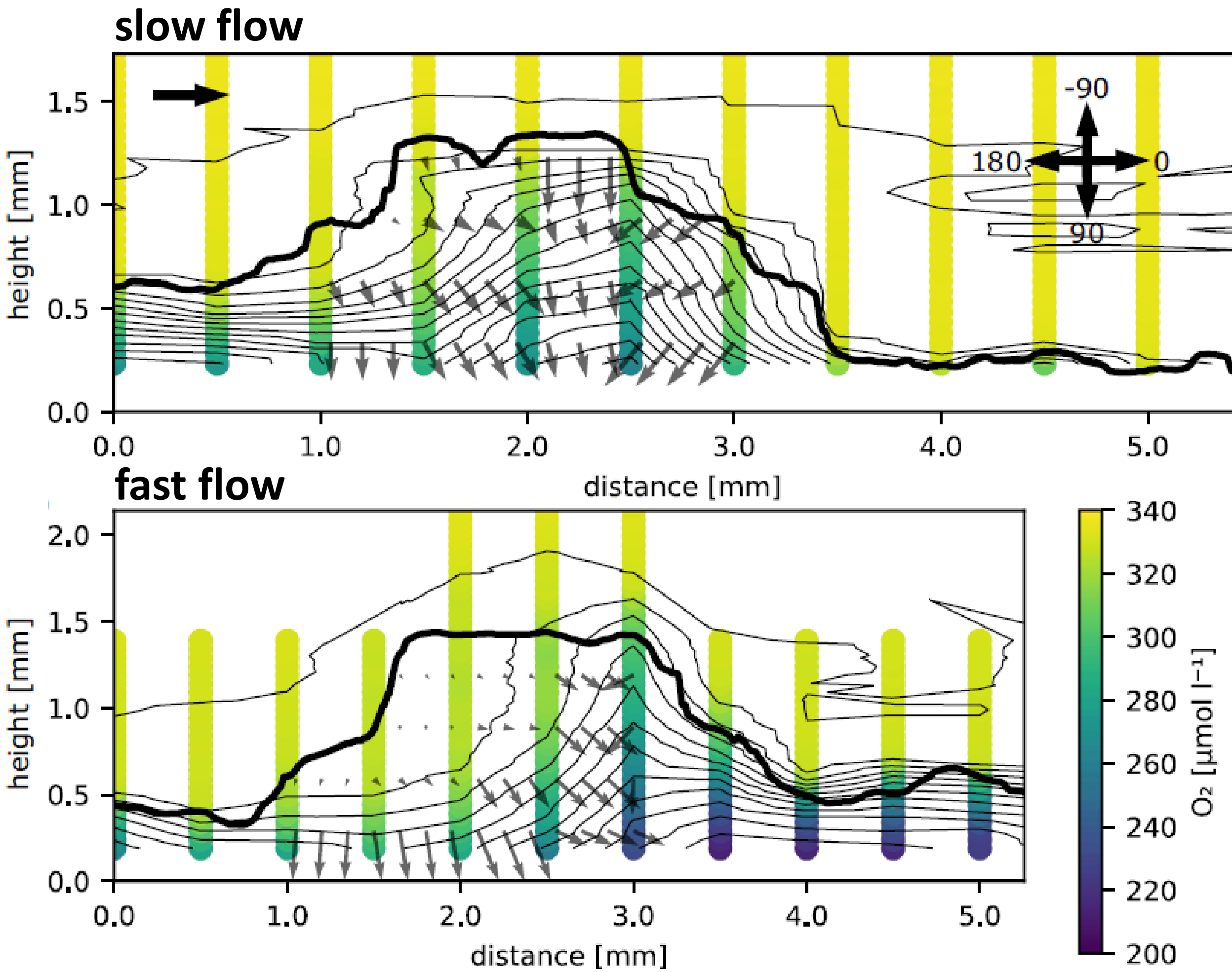
ARTICLE OPEN

Check for updates

Biophysical properties at patch scale shape the metabolism of biofilm landscapes

Anna Depetris[1], Giorgia Tagliavini[2,3], Hannes Peter[1], Michael Kühl[4], Markus Holzner[2,3] and Tom J. Battin[1]





Biofilm morphology, local hydraulics and the diffusion of oxygen shape the micro-meter scale 3D structure of complex phototrophic biofilms.

EPFL

take home messages

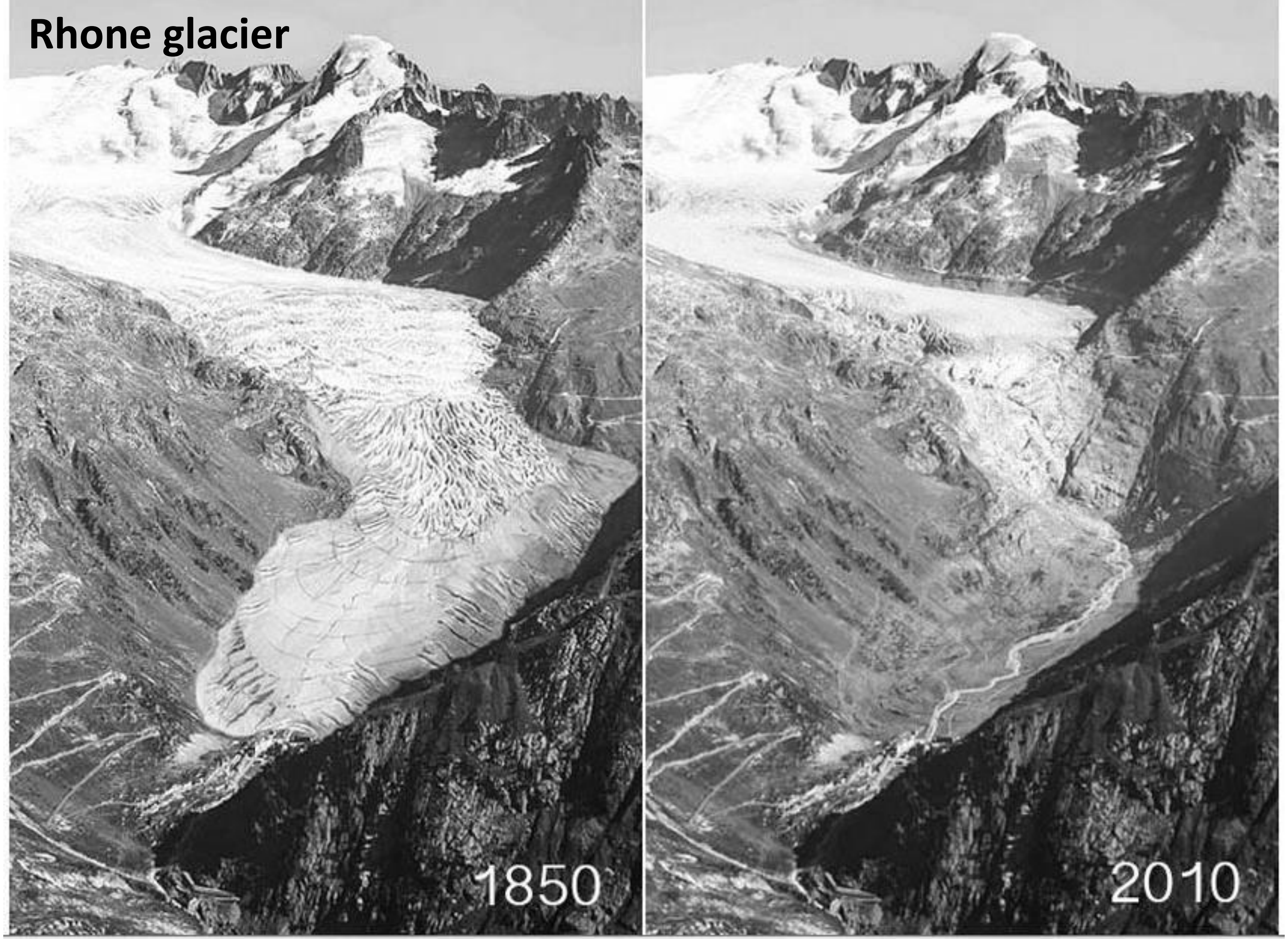
- Most microbes prefer a sessile (attached) lifestyle - embedded in complex biofilm communities
- The biofilm matrix enables the attachment of cells, provides physical stabiliy, protection and captures nutrients
- River biofilms are highly diverse, the microbes in these communities drive important ecosystem functions
- The flow of water, the diffusion of oxygen and nutrients shape biofilm morphology

the ecosystem scale

Vanishing Glaciers Project

How does glacier retreat affect microbial communities in glacier-fed streams?

Rhone glacier



EPFL

World map of the Vanishing Glaciers Project Expeditions

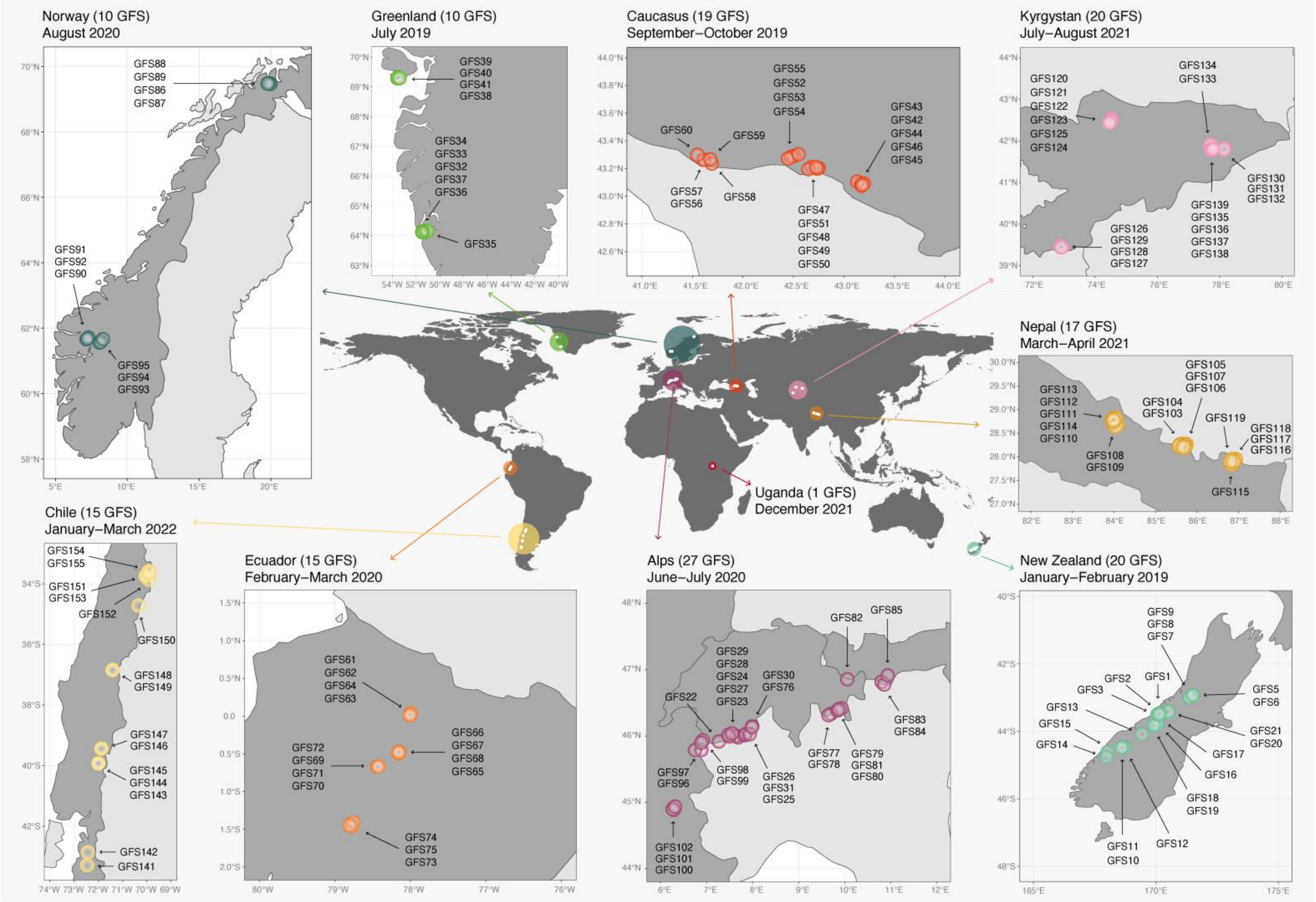
VANISHING GLACIERS PROJECT

EPFL

NOMIS FOUNDATION

NOMIS FOUNDATION Creating the Spark

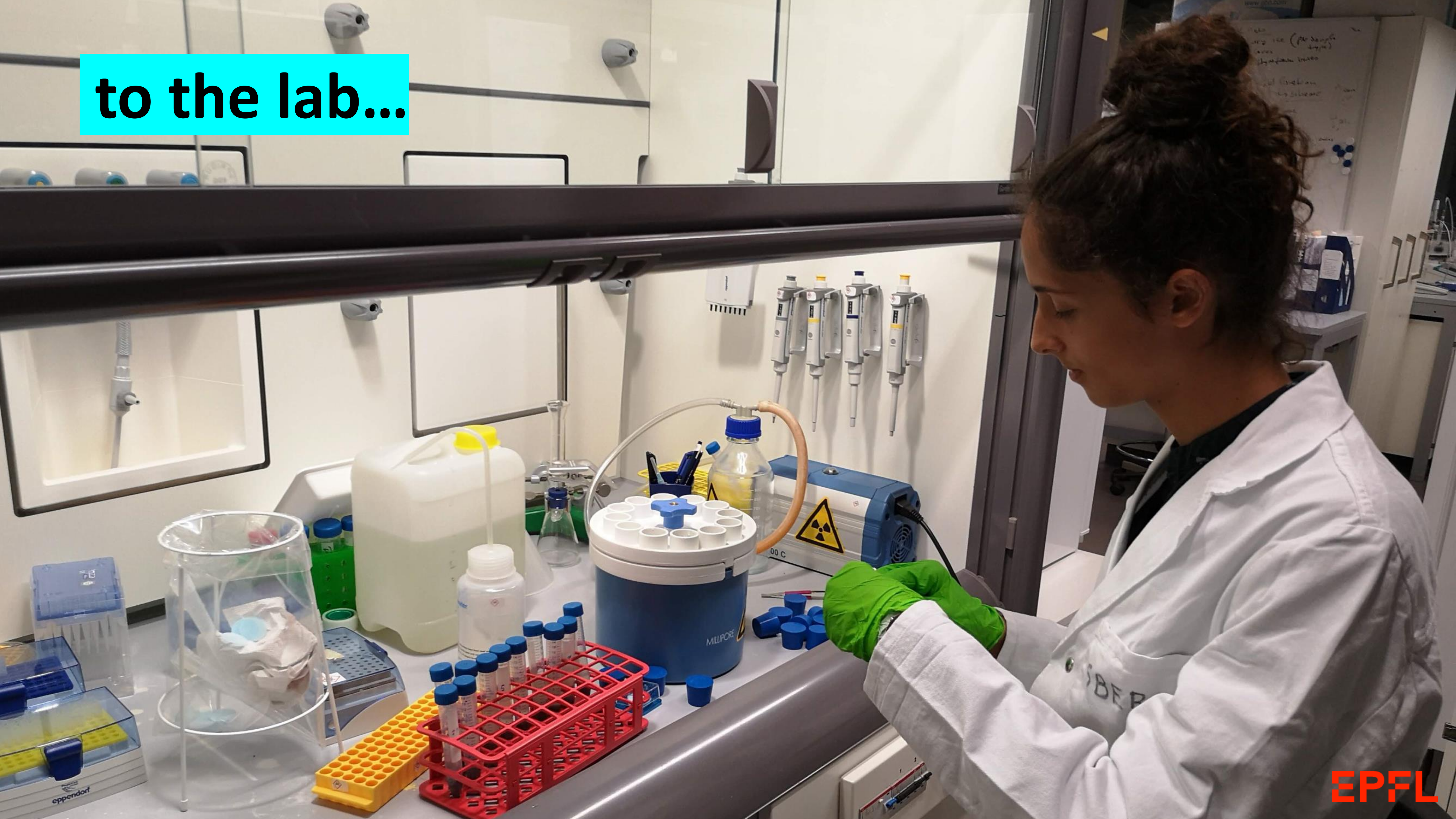
EPFL




UV radiation
extreme
environment
carbon sources
windows of
opportunity
turbidity
unstable substrate
oligotrophic
low temperature

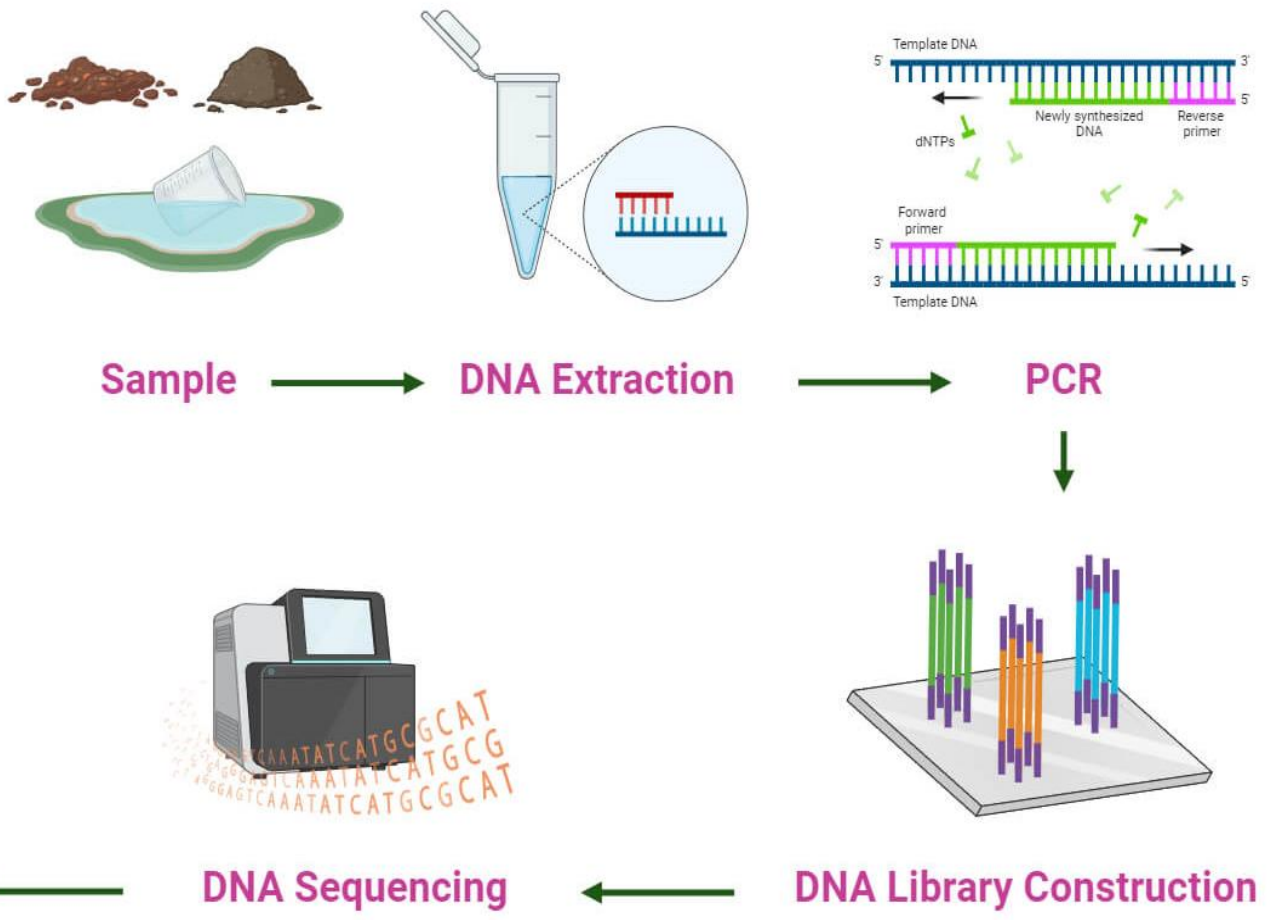
from the field...

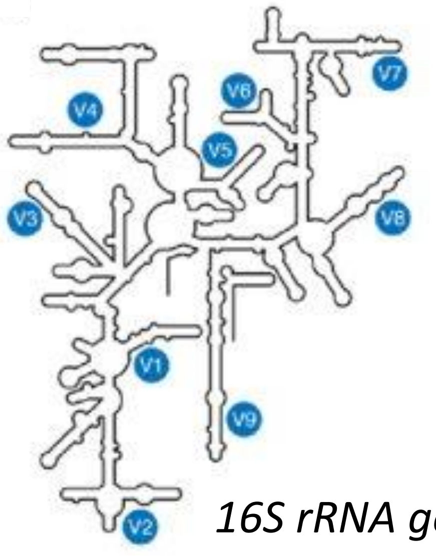
to the lab...



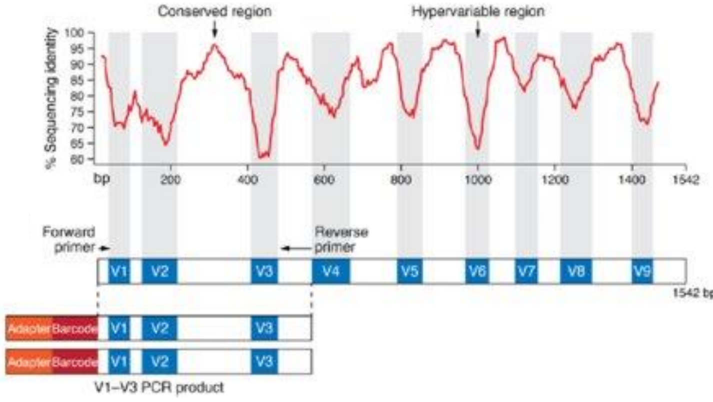

to the computer…
EPFL

16S rRNA Gene Sequencing





16S rRNA gene



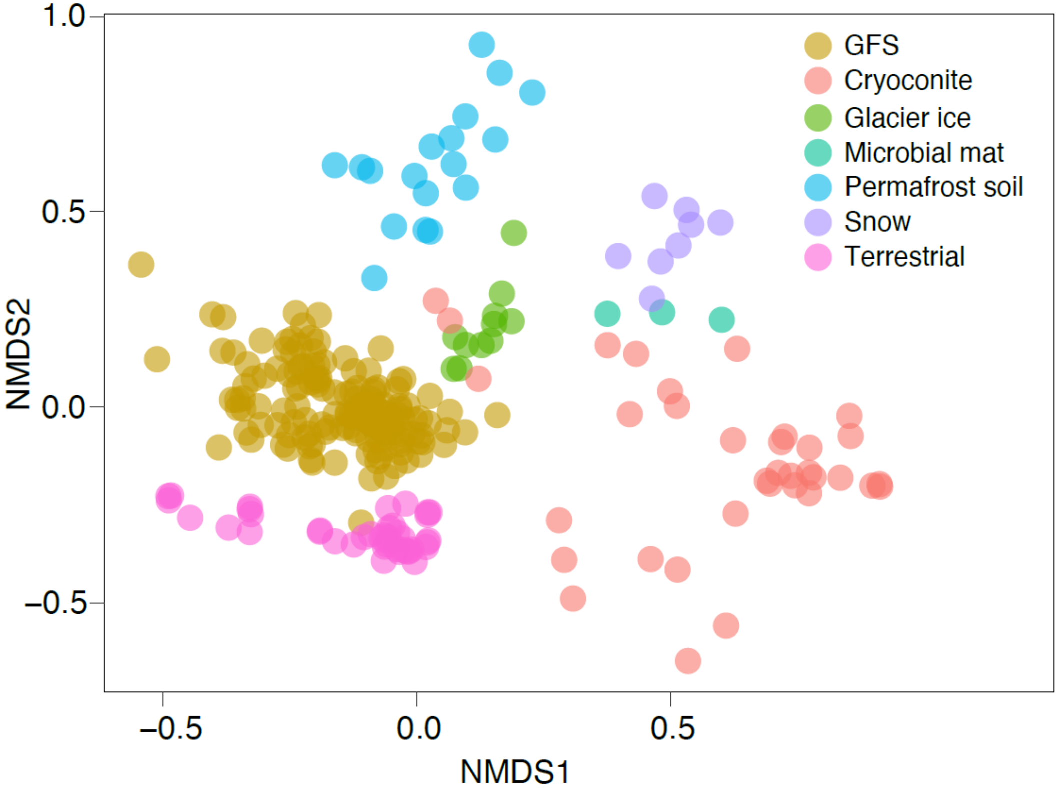
ARTICLE

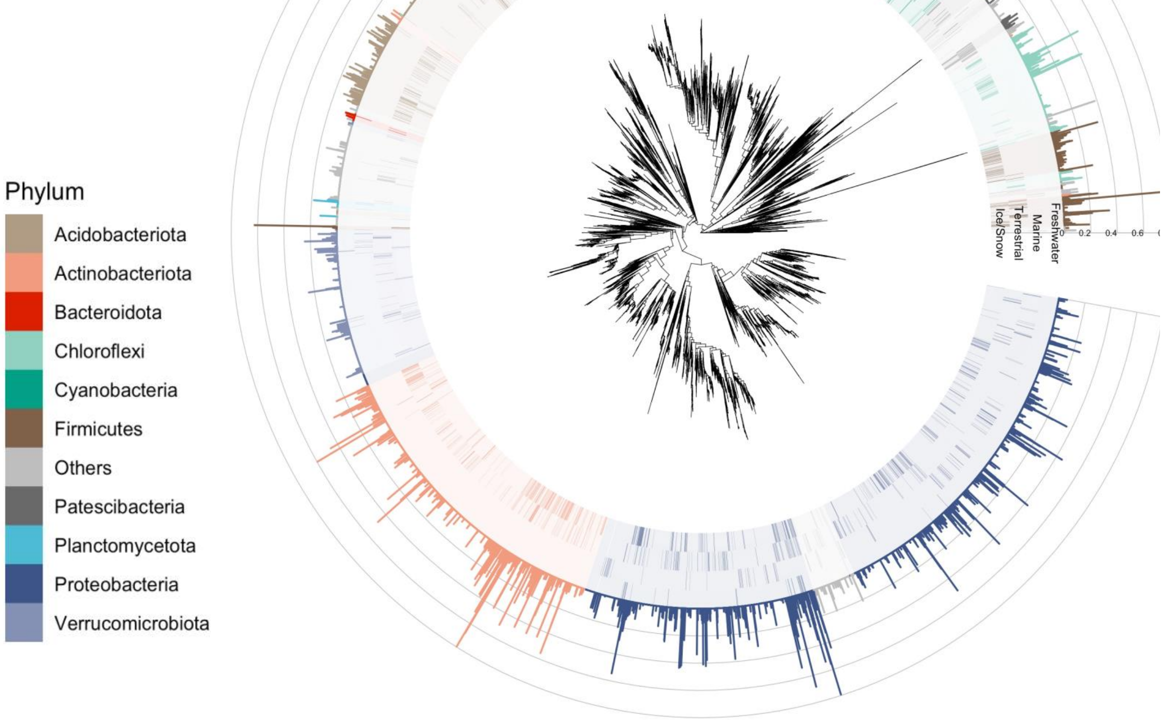
https://doi.org/10.1038/s41467-022-30816-4 OPEN

Check for updates

The microbiome of cryospheric ecosystems

Massimo Bourquin[1,5✉], Susheel Bhanu Busi[2,5], Stilianos Fodelianakis[1], Hannes Peter[1], Alex Washburne[3], Tyler J. Kohler[1], Leïla Ezzat[1], Grégoire Michoud[1], Paul Wilmes[2,4] & Tom J. Battin[1✉]





GFS microbiomes are composed of different microbes as compared to other cryospheric ecosystems.

The retreat of glaciers will impact this unique biodiversity.

Article
https://doi.org/10.1038/s41561-024-01393-6

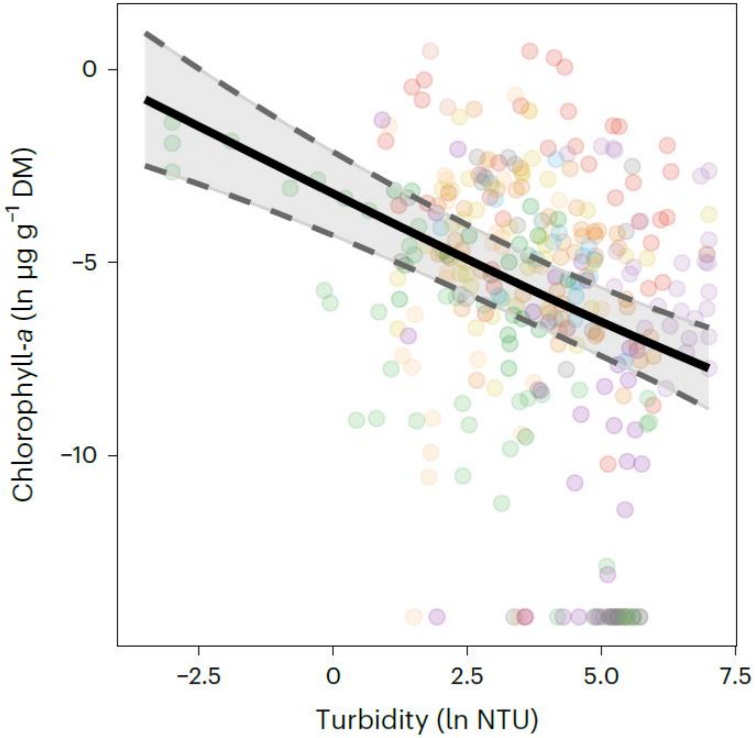
Global emergent responses of stream microbial metabolism to glacier shrinkage

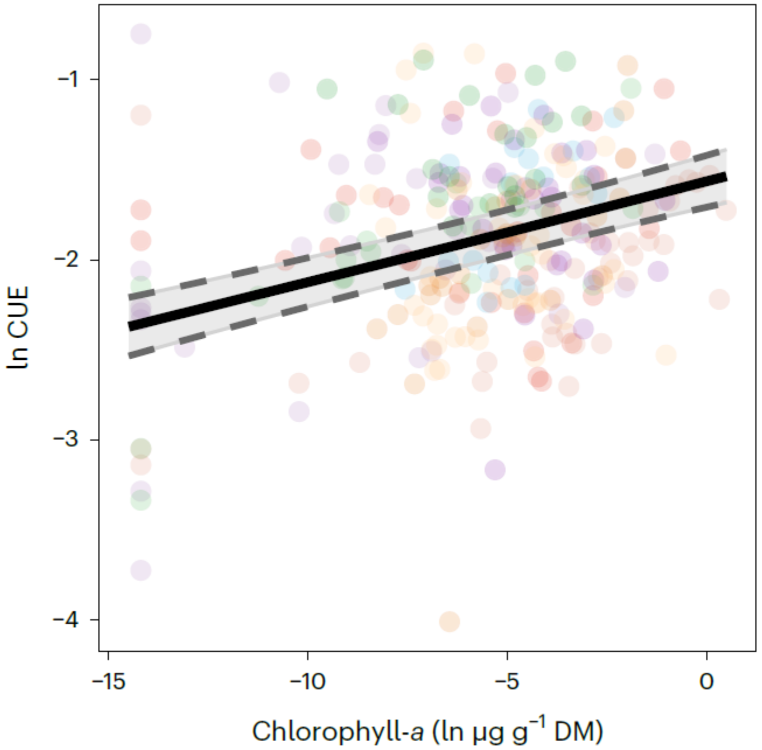
Received: 31 May 2023

Accepted: 30 January 2024

Published online: 1 March 2024

Tyler J. Kohler[1,2], Massimo Bourquin[1], Hannes Peter[1], Gabriel Yvon-Durocher[3], Robert L. Sinsabaugh[4], Nicola Deluigi[1], Michael Styllas[1], Vanishing Glaciers Field Team* & Tom J. Battin[1]





The vanishing of glaciers results in “greening” of GFS – with important consequences for microbial ecophysiology.

Article

Global diversity and biogeography of the glacier-fed stream bacterial microbiome

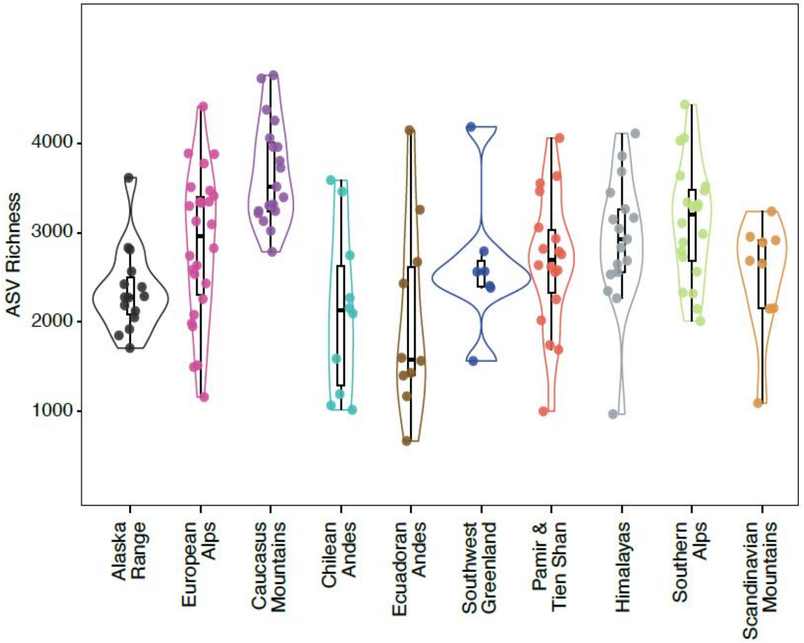
https://doi.org/10.1038/s41586-019-0000-0

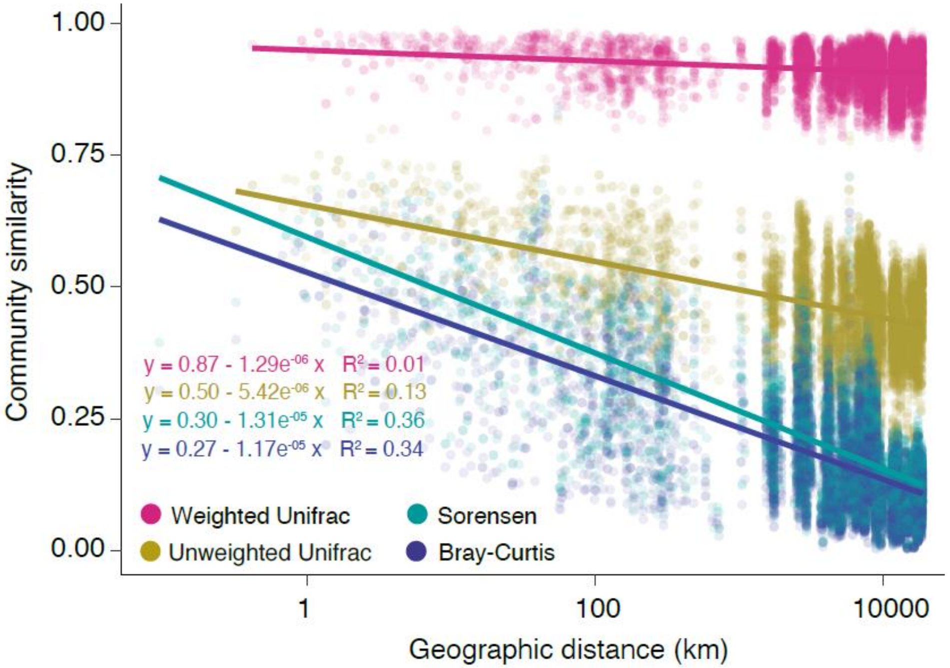
Received: 00 Month 20XX

Accepted: 00 Month 20XX

Published online: 00 Month 20XX

Leïla Ezzat[1,2*], Hannes Peter[1], Massimo Bourquin[1], Susheel Bhanu Busi[3,4], Grégoire Michoud[1], Stilianos Fodelianakis[1], Tyler J. Kohler[1,5], Thomas Lamy[2], Aileen Geers[1], Paraskevi Pramateftaki[1], Florian Baier[1], Ramona Marasco[6], Daniele Daffonchio[6], Nicola Deluigi[1], Paul Wilmes[4], Michail Styllas[1,7], Martina Schön[1], Matteo Tolosano[1], Vincent De Staercke[1], and Tom J. Battin[1*]





Despite the harsh conditions GFS microbial communities are highly diverse.

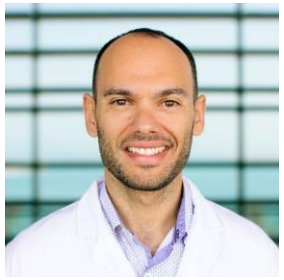
Across the world, GFS microbiomes are structured by spatial distance, regionality and environmental selection.

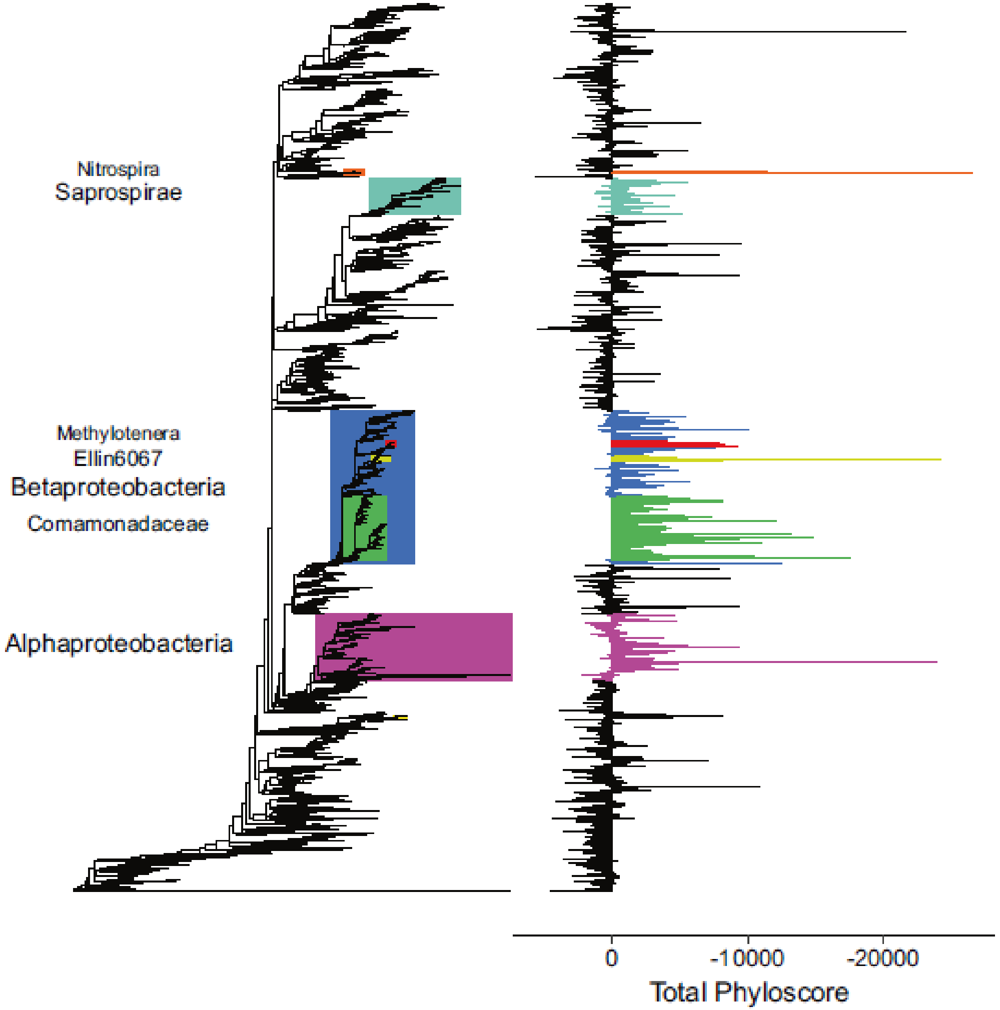
The selective environment (e.g. low nutrient availability=oligotrophy, cold temperature, unstable streambed) is similar in GFS around the world.

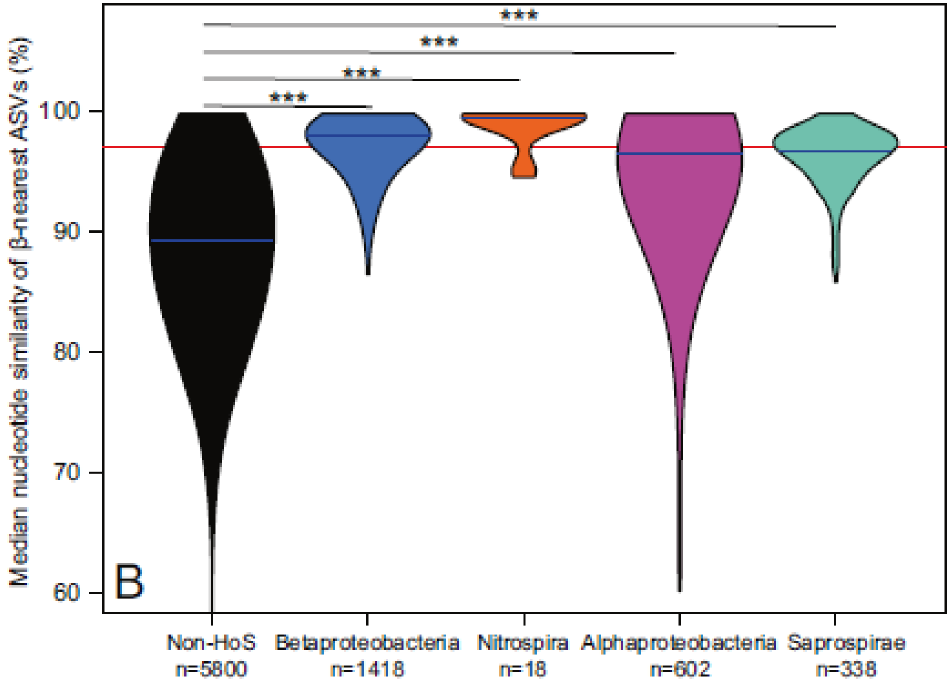
ARTICLE OPEN

Microdiversity characterizes prevalent phylogenetic clades in the glacier-fed stream microbiome

Stilianos Fodelianakis[1] ✉, Alex D. Washburne[2], Massimo Bourquin[1], Paraskevi Pramateftaki[1], Tyler J. Kohler[1], Michail Styllas[1], Matteo Tolosano[1], Vincent De Staercke[1], Martina Schön[1], Susheel Bhanu Busi[3], Jade Brandani[1], Paul Wilmes[3], Hannes Peter[1] and Tom J. Battin[1] ✉



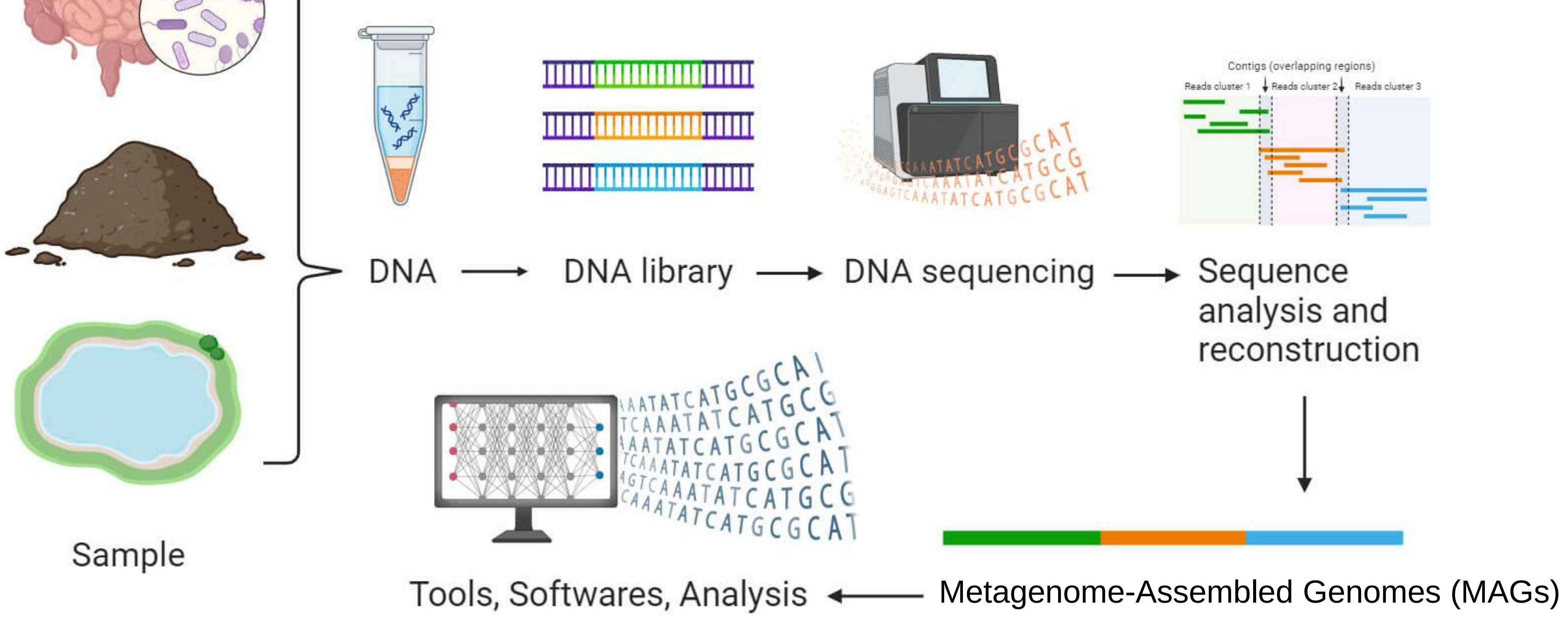




Extreme environmental conditions select for phylogenetically related clades. These clades can regionally diversify and become microdiverse.

EPFL

Metagenomics

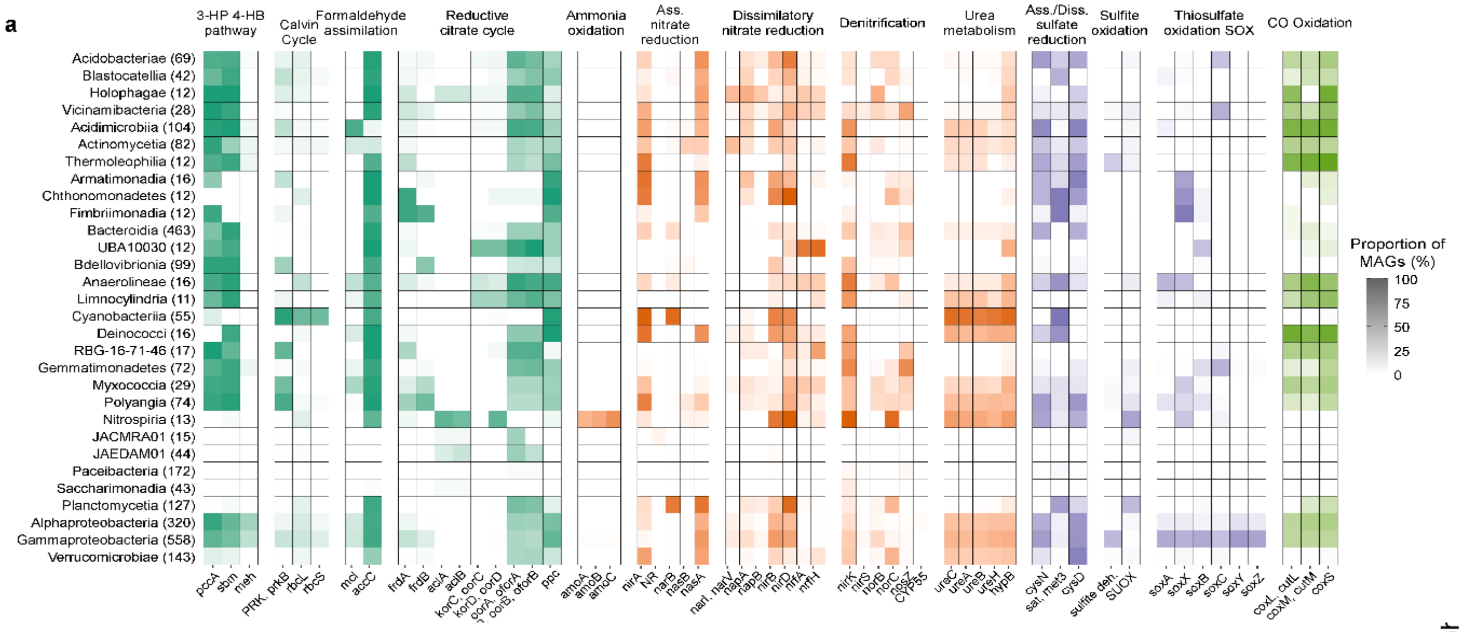


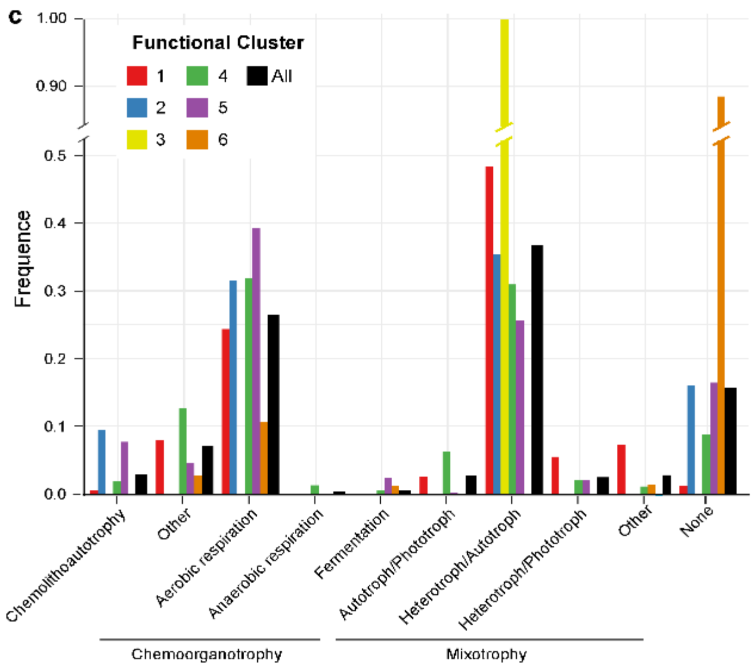
Functional potential, phylogeny,

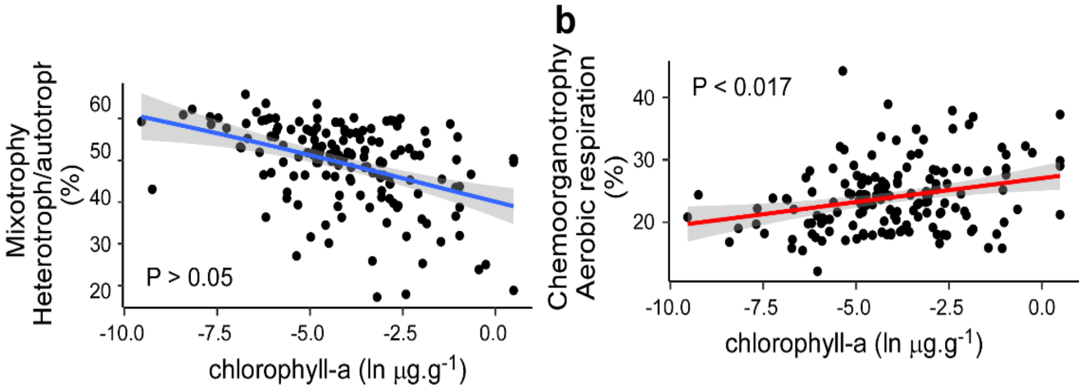
Mapping the metagenomic diversity of the multi-kingdom glacier-fed stream microbiome

Gregoire Michoud, Hannes Peter, Susheel Busi, Massimo Bourquin, Tyler Kohler, Aileen Geers, Leila Ezzat, Tom Battin

in press







Many microbes in GFS encode similar/same functions => functional redundancy (provides «insurance» in unstable habitats)

Chemolithoautotrophy and mixotrophy are important in GFS

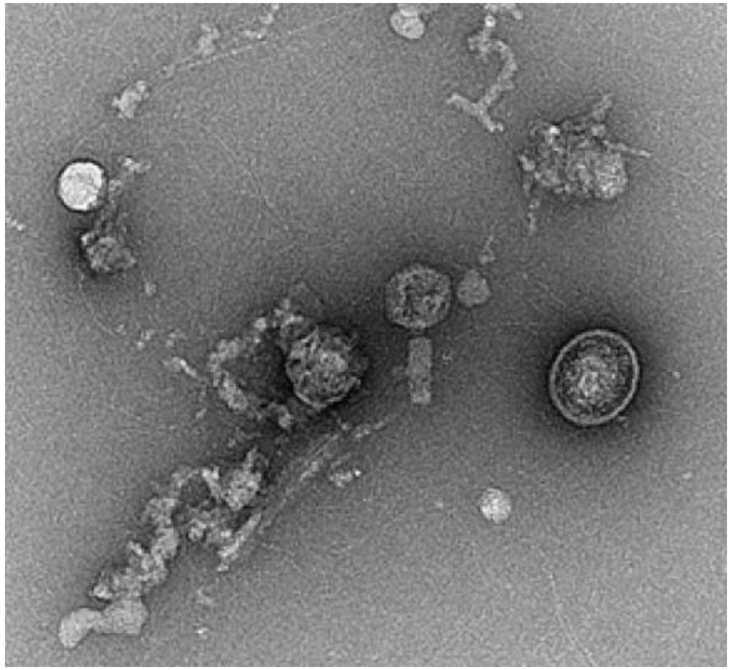
EPFL

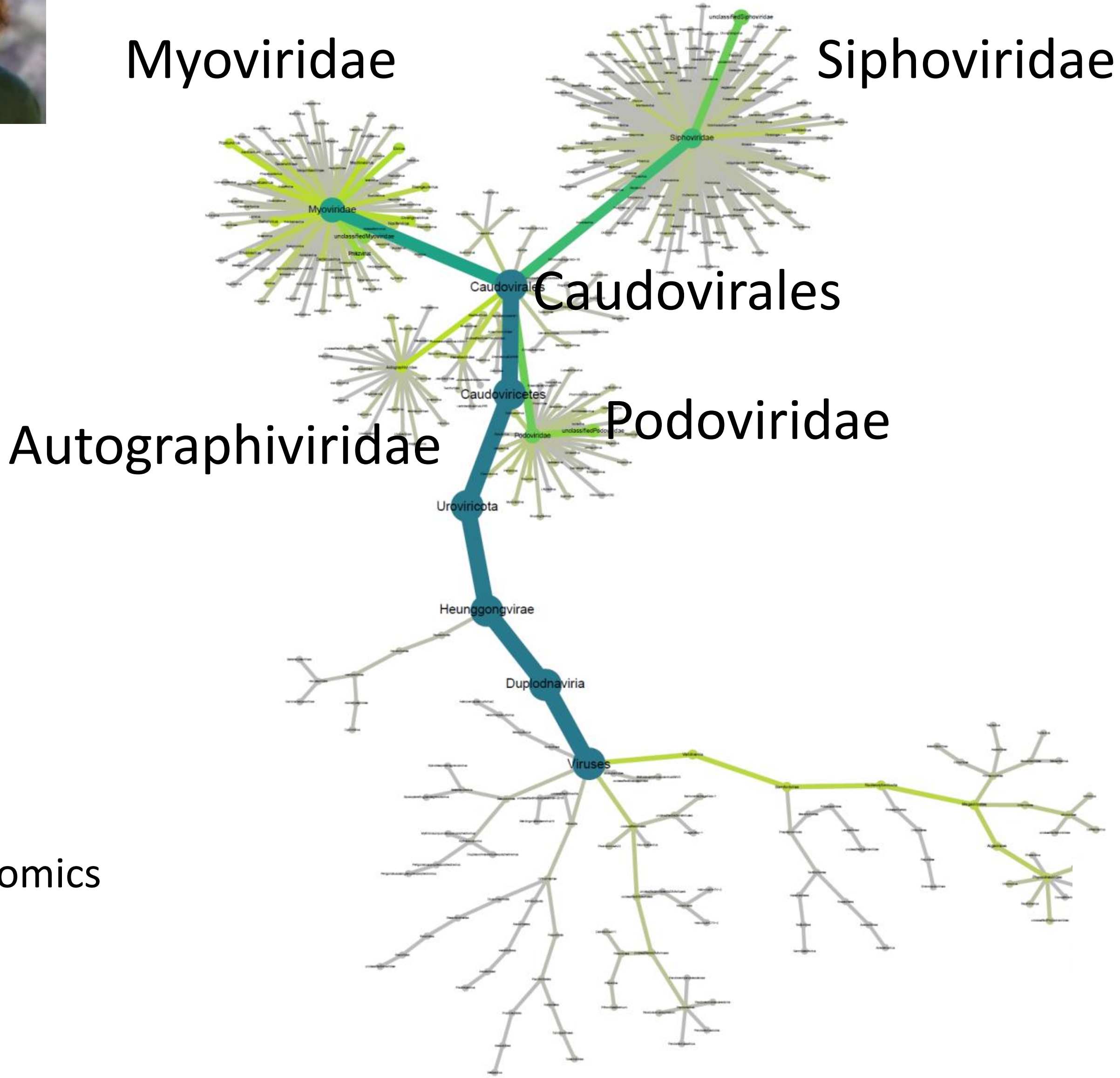
ISME www.nature.com/ismecomms

ARTICLE OPEN

Viral diversity is linked to bacterial community composition in alpine stream biofilms

Meriem Bekliz[1], Paraskevi Pramateftaki[1], Tom Jan Battin[1] and Hannes Peter[1]





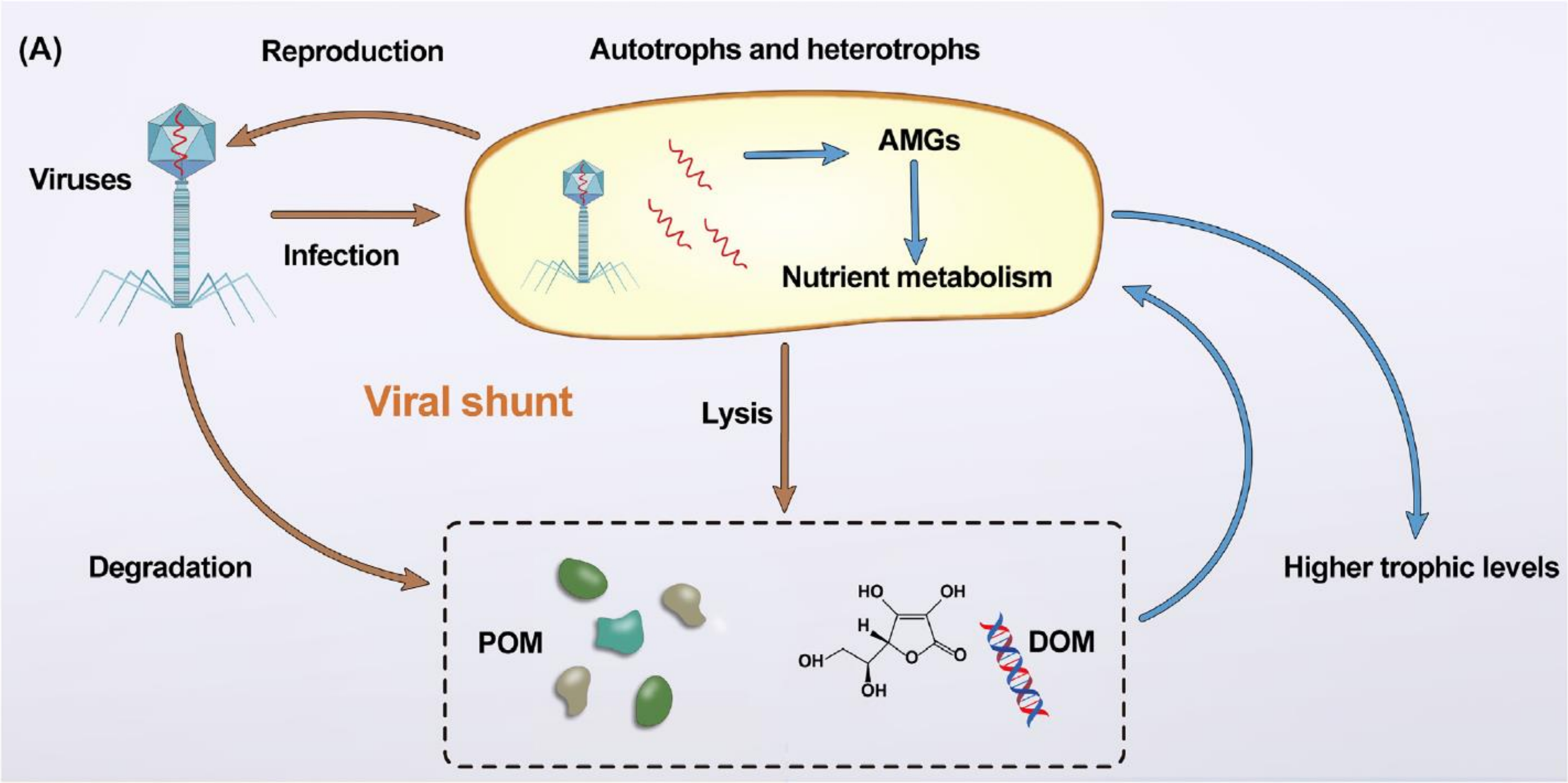
Studies on viruses in stream biofilms are scarce – metagenomics (viromics) allows first insights into their diversity.

Stream biofilm viral communities are highly diverse.

Viral and bacterial community composition is coupled (correlated).

EPFL

Viruses (phages) in aquatic ecosystems

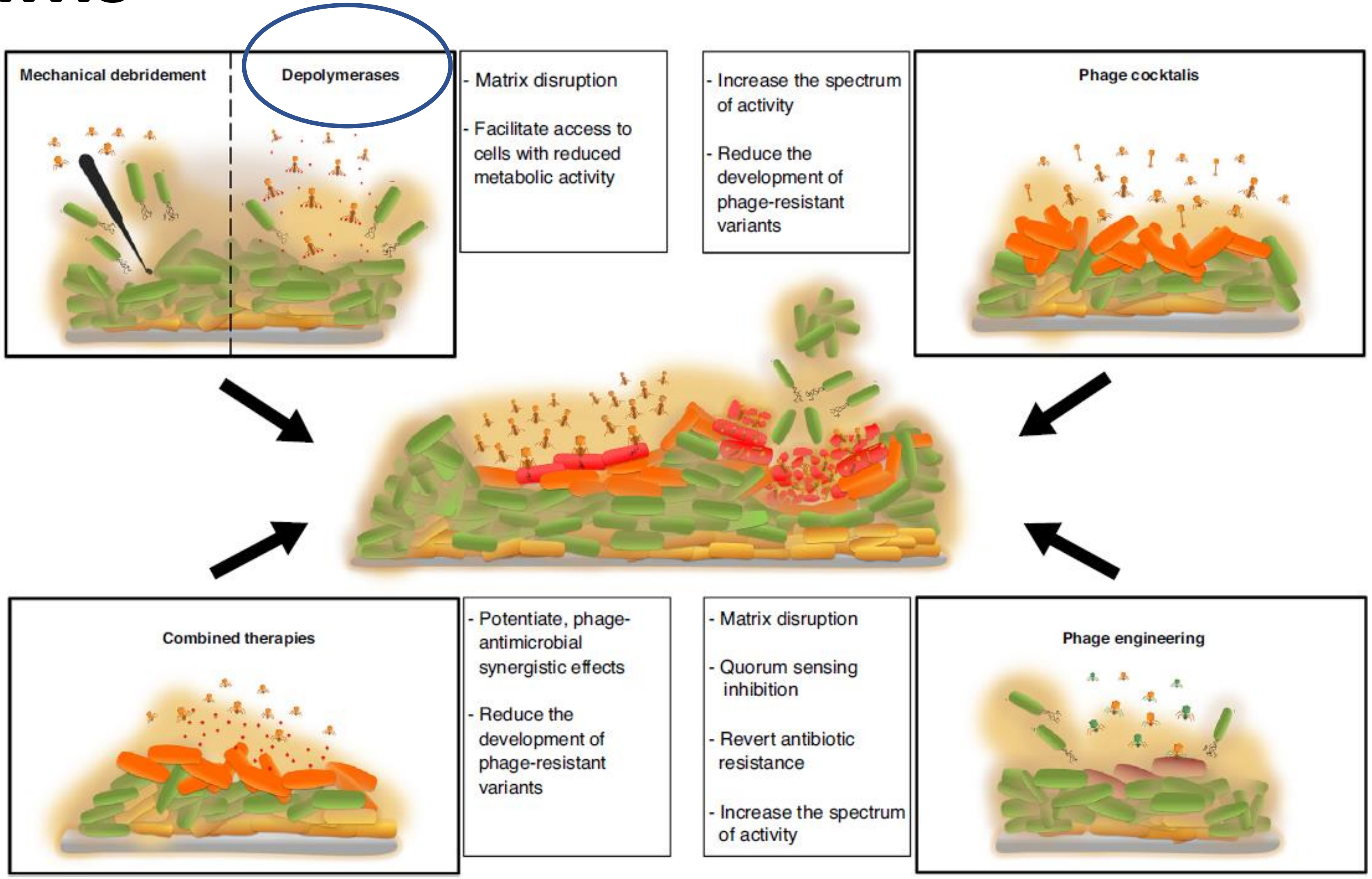


Huang et al. 2024 Trends in Microbiology

EPFL

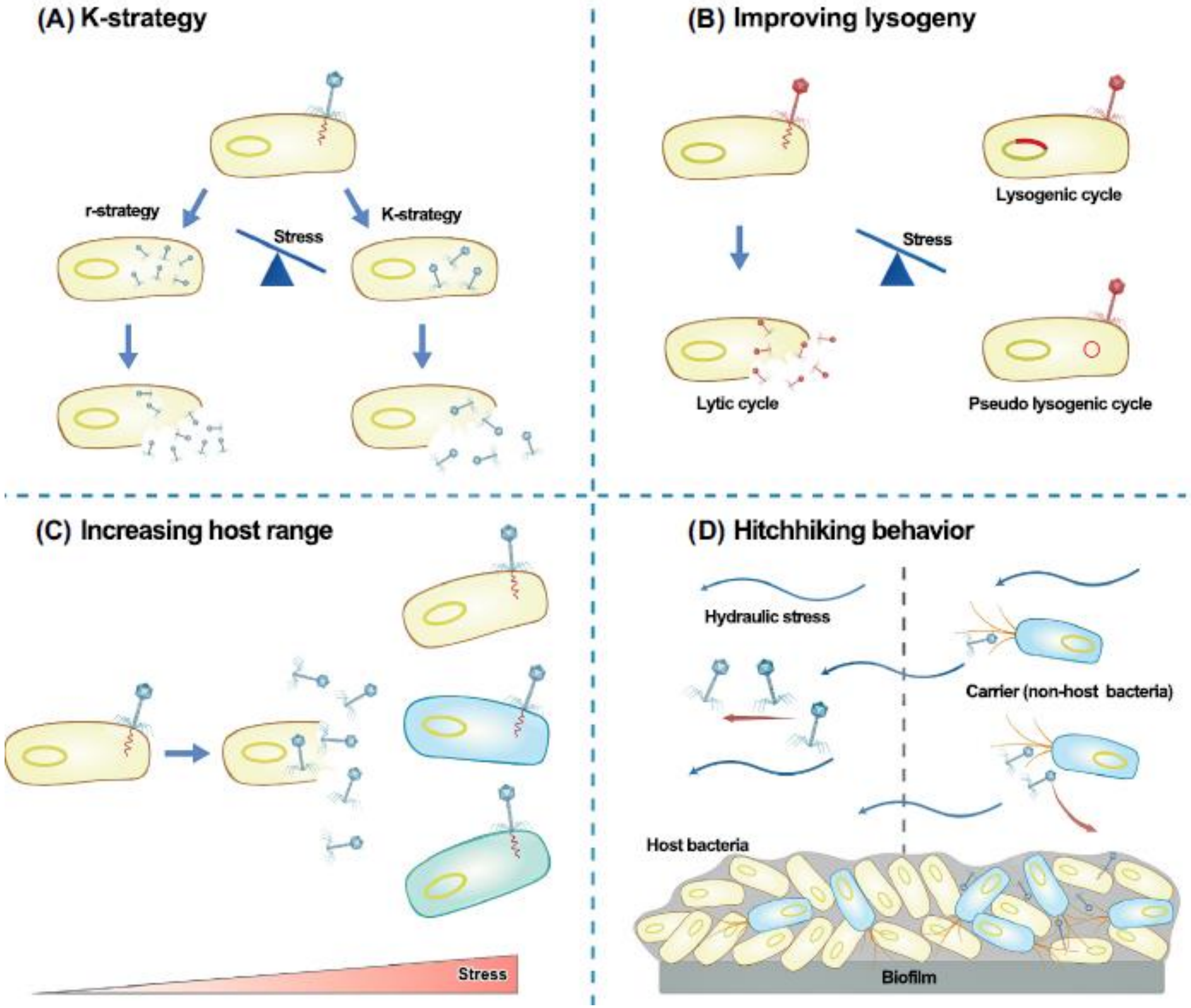
viruses and biofilms

phage-biofilm interaction studies are dominated by work on phage therapy



Pires et al. 2017

phages in extreme environments

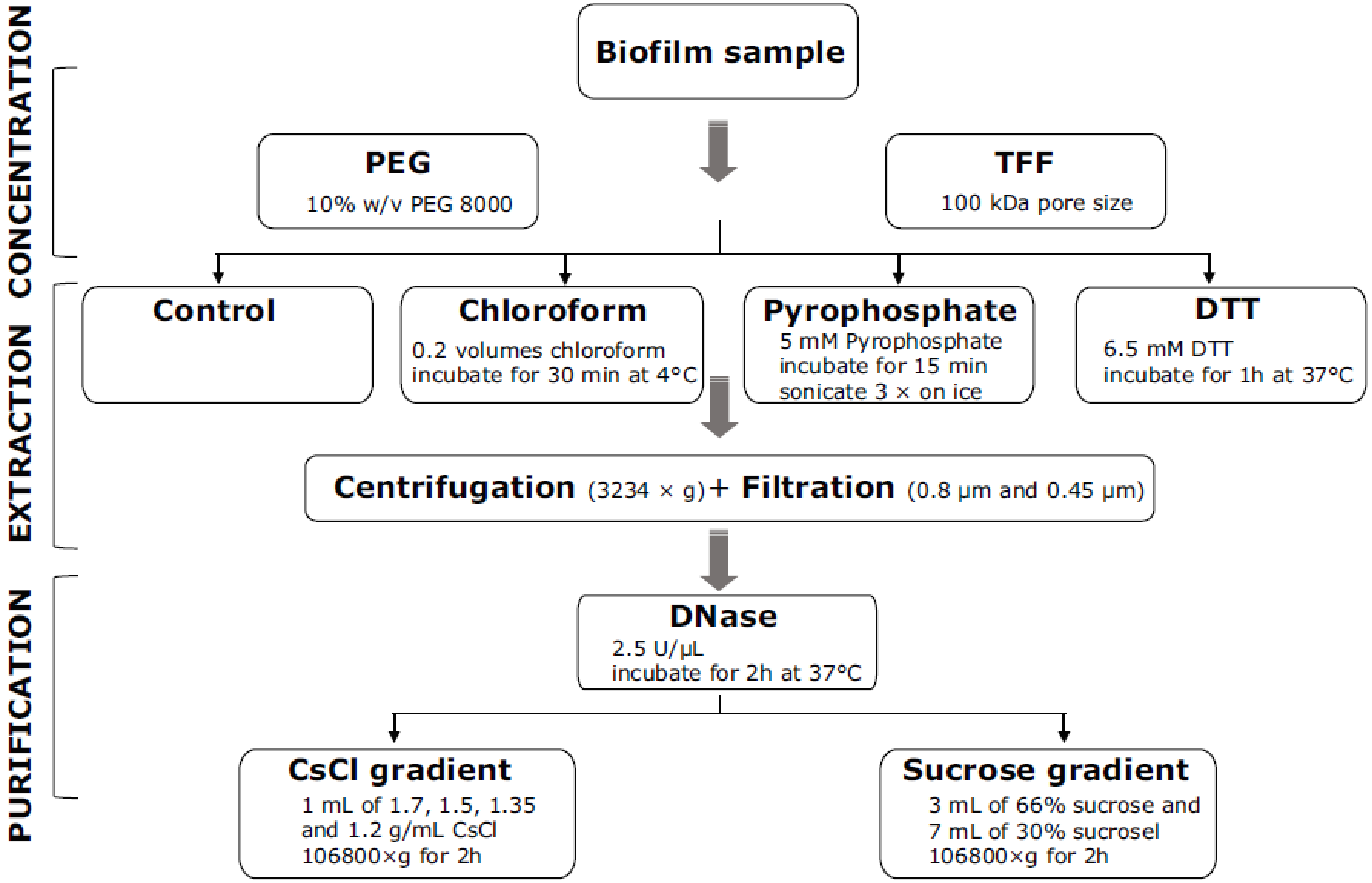


Huang et al. 2024 Trends in Microbiology

sample-to-sequence pipeline

Benchmarking protocols for the metagenomic analysis of stream biofilm viromes

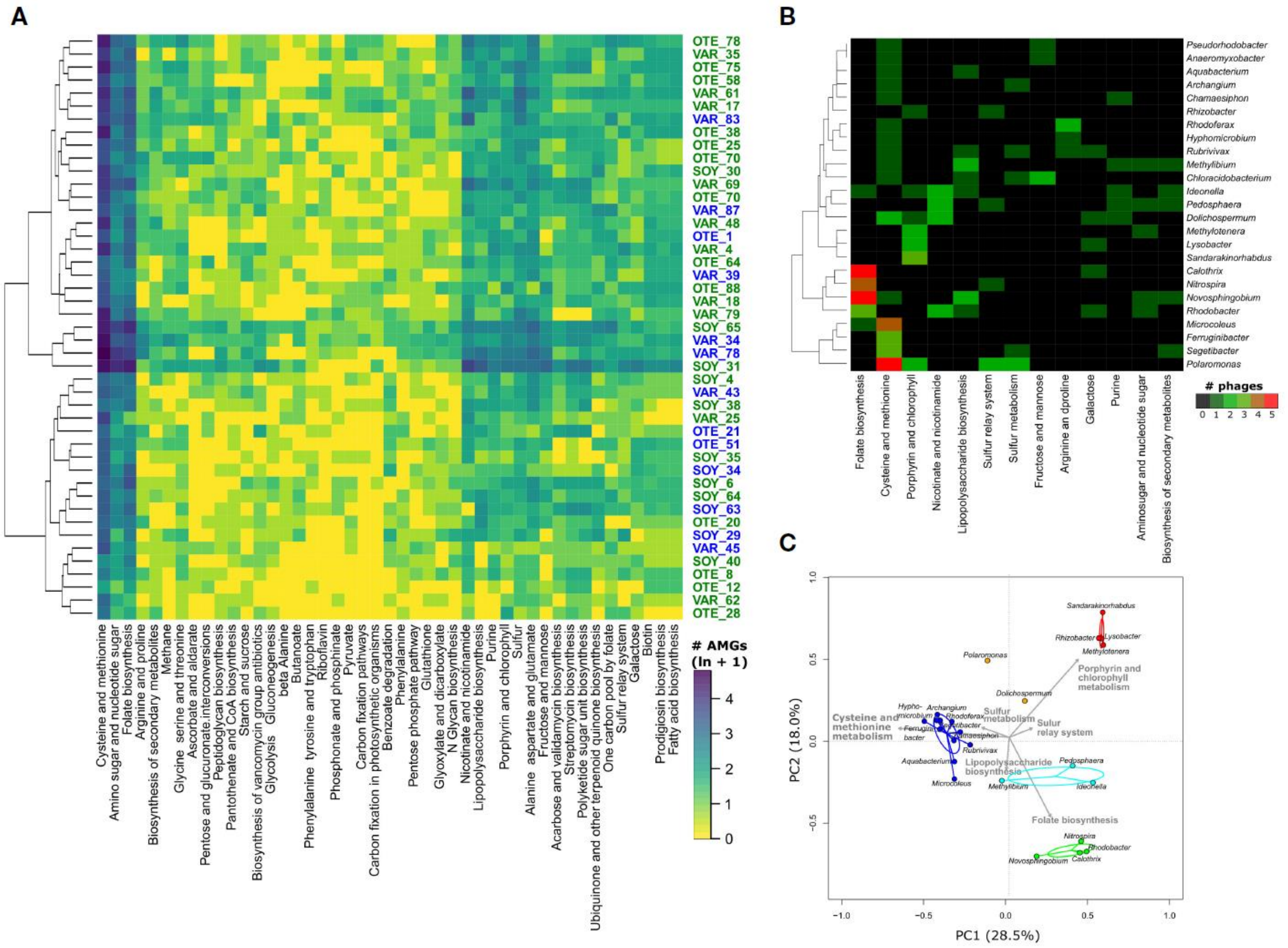
Meriem Bekliz, Jade Brandani, Massimo Bourquin, Tom J. Battin and Hannes Peter



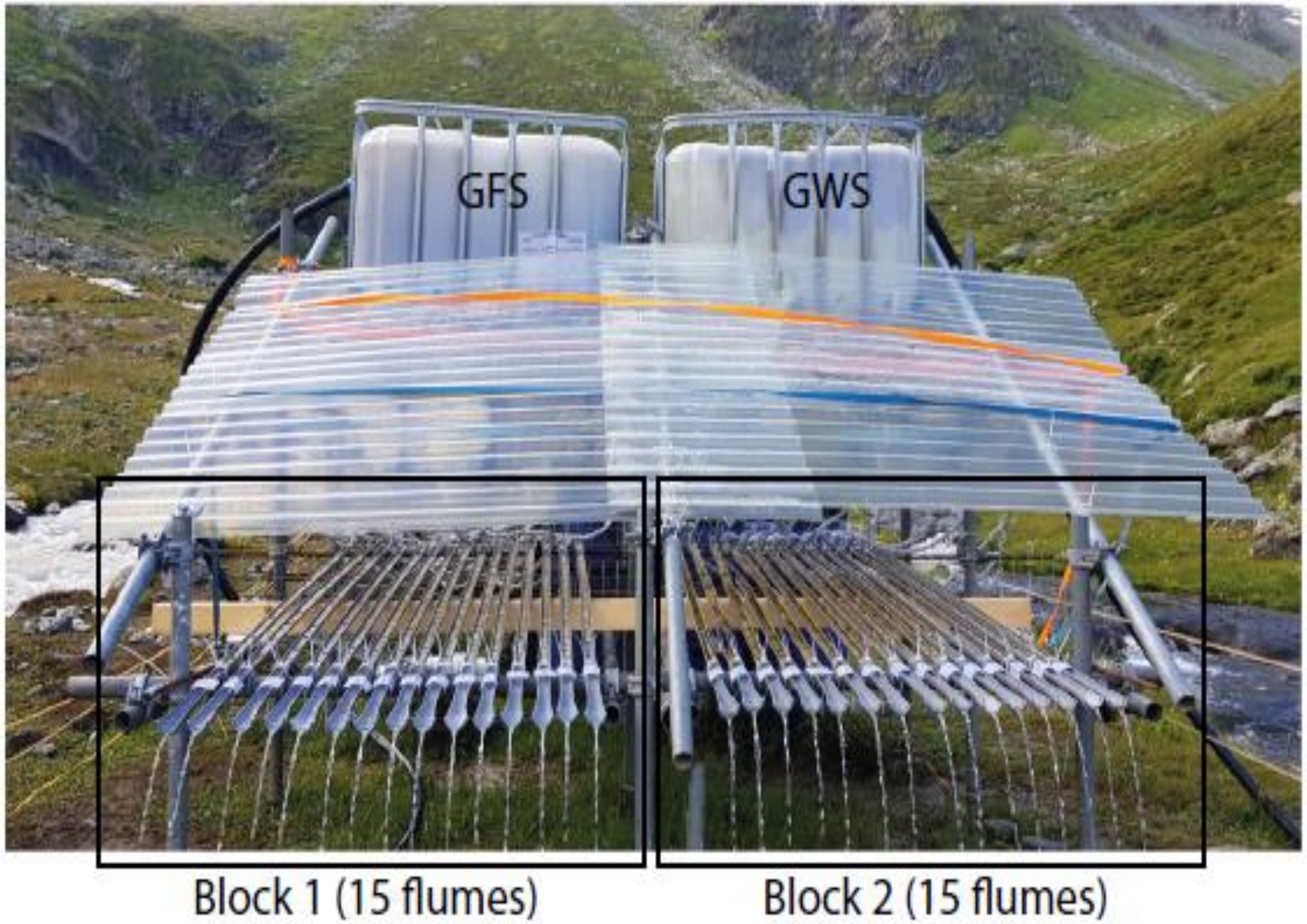
The role of phages for microdiverse bacterial communities in proglacial stream biofilms

Hannes Peter[1]*, Grégoire Michoud[1], Susheel Bhanu Busi[2,3] and Tom J. Battin[1]

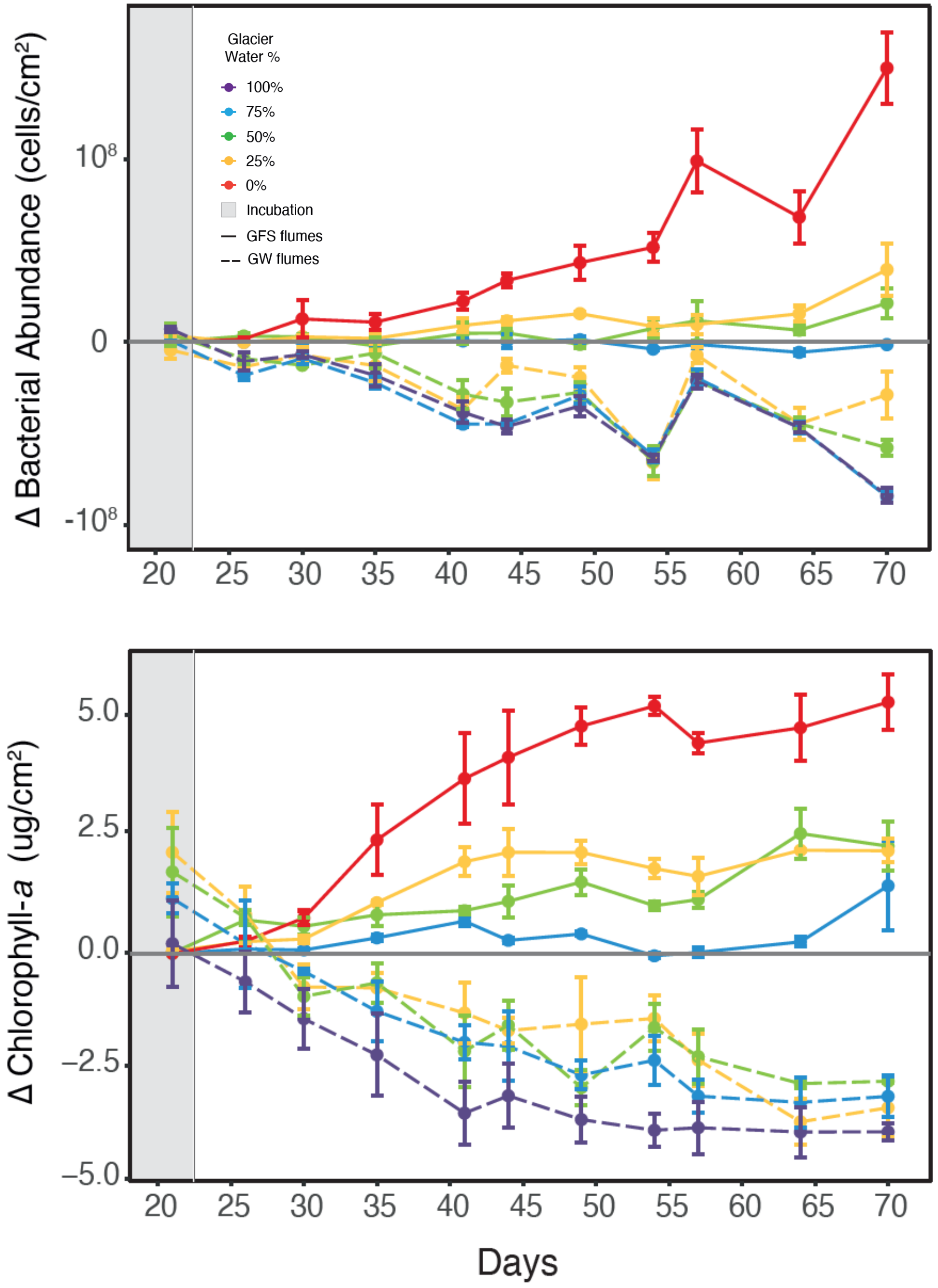
Viruses specific to bacteria living in glacier-fed streams carry beneficial genes (auxiliary metabolic genes)

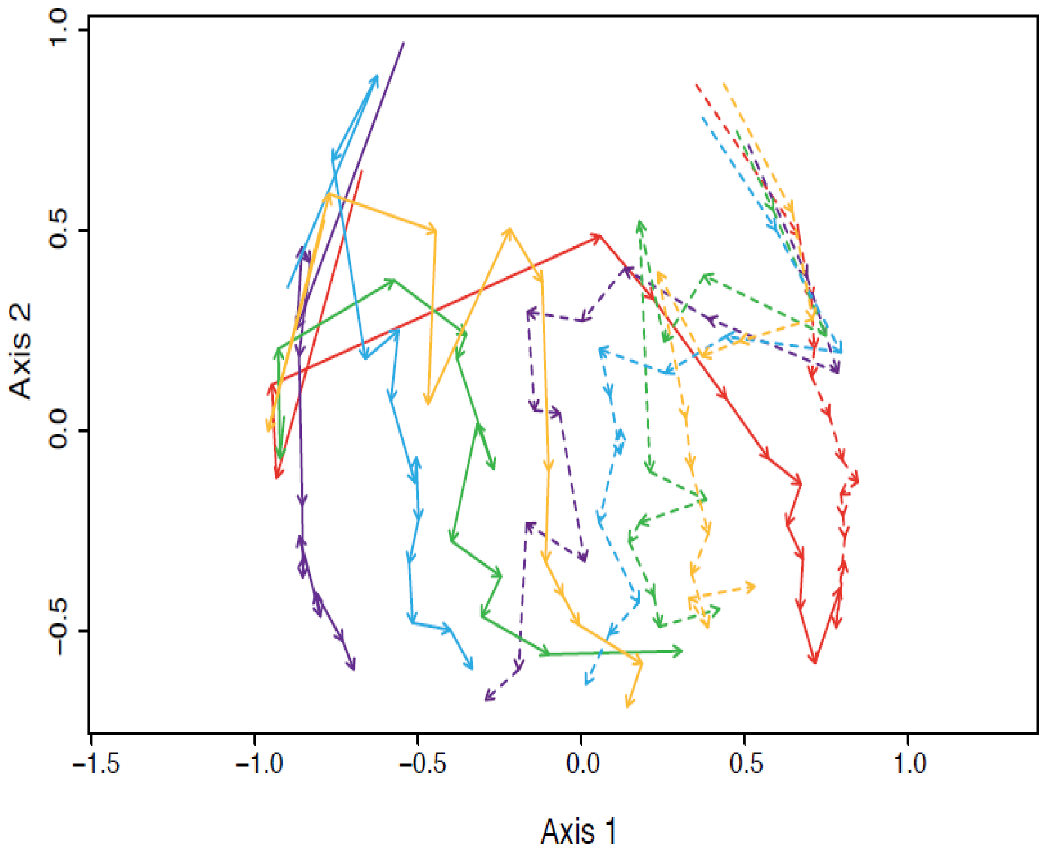


Climate-change experiments



Microbial communities act as sentinels of climate change.





Microbial communities respond very sensitively to simulated climate change.

take home messages

- Alpine cryospheric and freshwater ecosystems are important water resources – threatend because of climate change
- Molecular tools allow insights into the diversity, distribution and functioning of complex microbial communities
- Despite the harsh environmental conditions, GFS harbor a high degree of microbial diversity
- The selective environment favors few, well-adapted groups of bacteria – they are microdiverse
- Regionality and spatial processes (dispersal limitation, isolation) shape the global GFS biodiversity
- Viruses are still understudied in stream biofilms but may be benefitial to their bacterial hosts
- The unique biodiversity of GFS is particularly affected by climate change because of the vanishing of glaciers and the greening of alpine streams
- Global-change experiments allow mechanistic insights into the responses of microbial assemblages to change