HelmholtzZentrum münchen
German Research Center for Environmental Health

Effects of thermal energy usage on shallow groundwater ecosystems

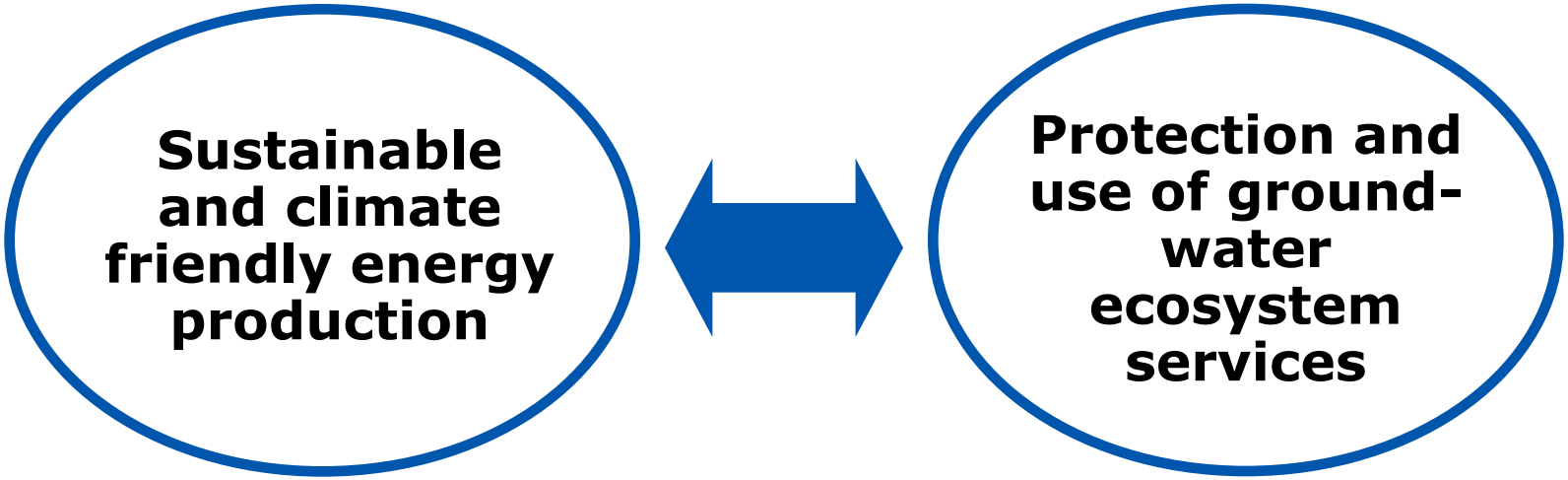
Christian Griebler, Heike Brielmann, Katrin Schreglmann, Francesco Ferraro, Tillmann Lueders, Stefanie Haehnlein[1], Susanne I. Schmidt[2], Philipp Blum[3] & Peter Bayer[4]

Institute of Groundwater Ecology
Helmholtz Zentrum München,
German Research Centre for Environmental Health

[1]Center of Applied Geosciences, University of Tübingen, Germany
[2]Centre for Systems Biology, University of Birmingham, Birmingham B15 2TT, UK
[3] Institute of Applied Geosciences, KIT, Karlsruhe, Germany
[4]Institute of Engineering Geology, ETH Zurich, Switzerland

HELMHOLTZ GEMEINSCHAFT

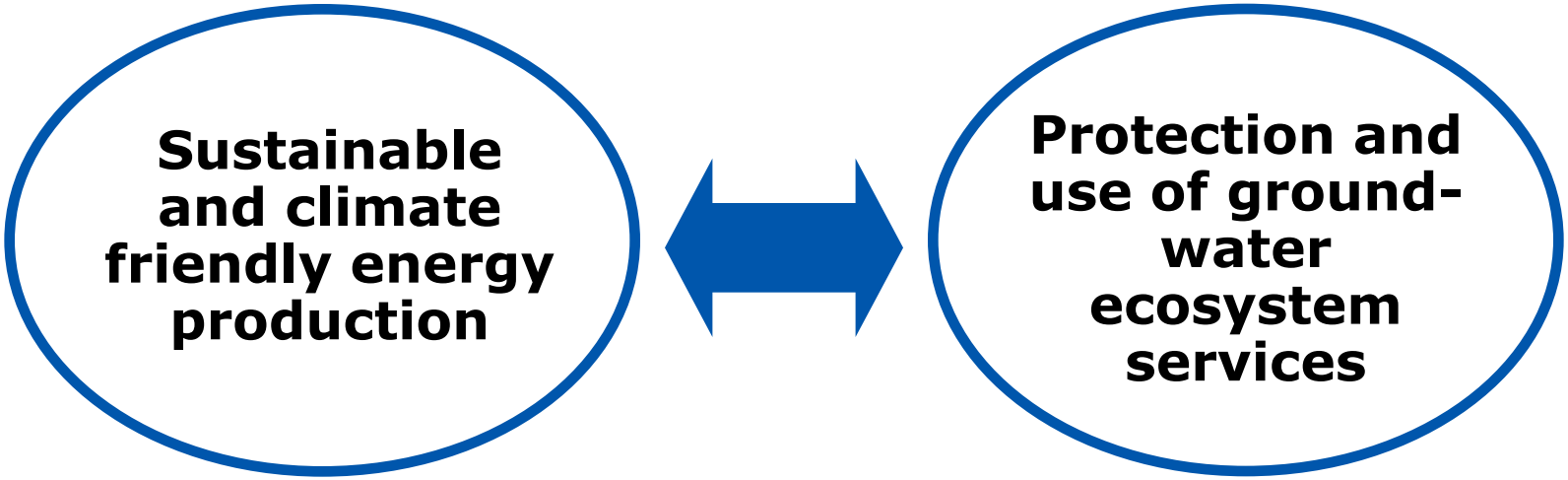
Our motivation is …



Shallow geothermy
Borehole heat exchanger (BHE)
Aquifer thermal energy storage (ATES)
Groundwater heat pump system (GHPS)

Goods and services
Drinking water
Bioremediation
Biodiversity

Our motivation is …



Changes in GW temperature may

- **change aquifer hydro- and geochemistry**
- **affect aquifer microbes and fauna**
- **affect groundwater quality and self purification**

Aim of our work

➔ **Contribute to knowledge-driven authorization practice, sustainable GW usage and integrated facility management.**

Temperature and ecosystem functions

Groundwater ecosystem services

Regulating services

- Purification processes (Contaminants, nutrients, pathogens)
- Sustaining the hydraulic connectivity and permeability
- Balance of water cycle
- Buffering floods and droughts

Supporting services

- Remineralization of nutrients
- Habitat for organisms
- Biodiversity as basis for various ecosystem functions
- Sustaining of food webs and cycling of matter

Provisioning services

- Drinking water (storage and provision)
- Mineral water
- Water for cooling purposes (industry) and irrigation (agriculture)
- Genetic ressources

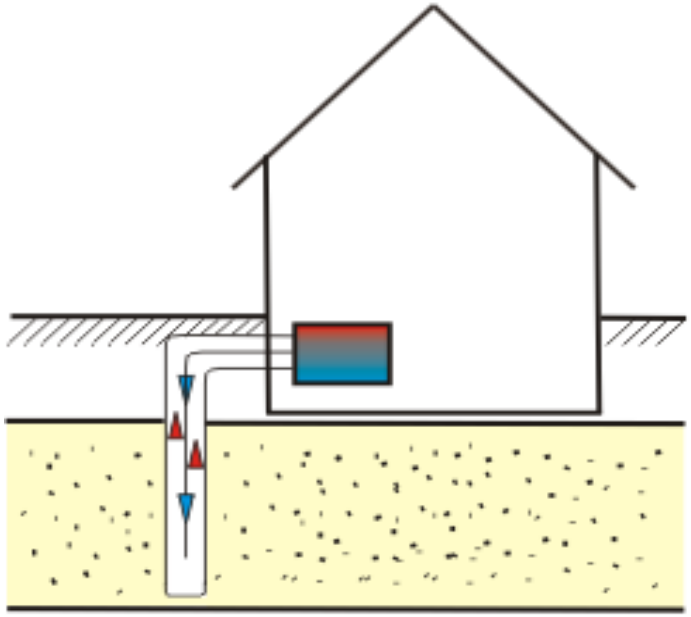
Cultural services

- Recreation (hot springs, spa, …)
- Tourism (Historic settlings at springs and in caves, cave expeditions)
- Identification and use of bioindicators

Goods and services of groundwater ecosystems distinguished into the four groups of services defined in the Millenium Ecosystem Assessment (MEA) Report

Geothermal energy use in the shallow subsurface

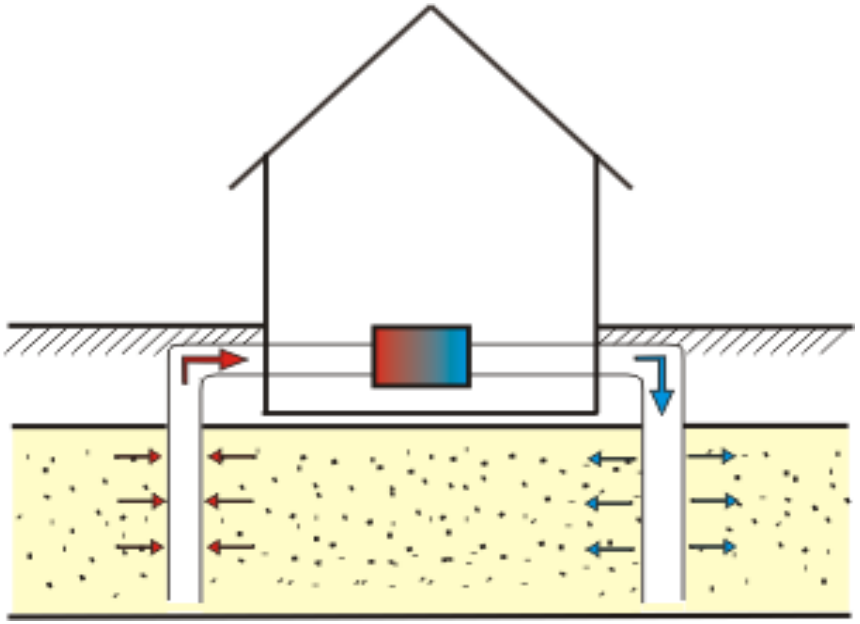
Closed systems



Borehole heat exchanger (BHE)

e.g. ground source heat pumps (GSHP)

Open systems



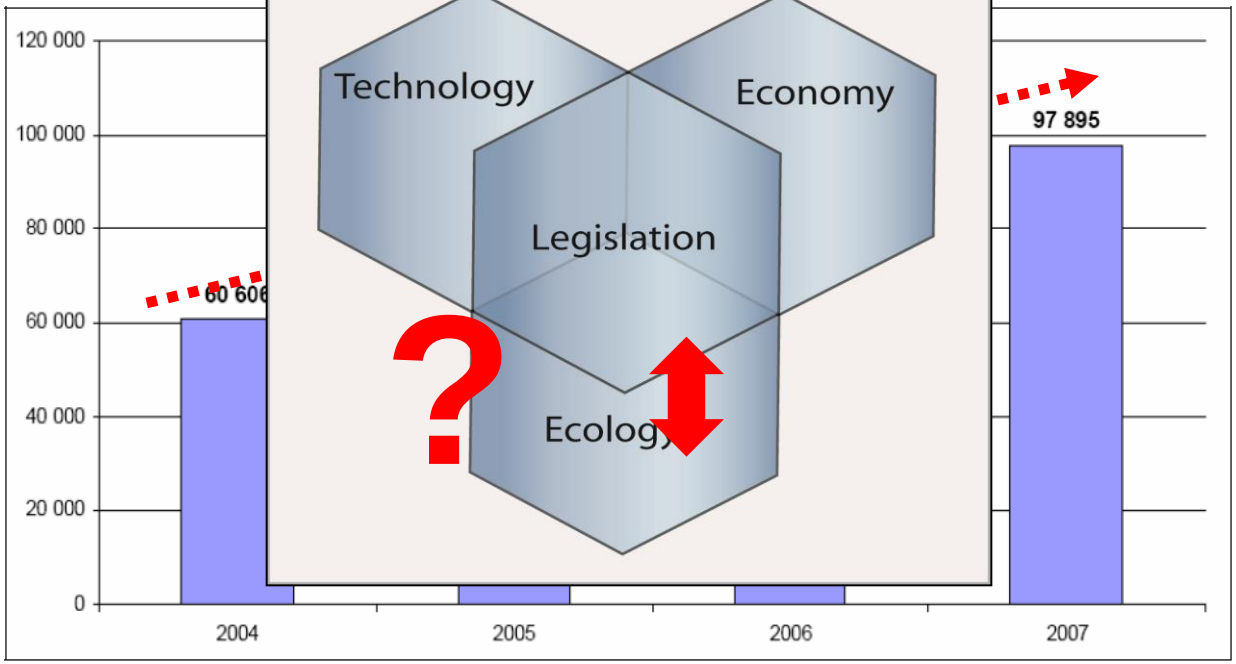
e.g. groundwater heat pump system (GHPS),
aquifer thermal energy storage (ATES)

A fast developing technology

- Rising number of shallow geothermal installations
- Awareness for environment protection
- Ground Water Directive

Total sales of GSHP in 8 European countries.

(Austria, Estonia ... zerland)



Source: Ground Reach, Final Report 2009, http://www.groundreach.eu/en/baustein/bs58/

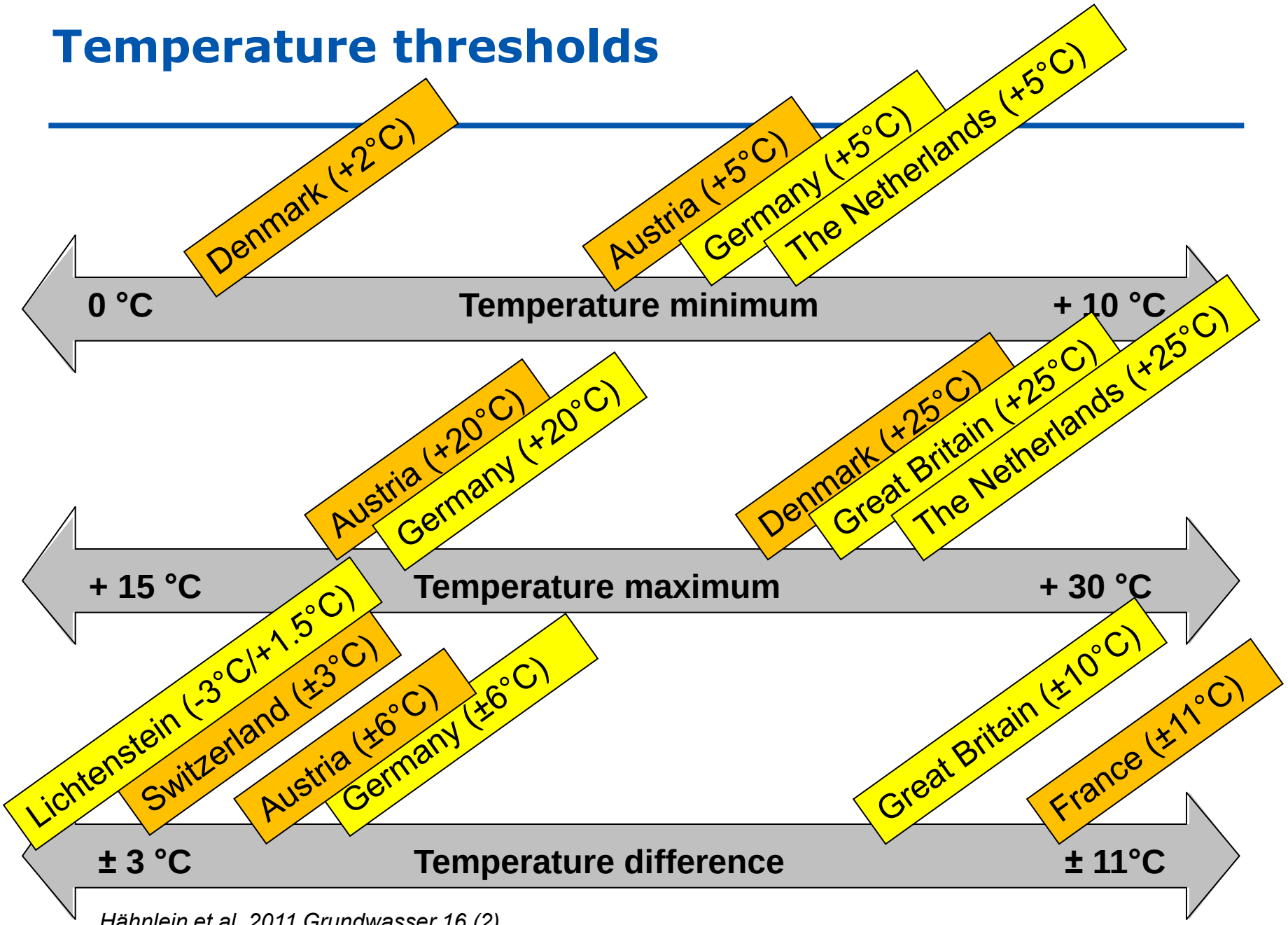
Legislation

	Closed systems			Open systems		
	Ecology	Technology	Minimum distances	Ecology	Technology	Minimum distances
Austria						
Belgium (Fl.)						
Canada						
Denmark						
Finland			preparation			
France						
Germany						
Great Britain						
Greece						
Hungary						
Ireland						
Japan						
Latvia						
Spain						
Sweden						
Switzerland						
Turkey						

No regulations | Legally binding | Recommended

Hähnlein et al. in prep.

Temperature thresholds



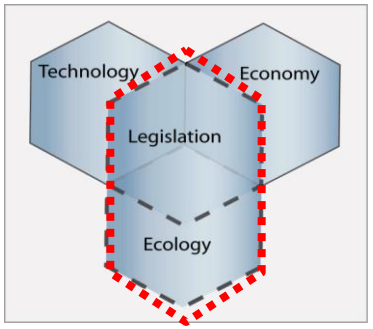
Hähnlein et al. 2011 Grundwasser 16 (2)

Ecological aspects in water legislation

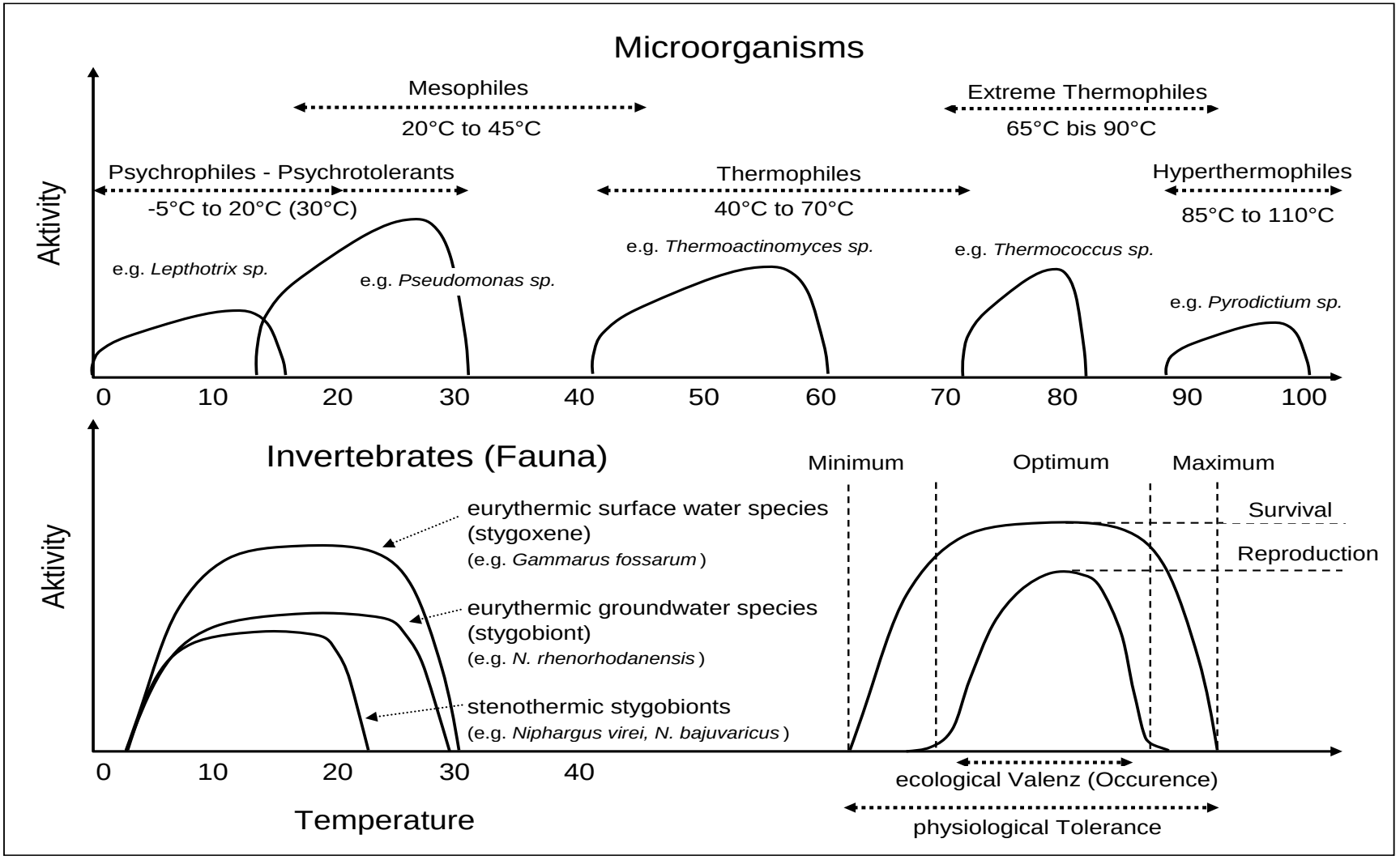
Germany: „Detrimental changes in physical, chemical and biological characteristics have to be avoided“ (Water Act)

Switzerland: „Biocenose of groundwater should be in natural state.” (Water Ordinance)

BUT: No precise definition of “detrimental changes” and “natural state”



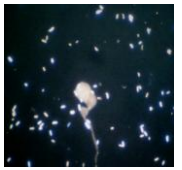
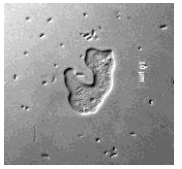
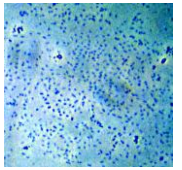
Organisms and temperature



Bacteria and temperature

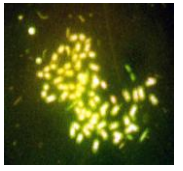
Moderate temperature changes may influence

- Cell morphology and living mode (aggregation)
- Cell composition (high % of unsat. FAs – fluidity)
- Feedback inhibition in pathways (stopp of AAs synth.)
- Enhanced intracellular proteolysis
- Gene expression

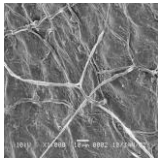




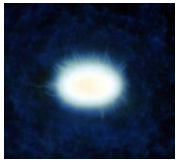
Sudden and pronounced temperature changes

- Adaptive shock response
- Cell death and lysis

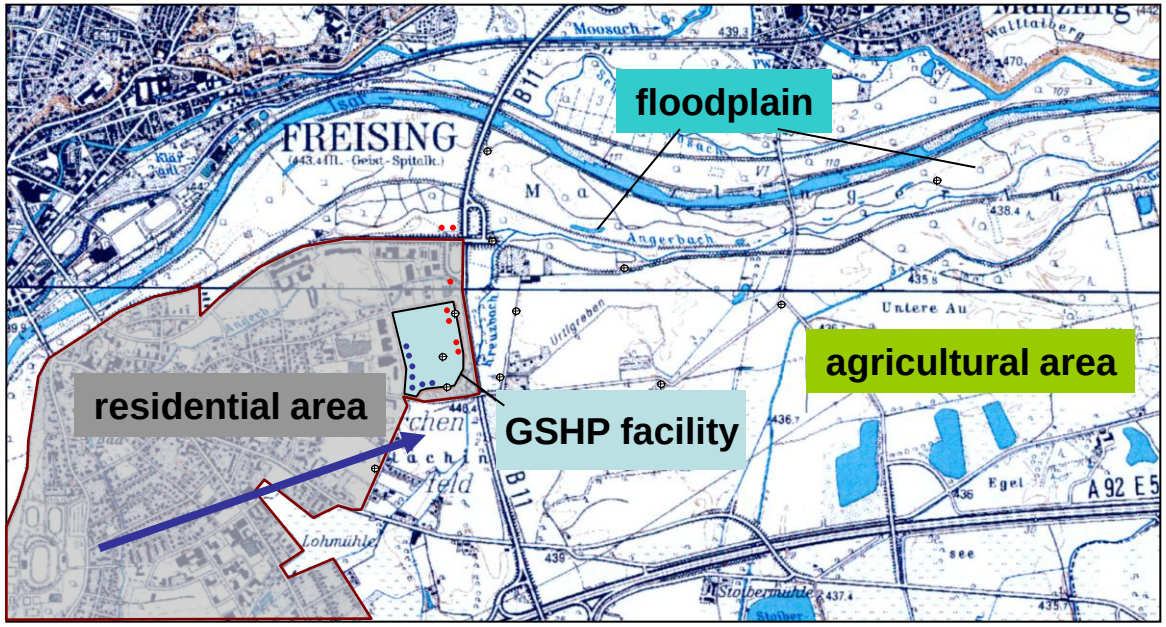



A sudden heating is more drastic than a sudden cooling !



AQITHERM - Project



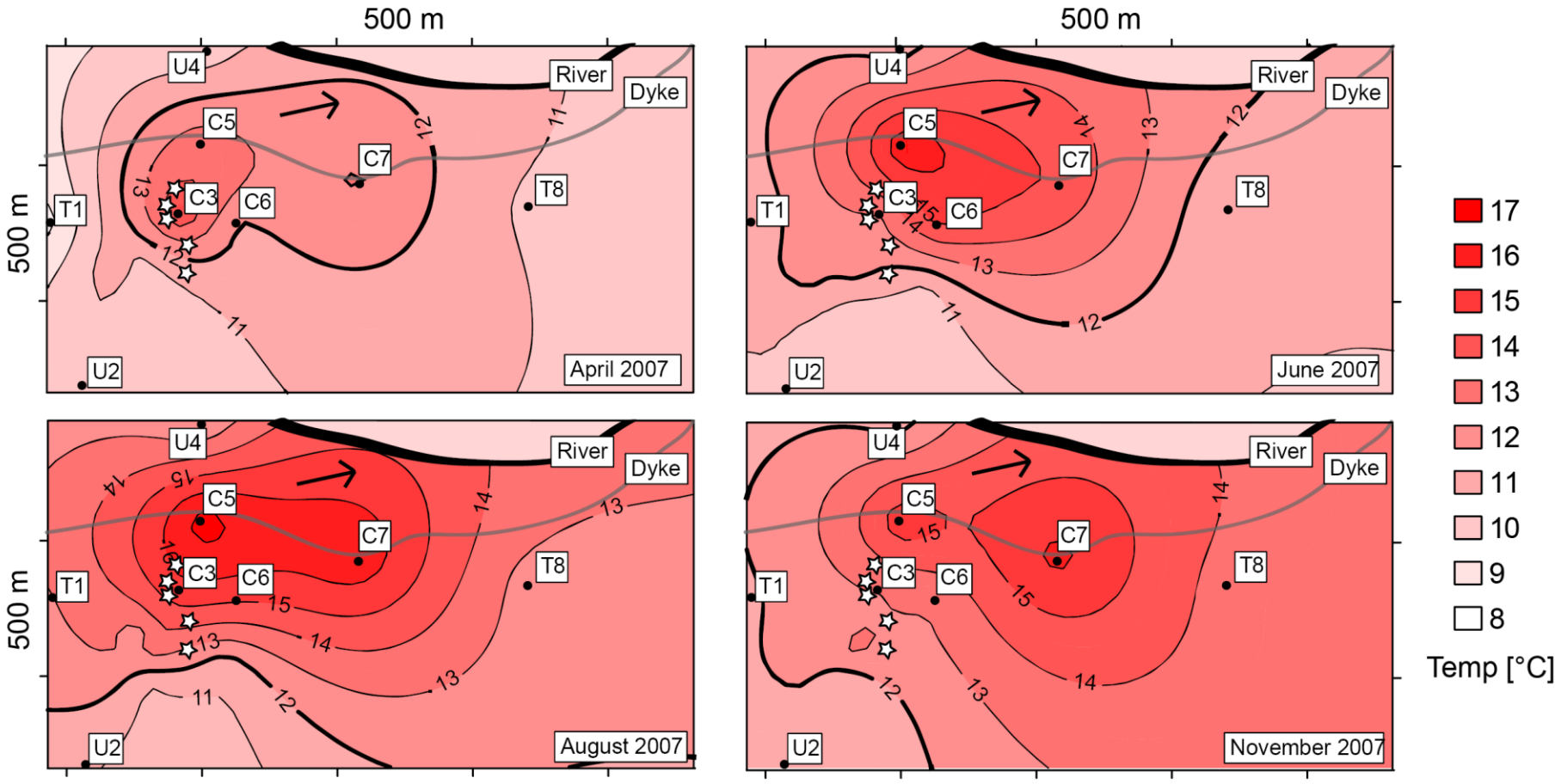
Extraction rate:
up to 3000m³/h

Groundwater heating:
up to 10°K, max. 21°C

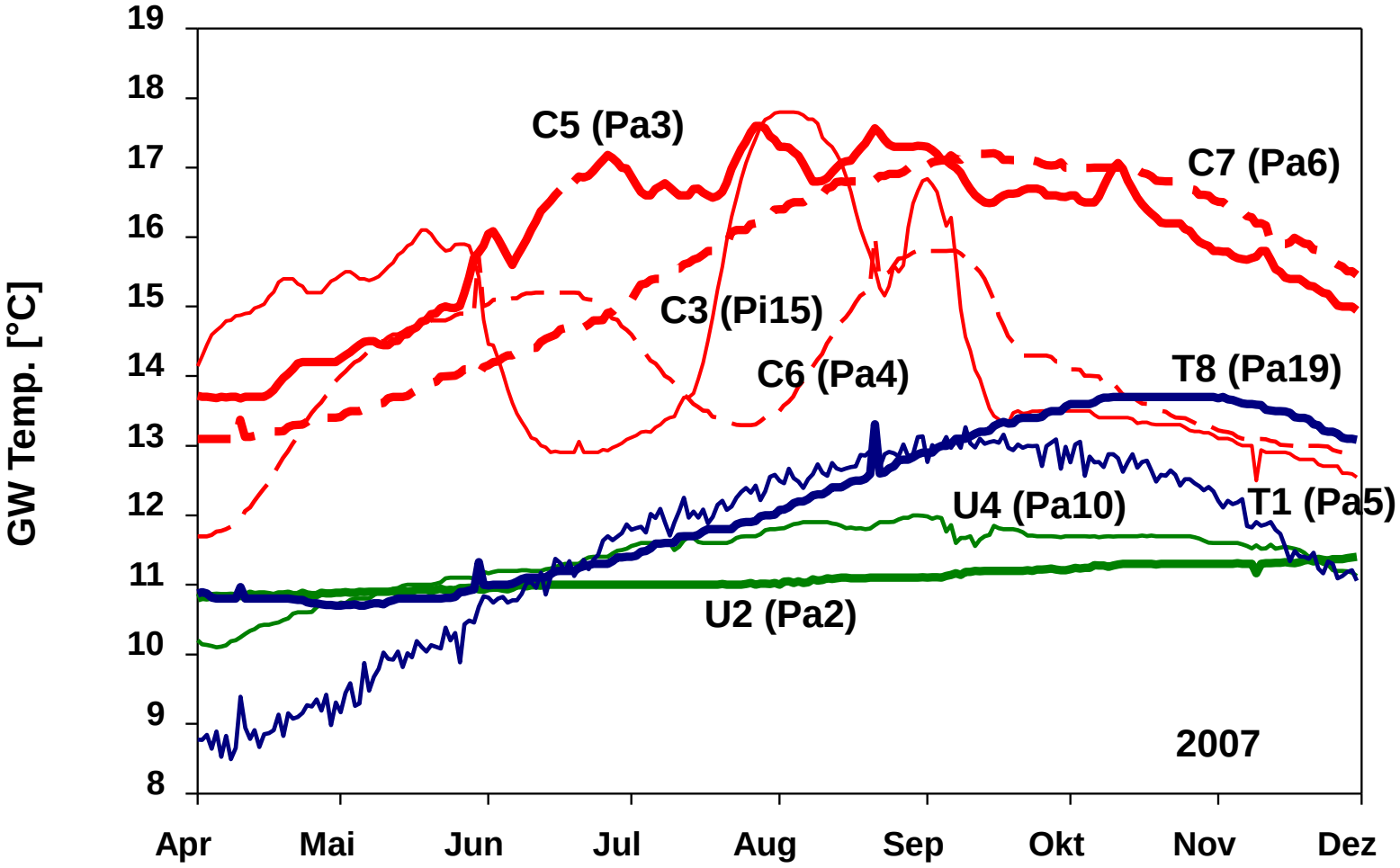
Hydrogeochemical characteristics:

- oxygenated, oligotrophic, oligoalimonic quaternary carbonate aquifer
- low mean annual concentrations of DOC (~1.3 mg L^{-1}) soluble reactive phosphorus (SRP, 46 ± 23 µg L^{-1}) and nitrate (~15 mg L^{-1}).
- mean natural GW temperature ~10.5 - 11°C

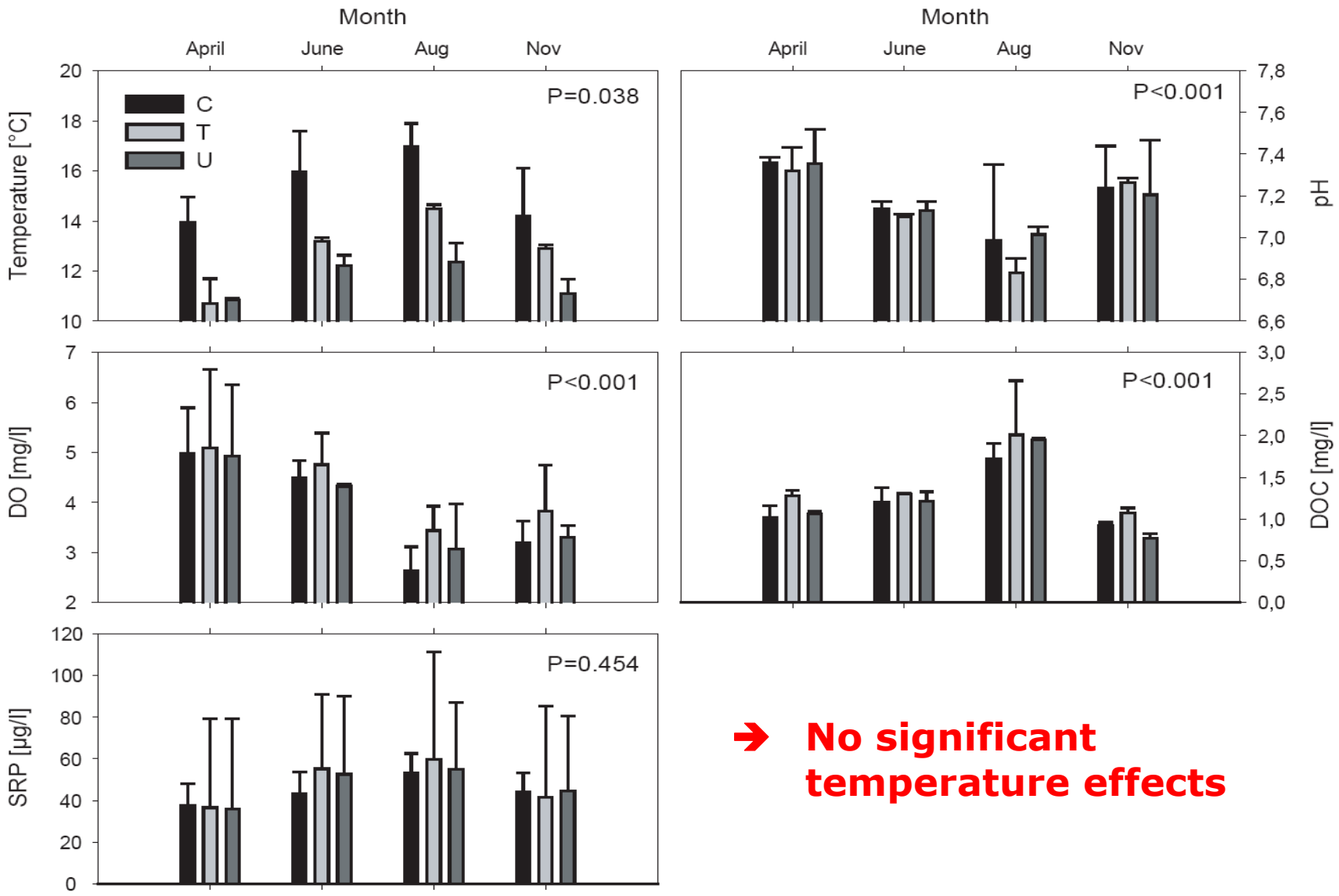
The heat plume



The sampling wells



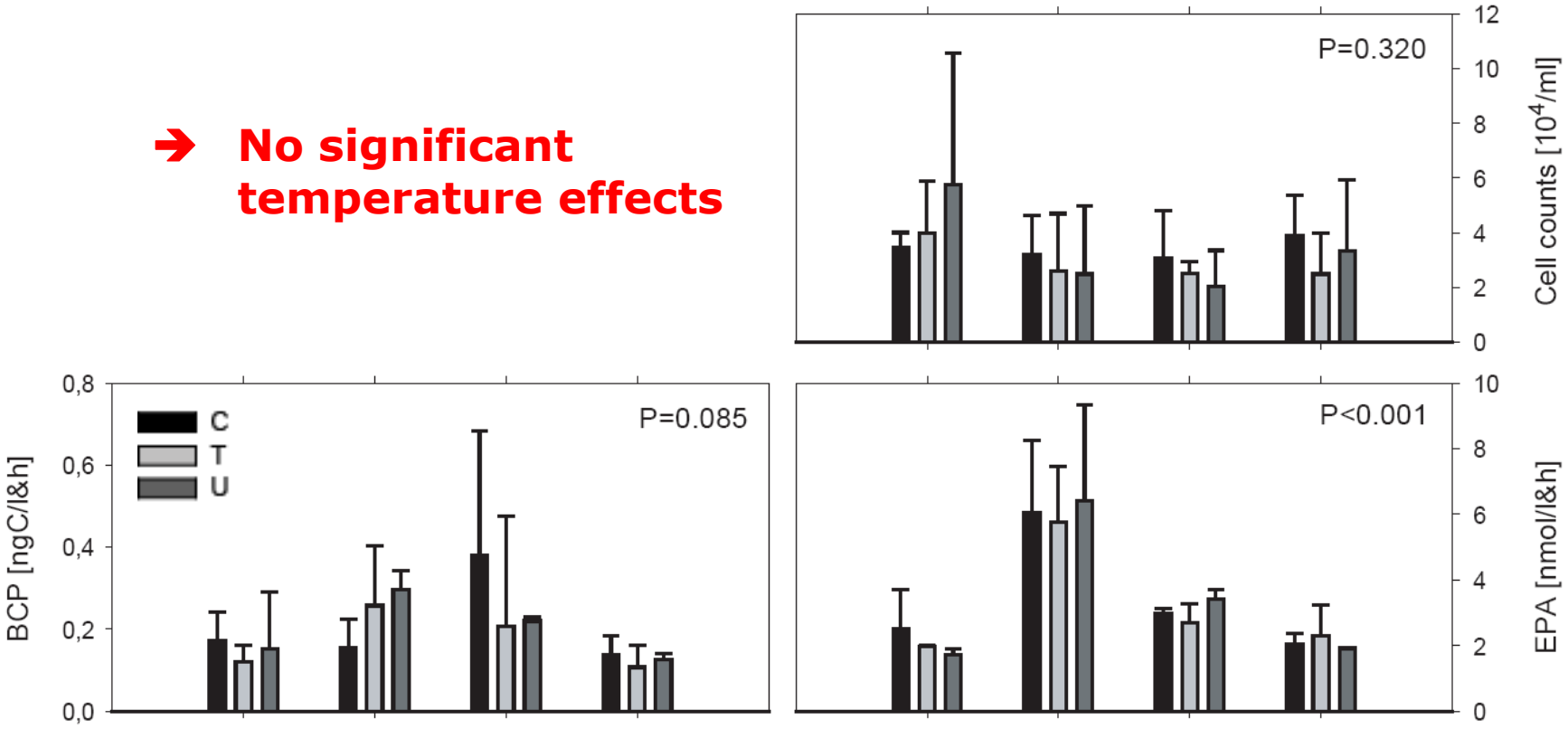
GW hydrogeochemistry



➔ **No significant temperature effects**

Microbial abundance and activity

➔ **No significant temperature effects**



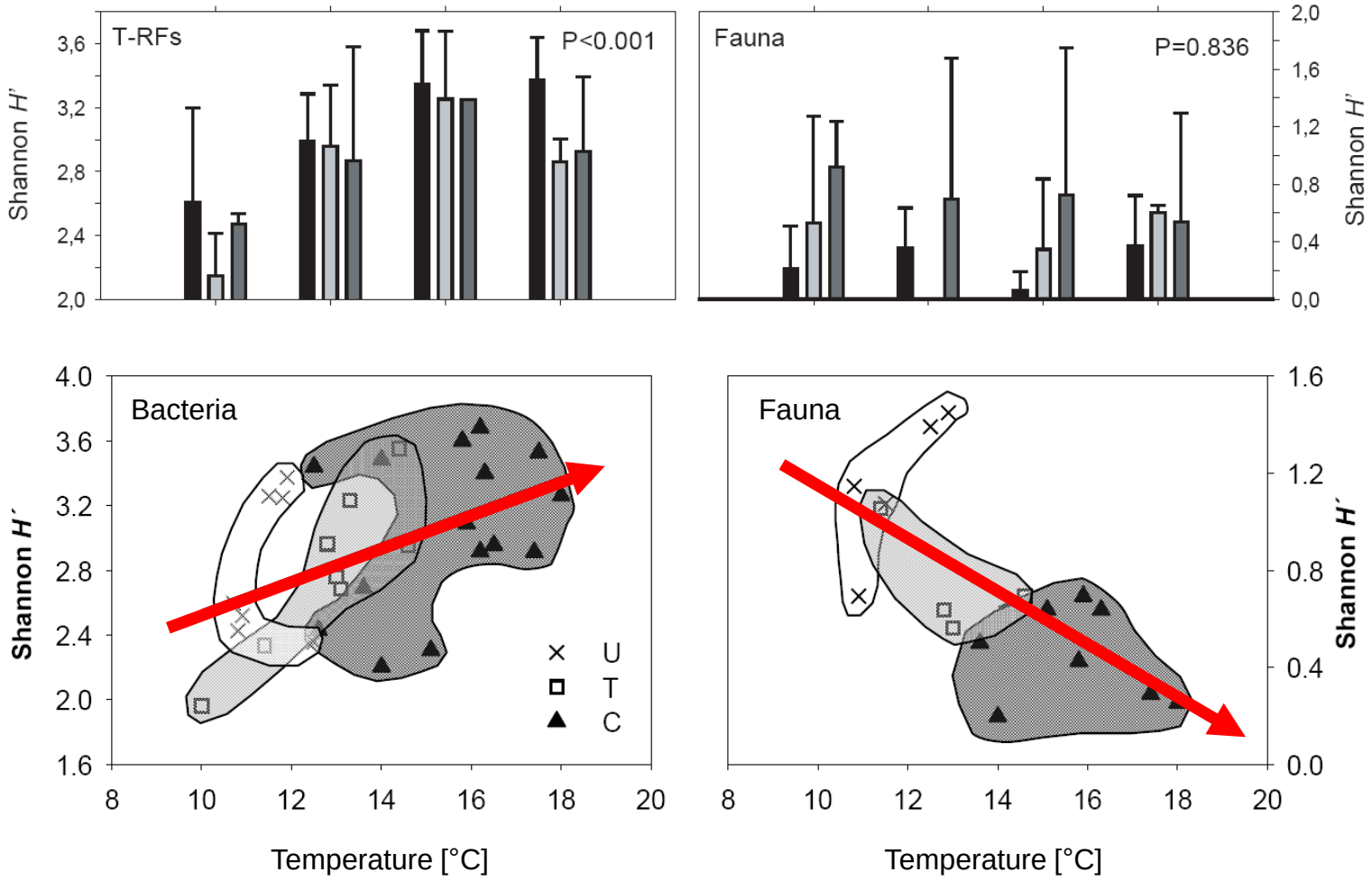
Drinking water hygienic indicators

Well	U2	U4	T1	T8	C3	C6	C7	C5
Temp [°C]	11.3	11.9	12.7	13.0	14.4	14.5	15.9	16.3
CFU ml^{-1}								
22°C	26	103	195	38	80	29	28	359
27°C	47	131	304	51	138	57	43	779
37°C	5	6	7	9	9	5	2	11
Coliforms	–	–	4	–	–	–	–	–
E. coli **[in 250 ml]**	–	1	–	–	–	–	1	–

➔ **No significant temperature effects**

Bacterial and faunal diversity

C Countinuously impacted
T Temperorally impacted
U Unimpacted



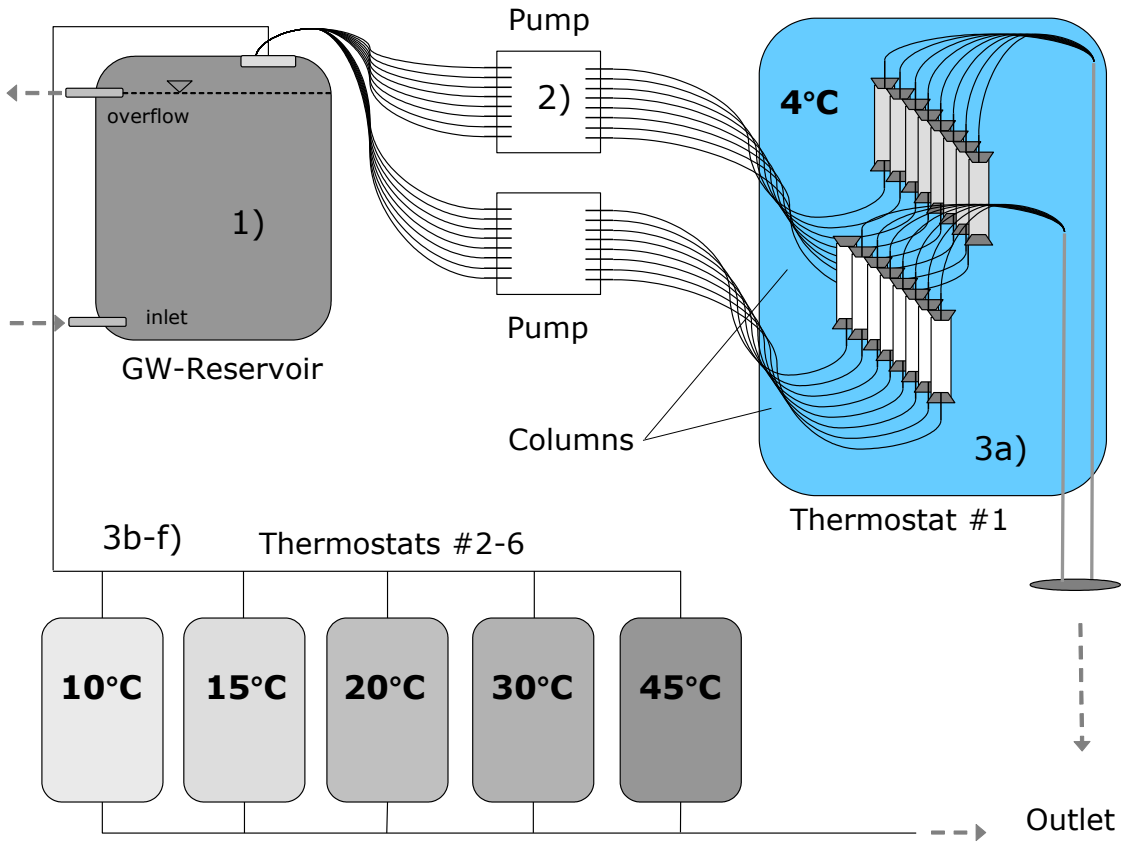
➔ **Significant effects of temperature on biodiversity**

Key determinant parameters for GW biotic variability (by CCA)

- ➔ **Surface water influence (reflected in higher Ca^{2+}, Mg^{2+}, K^{+} and lower PO_4^{2-} concentrations) explained ~8 – 15% of seasonal community variability.**
- ➔ **Temperature was the second dominant driver of observed community variation, explaining ~5 – 8% of variability.**
- ➔ **~80% of observed seasonal variability remained unexplained and was not significantly connected to temperature or surface water influence.**

Lab column experiments - energy limitation

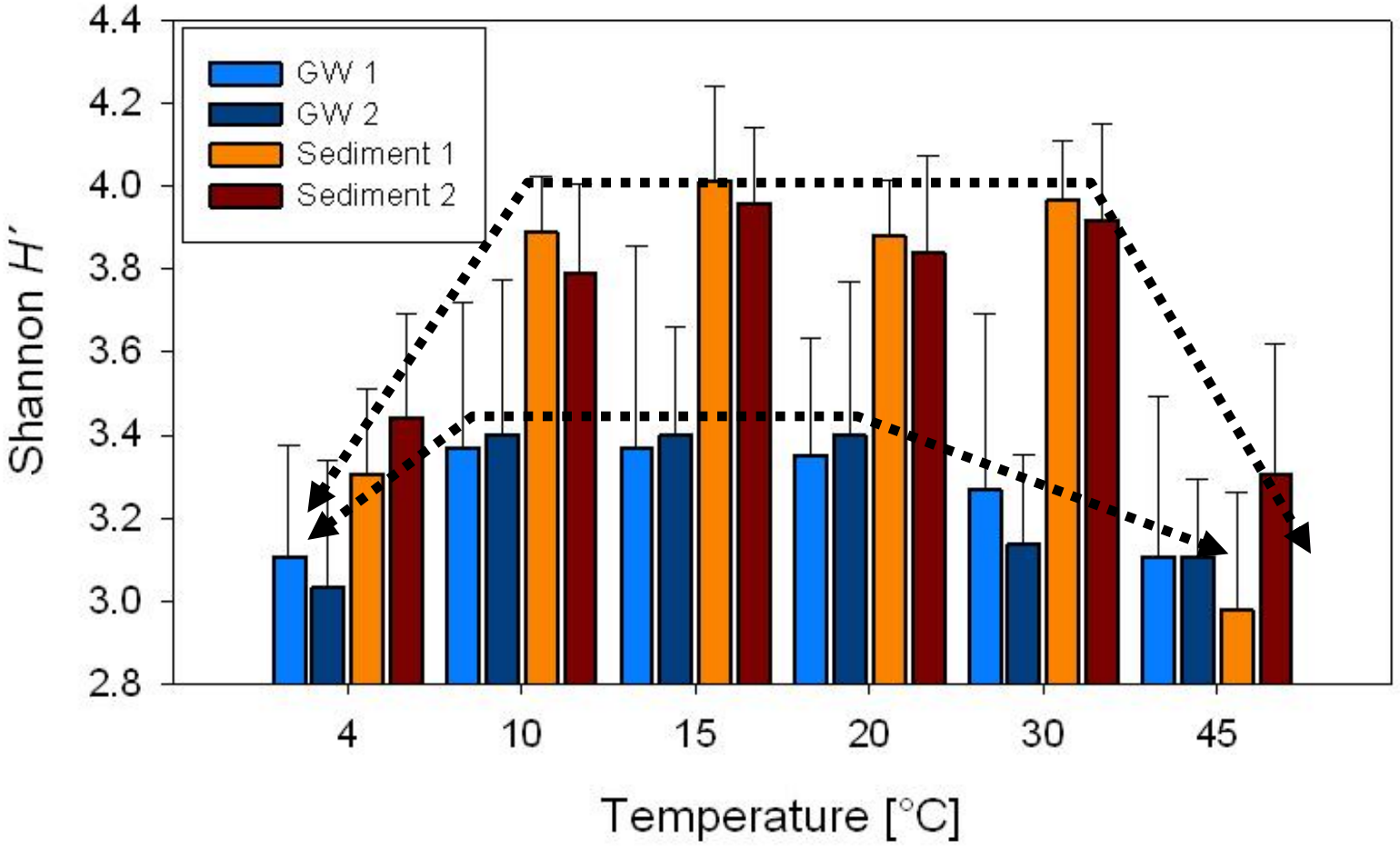
Set-up



Reduction of environmental complexity !

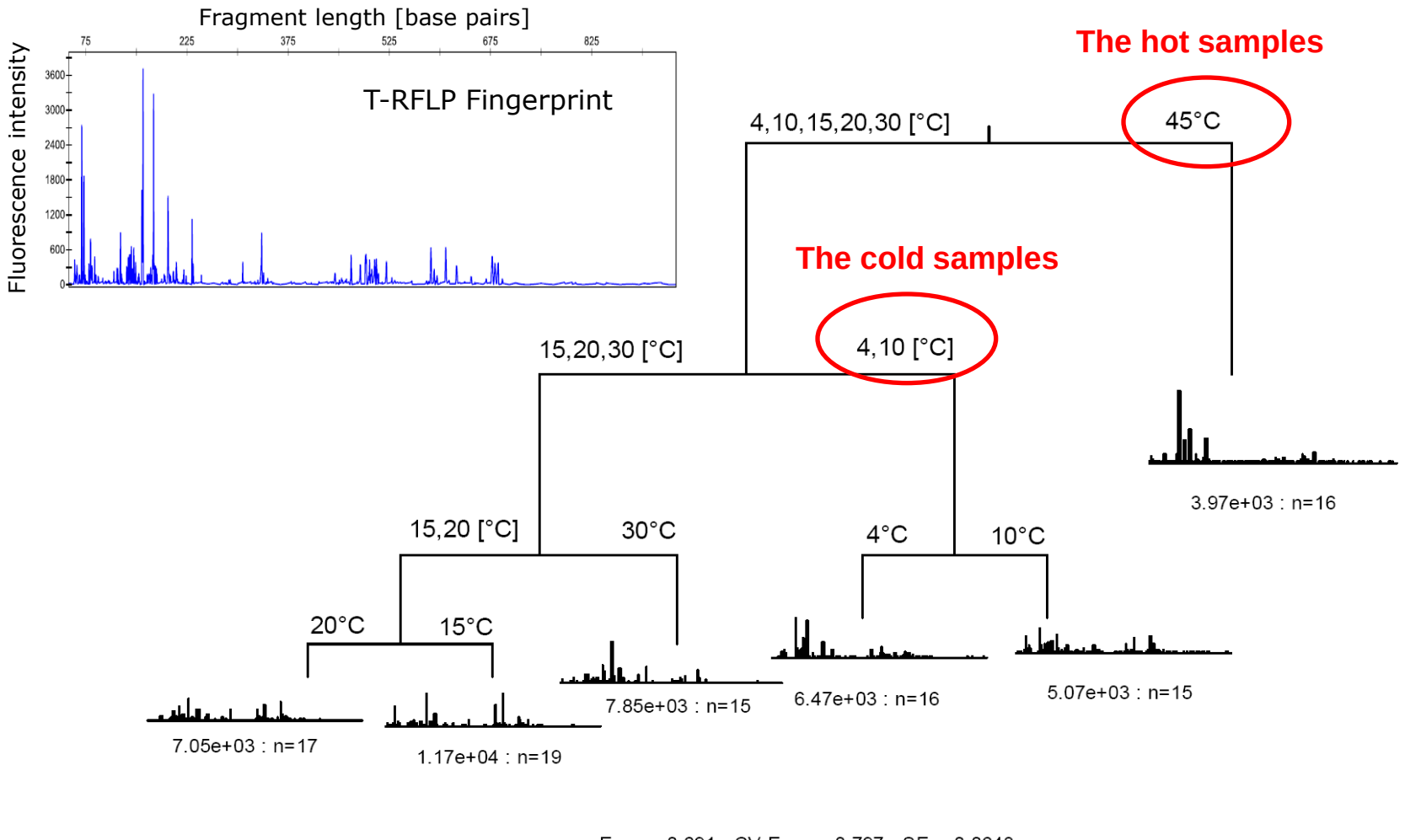
Lab column experiments - energy limitation

Exemplary results



Lab column experiments - energy limitation

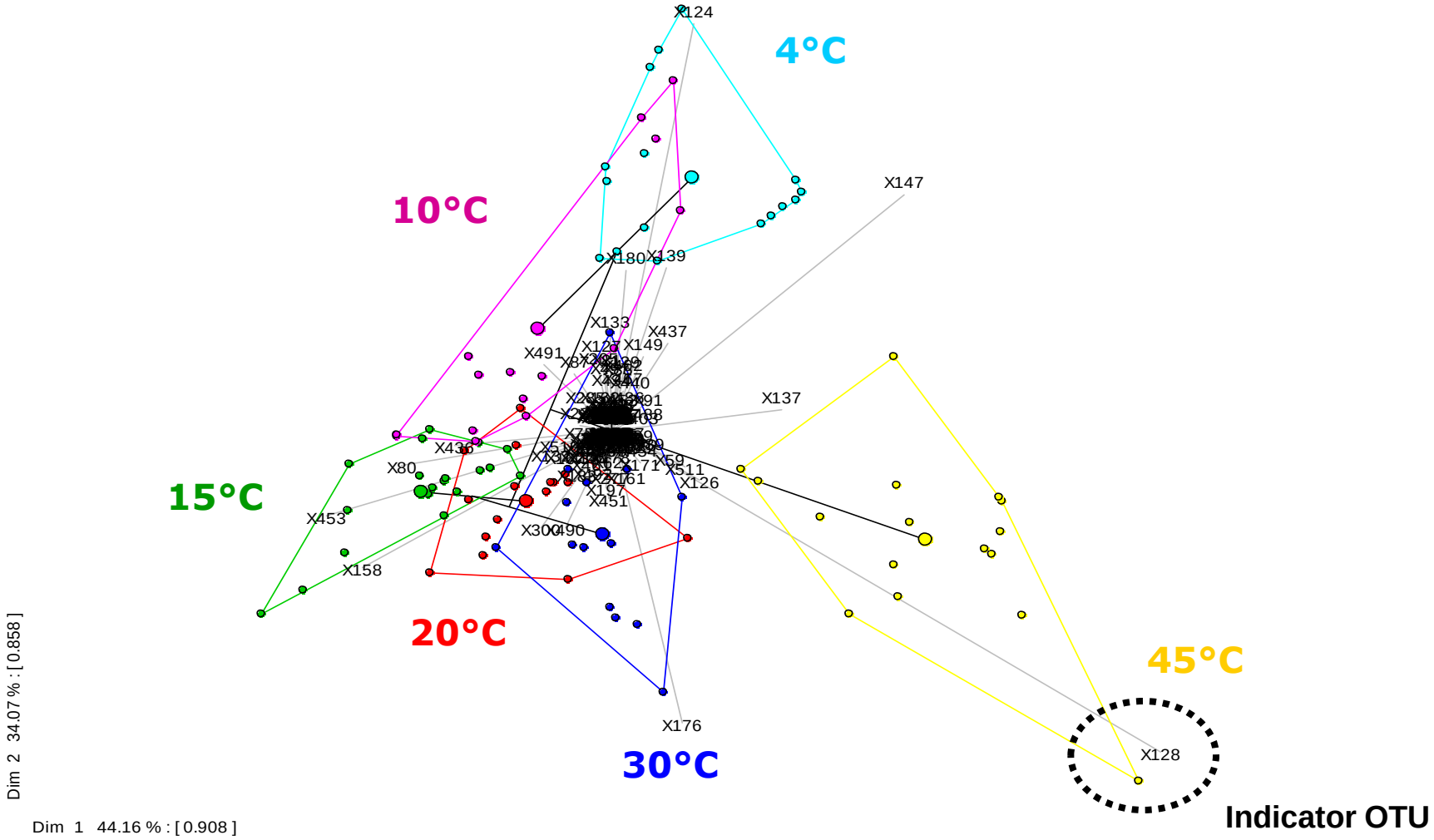
Multivariate regression tree (column sediments)



Lab column experiments - energy limitation

PCA - Biplot of group means

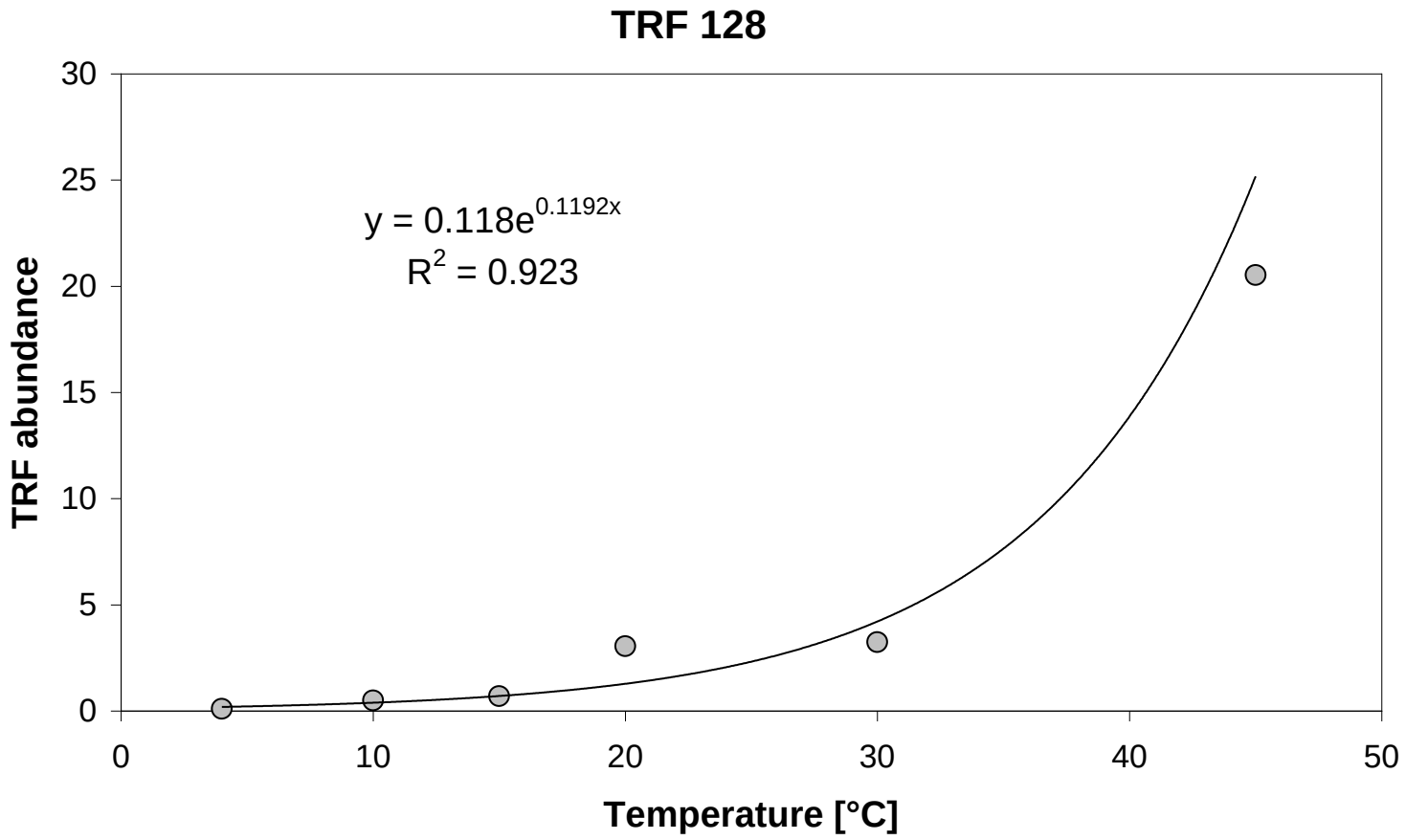
Identification of indicator T-RFs



Indicator OTU

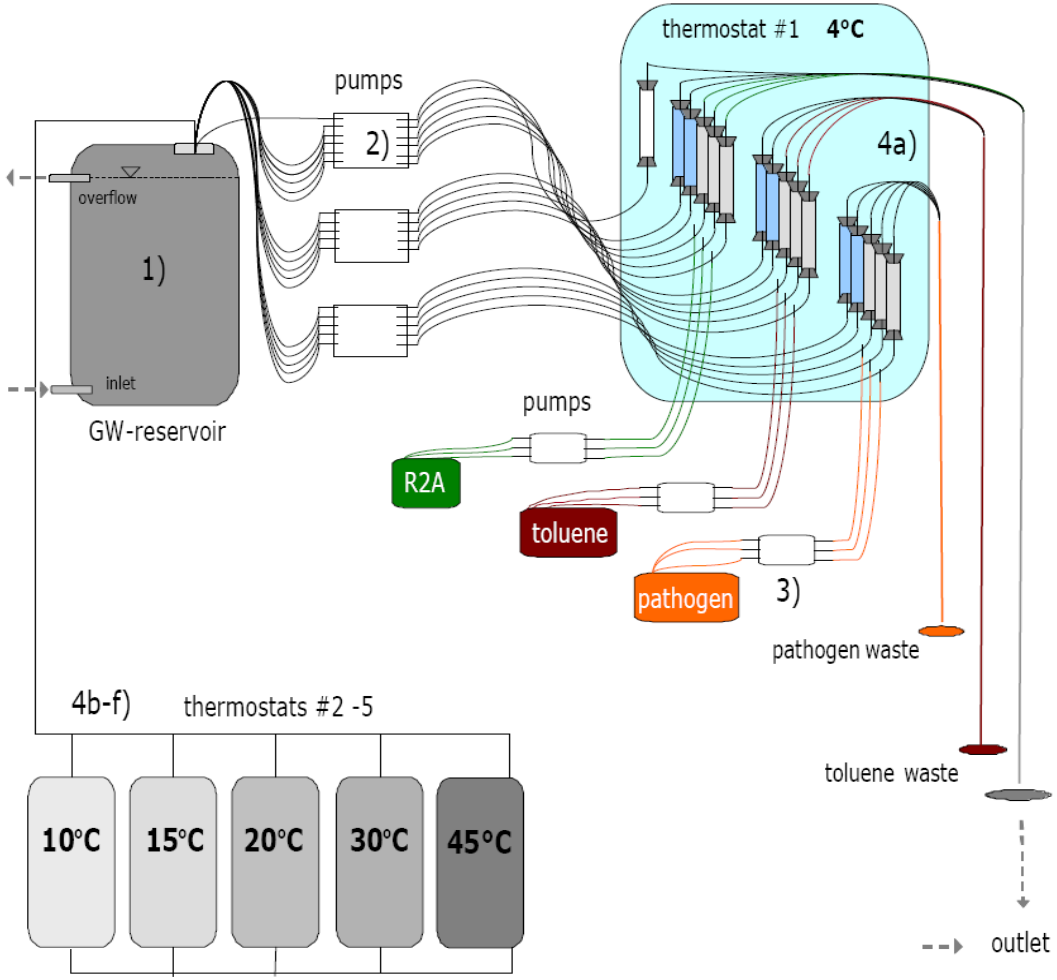
Lab column experiments - energy limitation

Identification of indicator OTUs (T-RFs)



Lab column experiments – multiple scenarios

Set-up



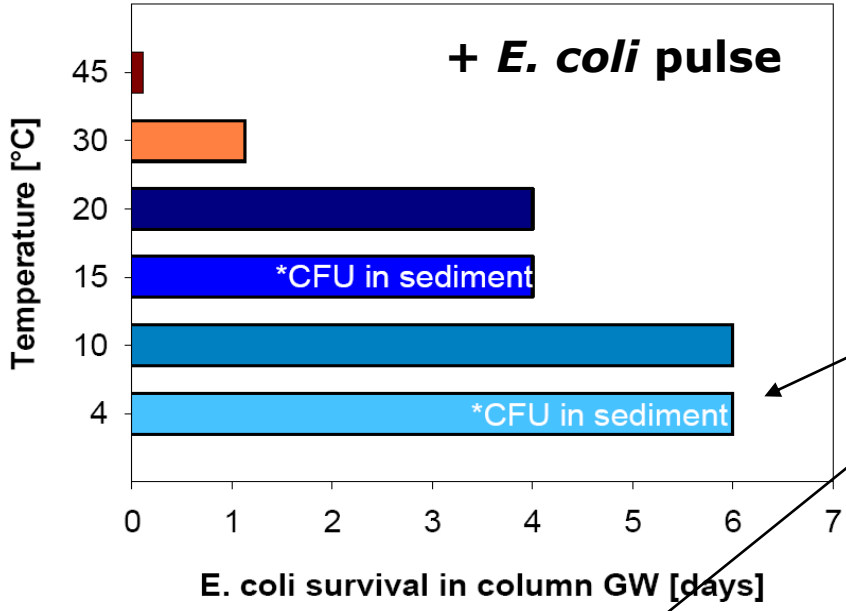
Influence of/to

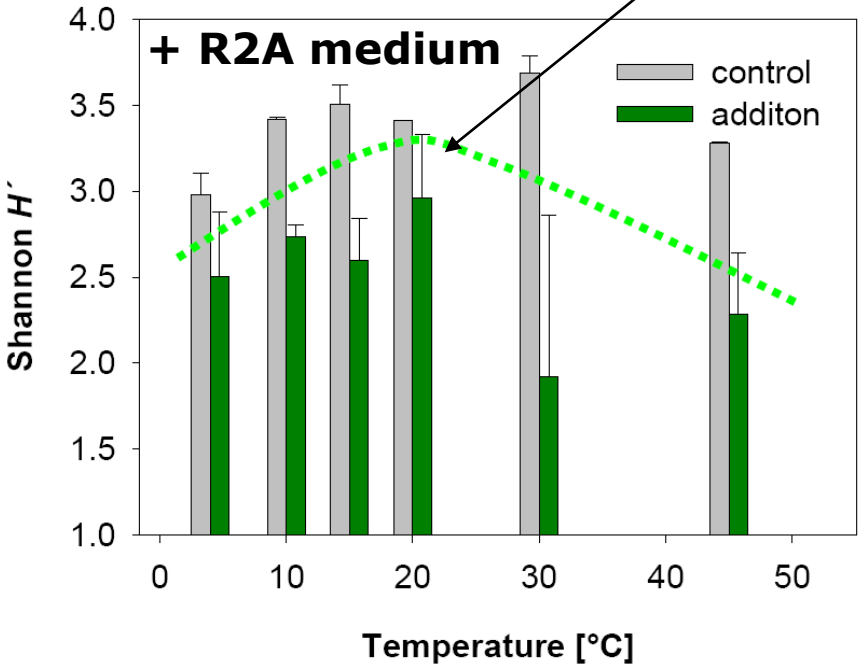
- Organic carbon and nutrients (R2A medium)
- Pathogens (*E. coli*)
- Organic contamination (toluene)

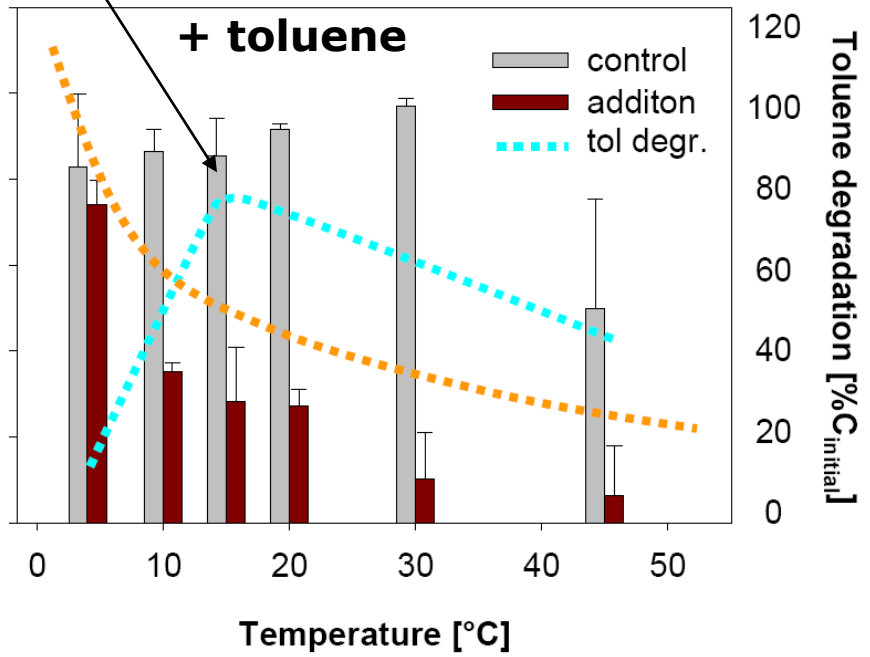
Lab column experiments

Exemplary results

- Longest survival of E. coli
- Highest bacterial diversity
- Highest toluene degradation efficiency

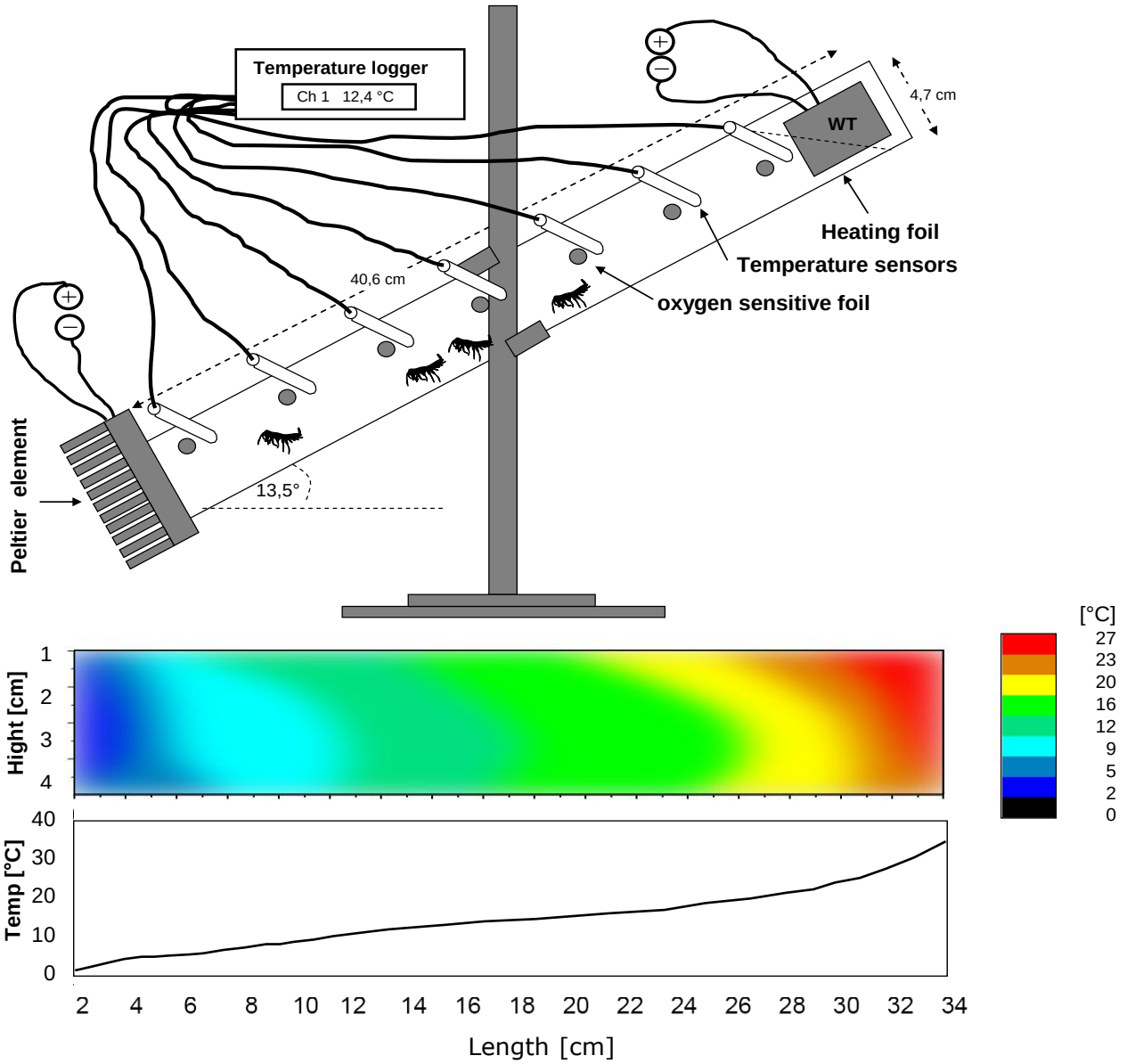






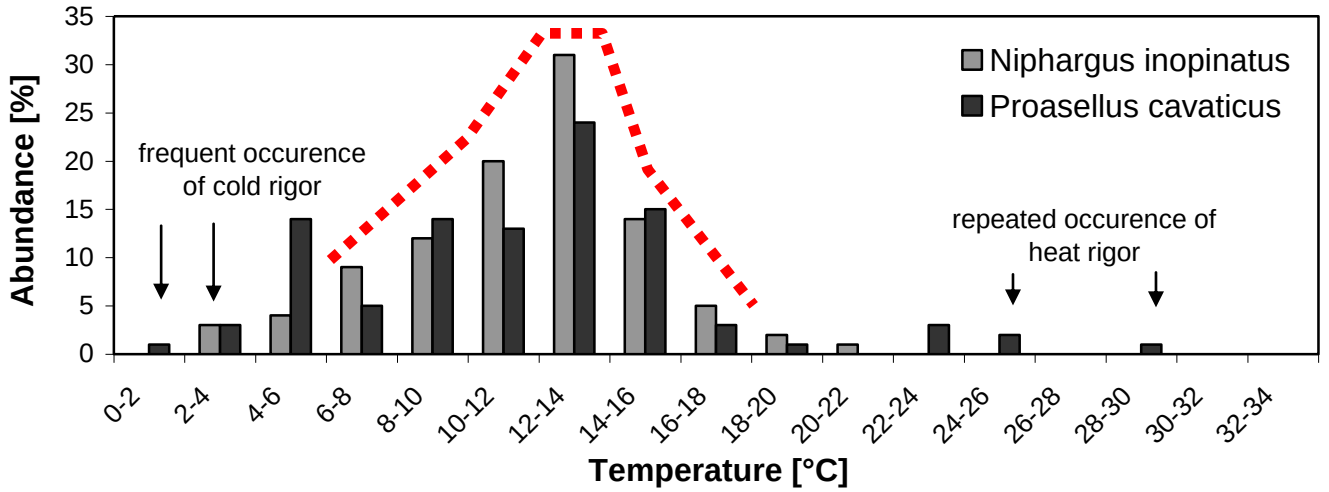
Lab experiments with GW fauna

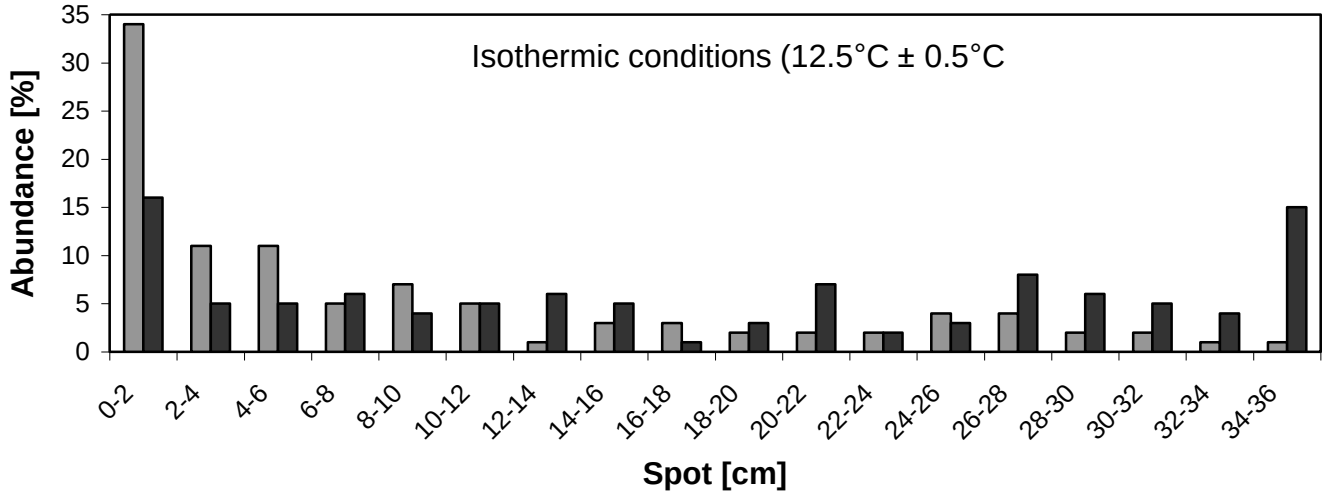
Temperature preference of GW invertebrates



Lab experiments with GW fauna

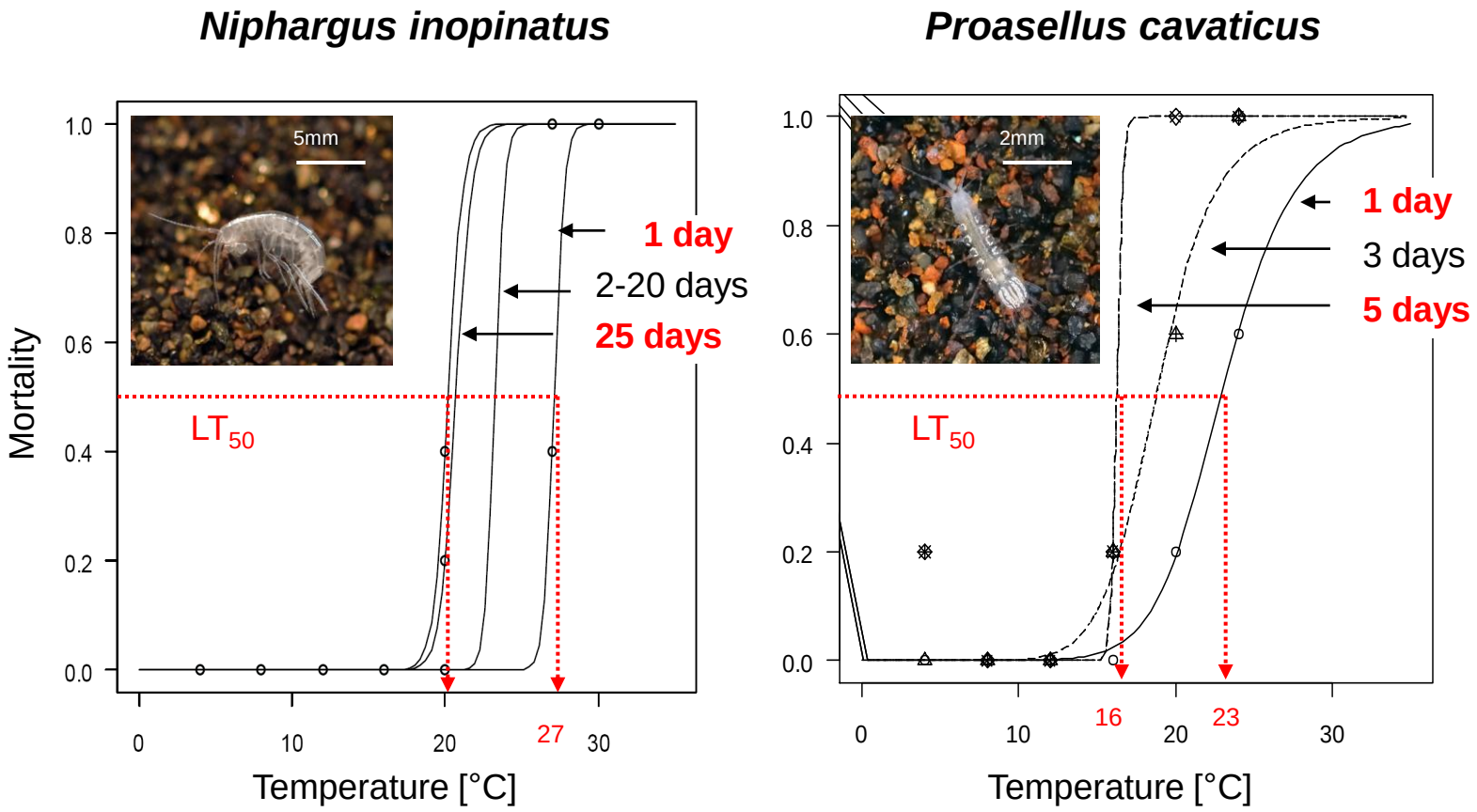
Temperature preference of GW invertebrates





Lab experiments

Temperature tolerance of GW invertebrates



Summary (1)

- **GW temperature did not significantly affect:**
  - Physical-chemical conditions
  - Total bacterial cell counts
  - Bacterial carbon production
  - Survival or growth of faecal bacteria (total CFUs, coliforms, *E. coli*)
  - Abundance of GW invertebrates

  in an energy limited porous aquifer

- Yet, **heat discharge affected** intrinsic aquifer **biodiversity**:
  - Bacterial diversity increased with temperature
  - Faunal diversity apparently decreased

➔ **In the investigated oligotrophic aquifer, and for the temperature ranges encountered, temperature discharge posed no obvious threat to GW quality and ecosystem functions.**

Summary (2)

- **GW temperature did significantly affect:**
  -Bacterial activities and diversity in water and sediments
  of column experiments

  - Survival of faecal bacteria (*E. coli*)
  in column experiments

➔ **temperature changes poses a serious threat to GW quality and ecosystem functions in aquifers with elevated background concentrations of organic carbon and nutrients**

- **GW temperature did significantly affect:**
  - migration behaviour of selected groundwater invertebrates
  - survival of groundwater invertebrates

➔ **temperature changes pose a serious stress to groundwater fauna**

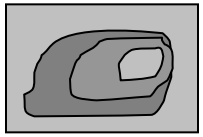
Future activities
UBA (German Federal Environment Agency) Project

Field investigations

2010 - 2013

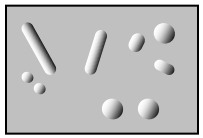
Lab investigations

Temperature



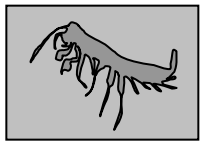
Hydrogeochemistry

T, DO, pH, EC, DOC, SRP, major ions



Microbial parameters

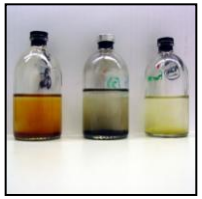
Cell numbers, biomass, activity, diversity



Groundwater fauna

Composition and diversity

Season



Pathogenic microbes and viruses

Decay, reproduction, transport *Legionella sp.*

Ground source heat pumps

Biodegradation of well fillings, BIOLOG tests

Groundwater fauna

Temperature tolerance

Temperature

Acknowledgements

- This work was financed by a grant from the **Life-Science-Foundation** (http://www.life-science-stiftung.org).

- W. Adam (Wasserwirtschaftsamt Freising), H. König and F. Meyfarth (Texas Instruments Germany, Freising) for general project and sampling support.

- E. Schrade, V. Hammerl, R. Schaupp, K. Groißmeier and A. Balmert (all Technical University of Munich) as well as G. Hinreiner, G. Teichmann, S. Schaefer, S.I. Schmidt and M. Stoeckl (Helmholtz Zentrum München) for project assistance.

- Umwelt Bundes Amt
  Für Mensch und Umwelt

  systherma
  Planungsbüro für Erdwärmesysteme GmbH

ISSM 2011
8th International Symposium
of Subsurface Microbiology

September 11–16, 2011
Garmisch-Partenkirchen, Germany
www.issm2011.com

ISSM 2011

Deadline for abstract submission 14th May

microbial life below our feet

principles and challenges
of subsurface ecosystems

Topics and Keynote speakers

Microbiology of hydrocarbon reservoirs & contaminated sites
(Ian Head, Frank Löffler, Barbara Sherwood-Lollar)

Microbial ecology of the shallow subsurface
(Ken Nealson, Karsten Pedersen, Christian Griebler)

Deep & Extreme environments
(Bo Barker Jørgensen, Ken Takai, Tory Hoehler)

HelmholtzZentrum münchen
German Research Center for Environmental Health