Subterranean crustaceans as potential bioindicator organisms of environmental stress in hyporheic zone

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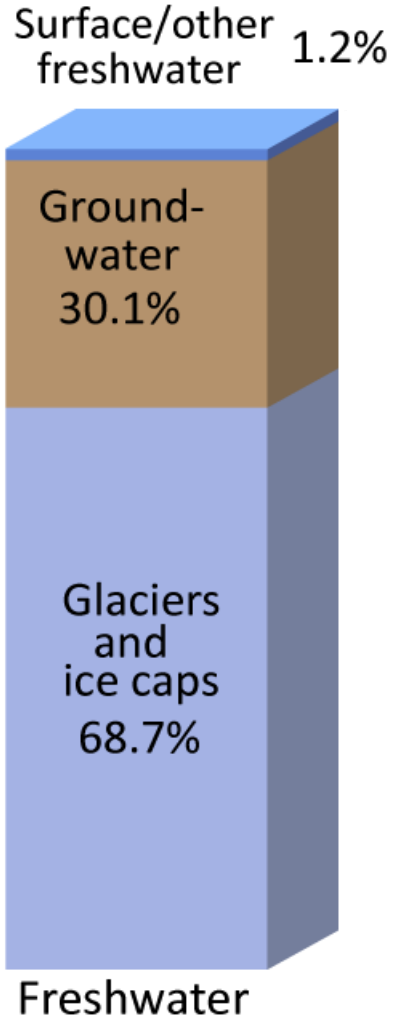
Groundwater ecosystems

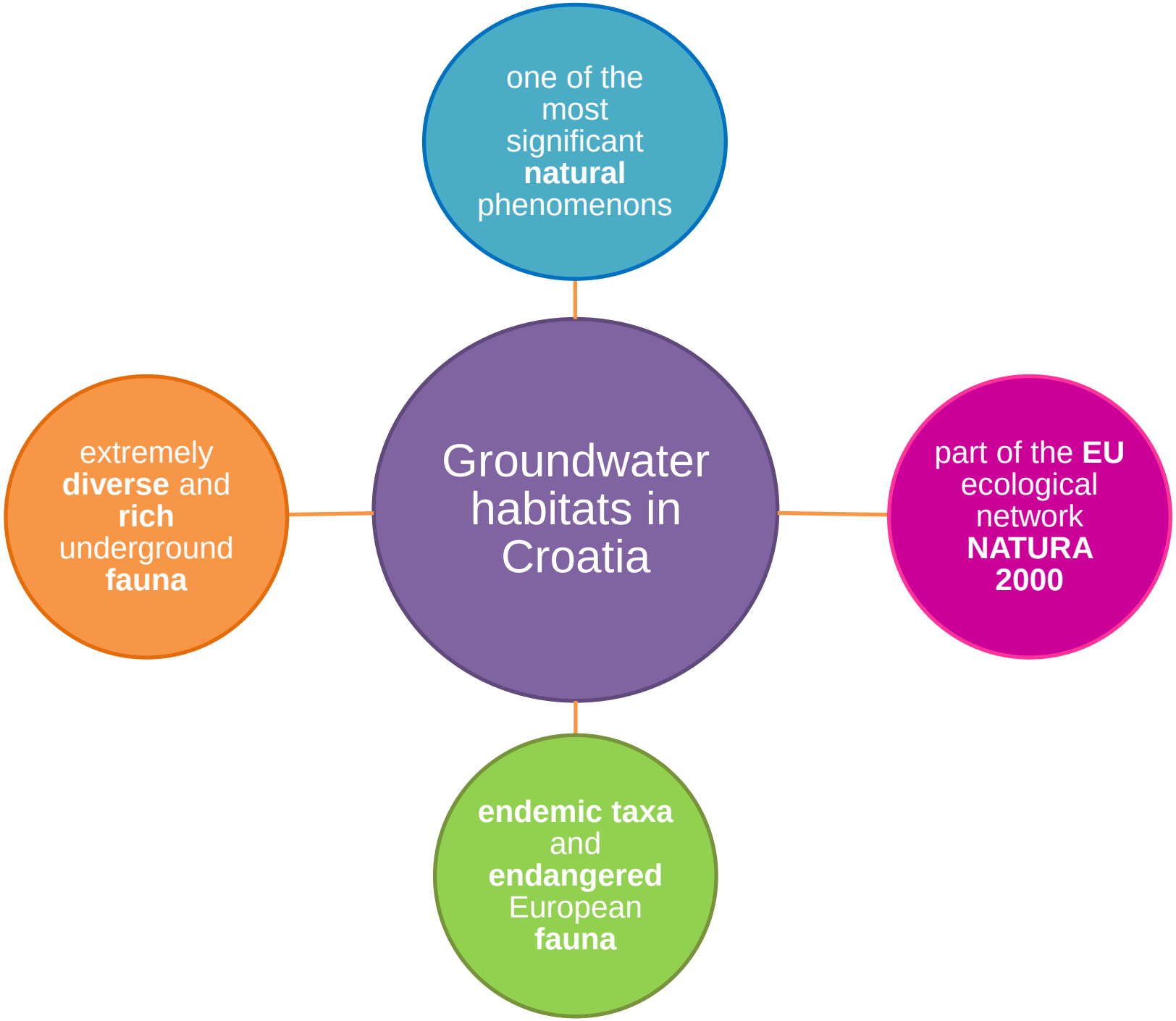
- they represent for about 30% of freshwater on Earth and 99% of unfrozen water on land → groundwater as critical resource on the planet

- many services that groundwater ecosystems provide to humans - **drinking water** supply and water use for **irrigation** for traditional and intensive agricultures

- groundwater quality is under threat in many areas - **agriculture** practices, **industrial** development and **urbanization**
- reliable **evaluations** of groundwater ecosystem health have become essential for the proposal, the establishment and the use of restoration strategies



Shiklomanov, 1993.


one of the most significant **natural** phenomenons
extremely **diverse** and **rich** underground **fauna**
Groundwater habitats in Croatia
part of the **EU** ecological network **NATURA 2000**
endemic taxa and **endangered** European **fauna**

Groundwater quality assessment

- in Europe, groundwater quality is still evaluated based on physical, chemical and hydrological characteristics (European Commission,2006), although the inclusion of ecological criteria has been repeatedly advocated

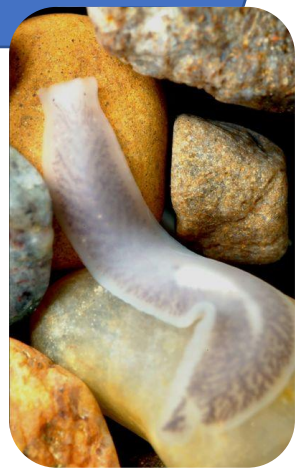
Groundwater quality assessment

Physico-chemical parameters

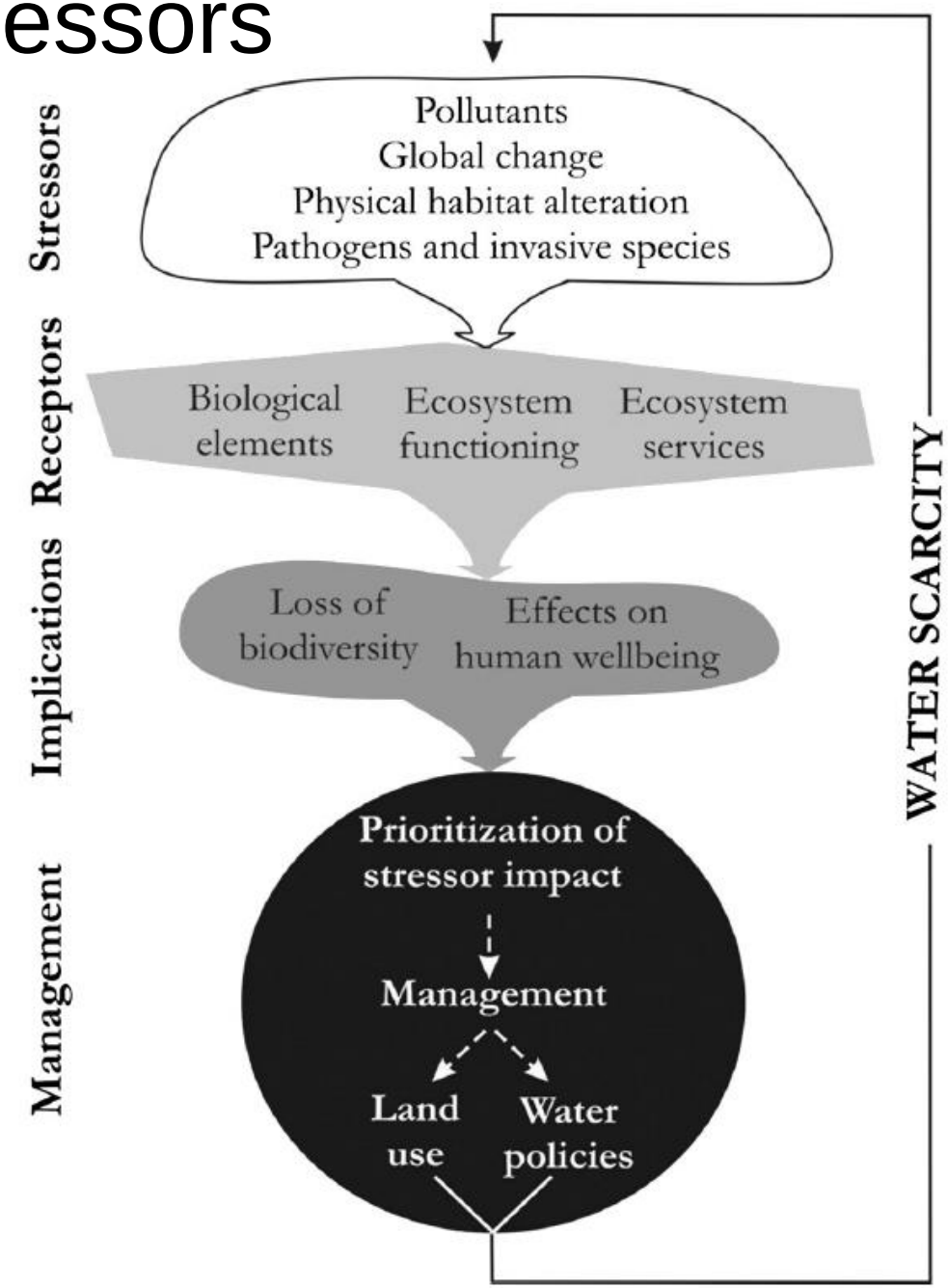
- temperature
- pH
- conductivity
- total dissolved solids
- dissolved oxygen (DO)
- m-alkalinity
- $P\text{-}PO_4^{3-}$
- NH_4^+

Bioindicator organisms

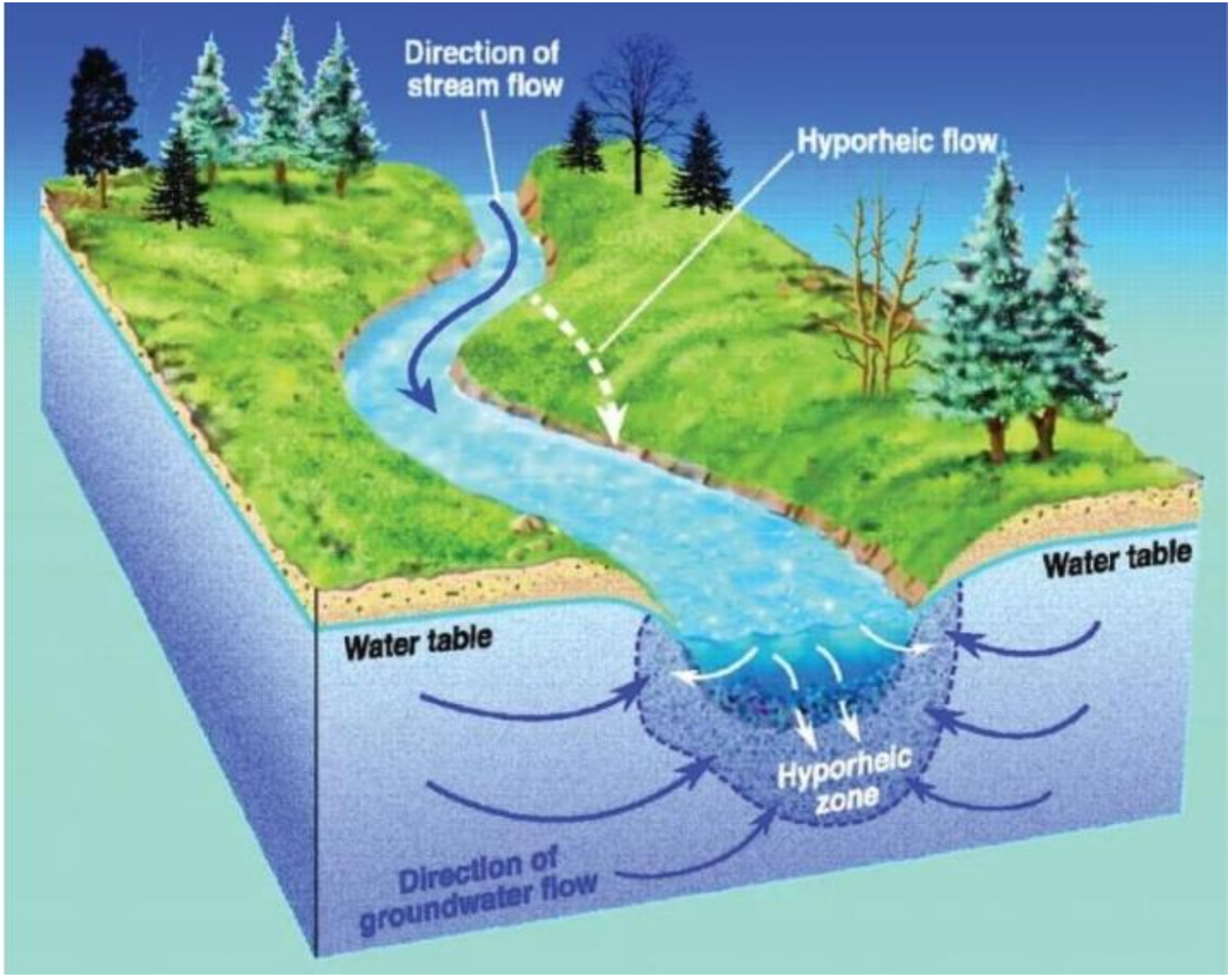
- organisms that **accumulate pollutants**
- they are used to monitor the impact of **pollution** in the aquatic environment



Environmental stressors



What is hyporheic zone?

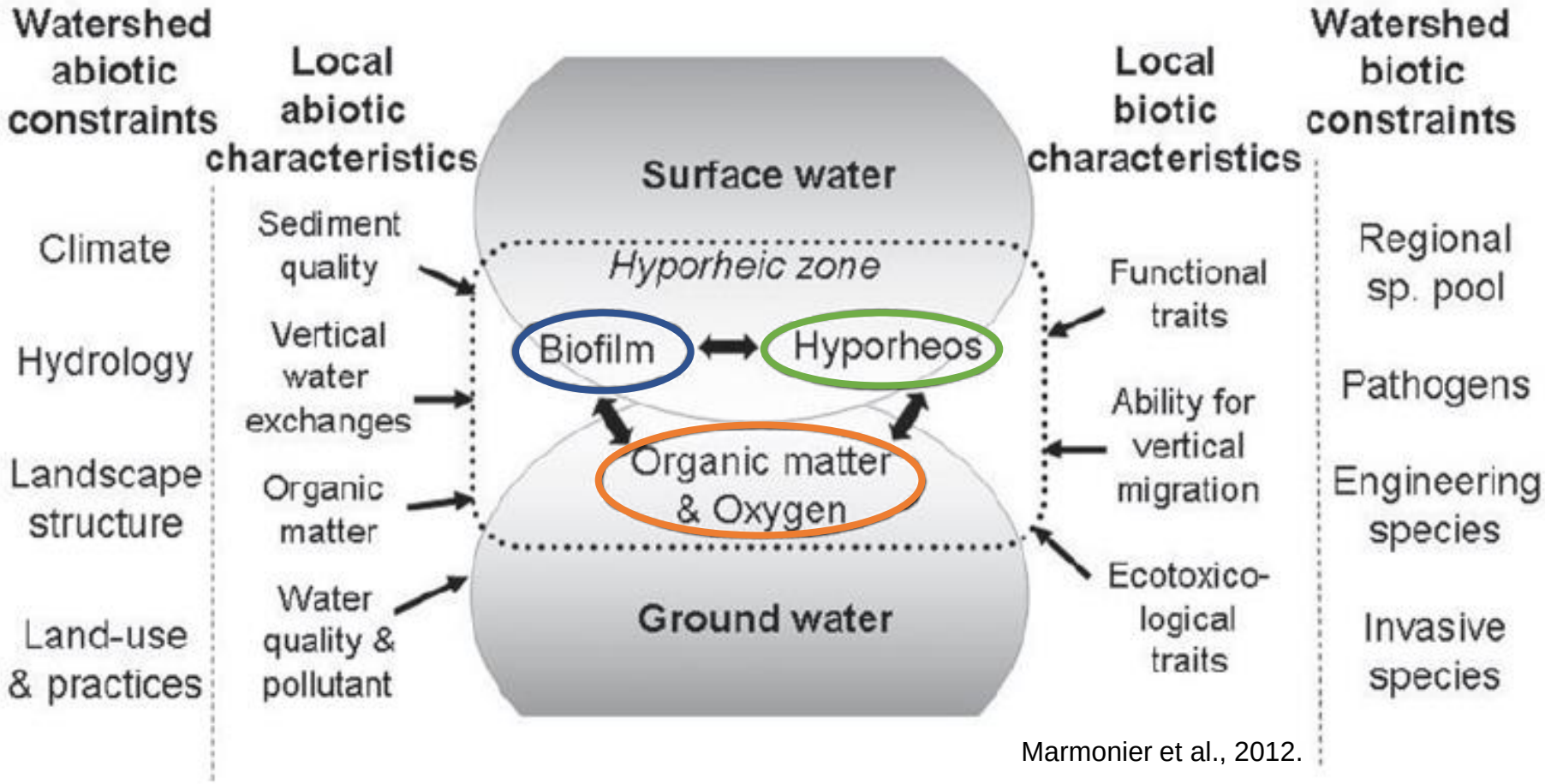


"Hypo" = under + "Rheos" = flow

a unique habitat that is located at the interface of surface water and groundwater within river corridors *(Orghidan,1955)*

they belong to the most threatened aquatic environments → strong anthropogenic impact

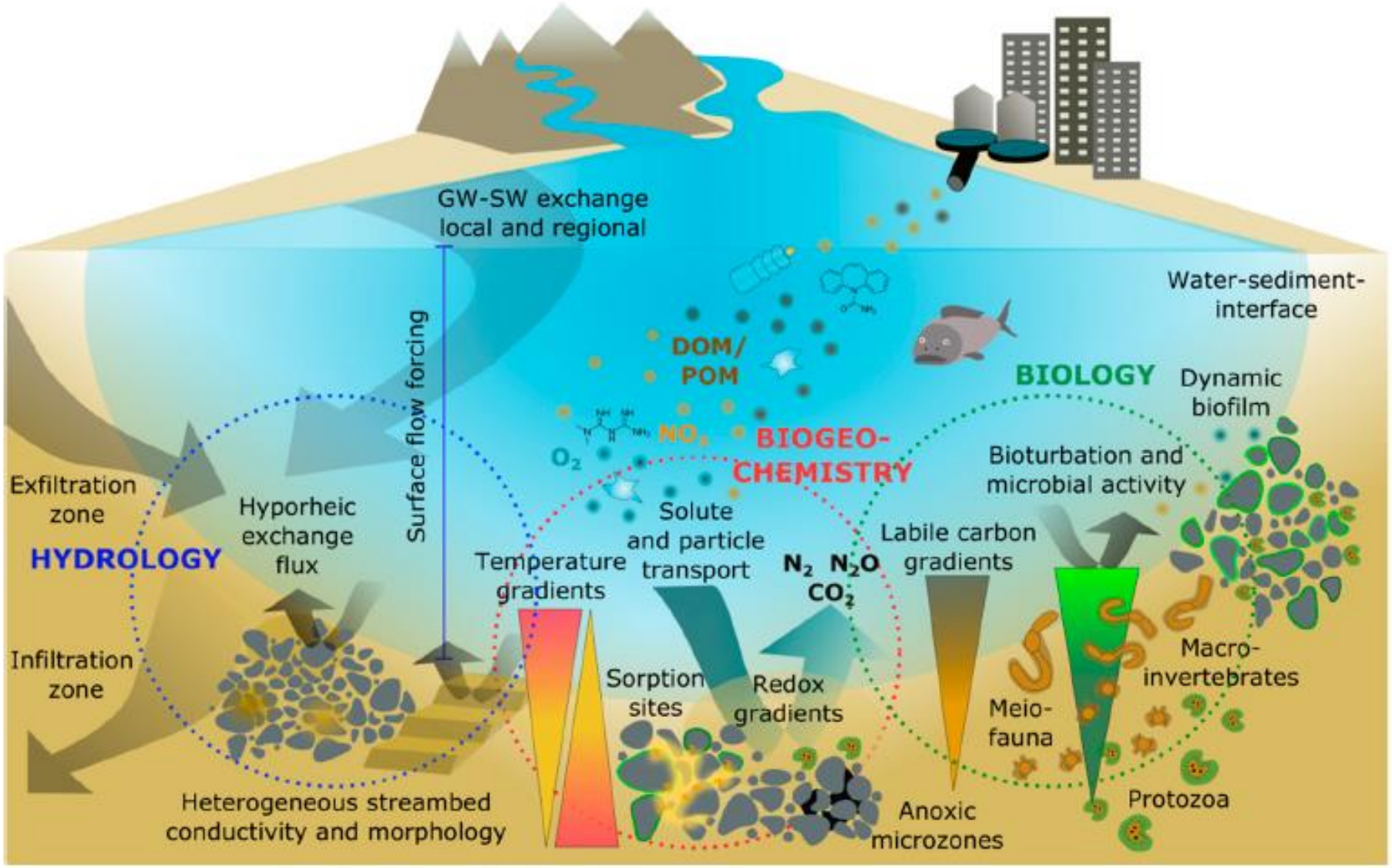
Hyporheic zone (HZ): link between hydrological, ecological and biogeochemical processes



Marmonier et al., 2012.

- the abiotic and biotic variables control processes in the hyporheic zone at local and watershed scales

Hyporheic zone: link between hydrological, ecological and biogeochemical processes



Lewandowski et al., 2019.

- the HZ plays a crucial role in **nutrient turnover**, **removal** of **trace organic compounds** and **particle retention** in streams

- important habitat and **refuge** for aquatic organisms, as well as a reservoir of **biodiversity**

Groundwater bioindicator organisms

Groundwater decapods

Orconectes australis australis

Groundwater amphipods

Niphargus aquilex

Niphargus resson

Microorganisms

Groundwater amphipods

- developed morphological, behavioral and physiological adaptations to subterranean habitats
- specific small and elongated forms of organisms
- accumulate metals from the environment

Niphargus miljeticus

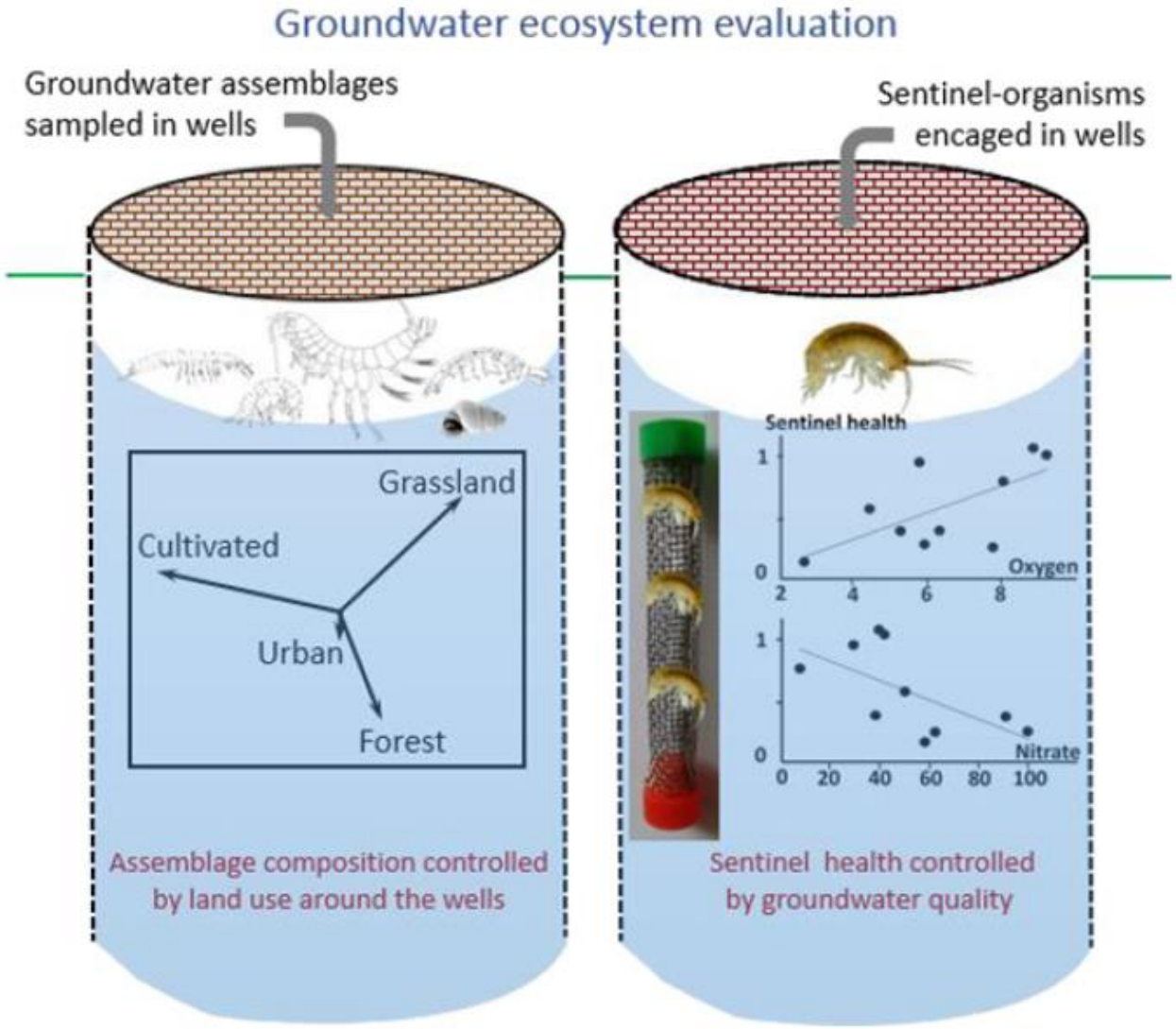
Niphargus longicaudatus

1. Stygobionts as bioindicators of long-term exposure

- use of stygobionts - may be **resistant** to **long-term exposure** (one month of starvation) Marmonier et al. (2013)
- allow assessing diffuse pollution or providing a comprehensive evaluation of groundwater ecological quality
- health criteria for evaluating the degree of environmental disturbance resulting from exposure:

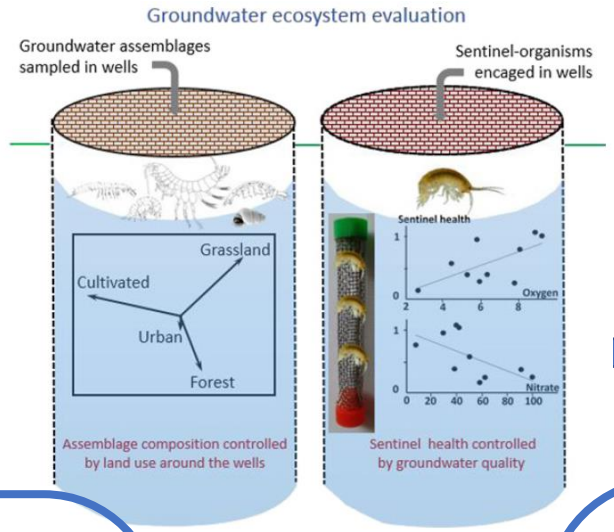
1. survival rate
2. feeding activity
3. physiological parameters (e.g., respiration, vitellogenesis,
4. life-history traits (e.g., reproduction)

2. Assessing the ecological status of groundwater ecosystems



Marmonier et al., 2018.

2. Assessing the ecological status of groundwater ecosystems

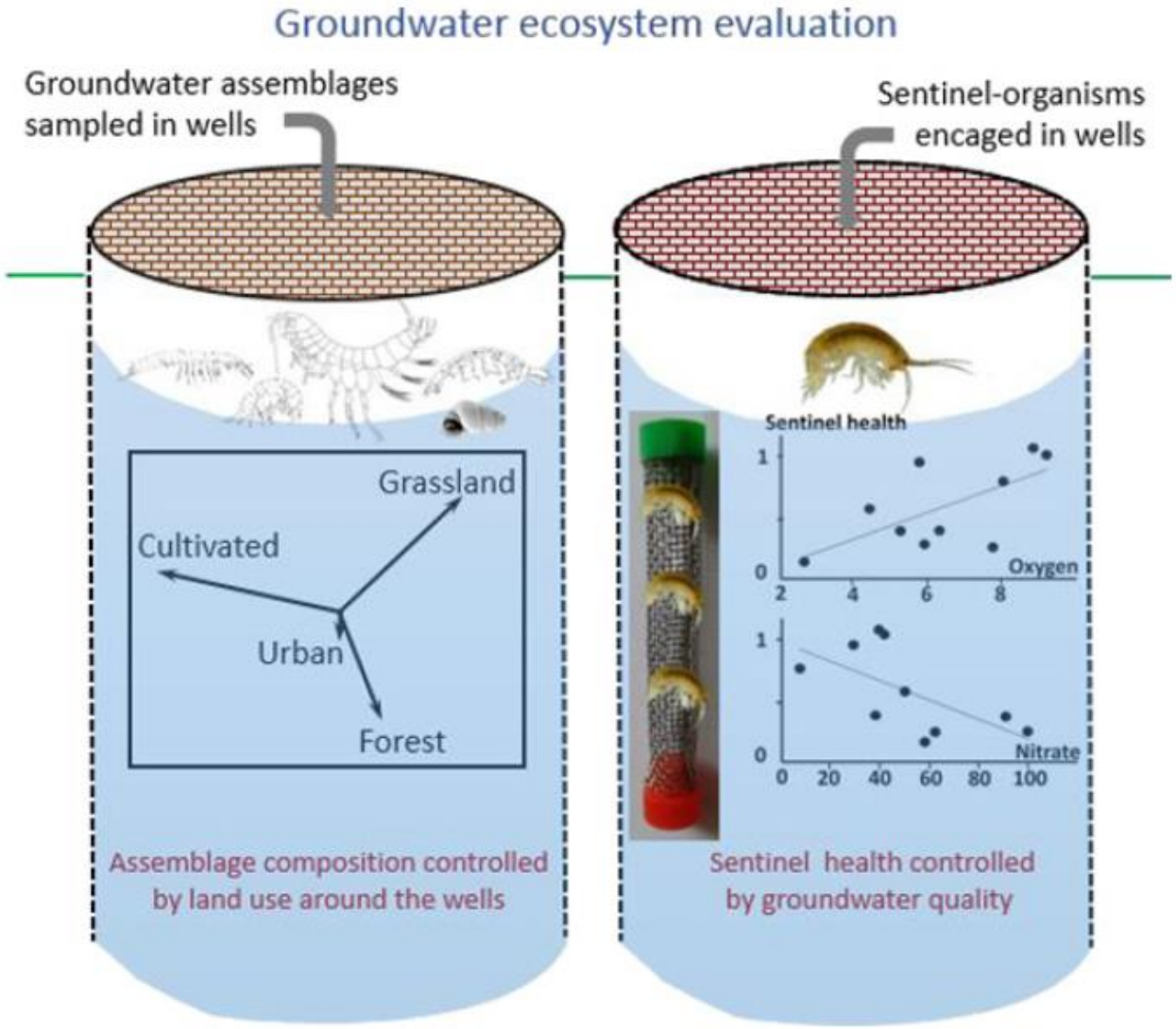


- sampling *in situ*: the composition of invertebrate assemblages
- abundance, species richness, and assemblage composition significantly changed with agricultural land use or urbanization around the wells

- in situ exposure of sentinel organisms to quantify their response to the environmental pressures
- amphipods exposed for one week to the in situ conditions at two seasons with contrasted concentrations of pollutants

2. Assessing the ecological status of groundwater ecosystems

Intensive **agricultural** practices or **urbanization** - significantly associated to **decreases** in **abundance**, species richness and changes in the composition of hypogean crustacean assemblages (long-term trends).



Marmonier et al., 2018.

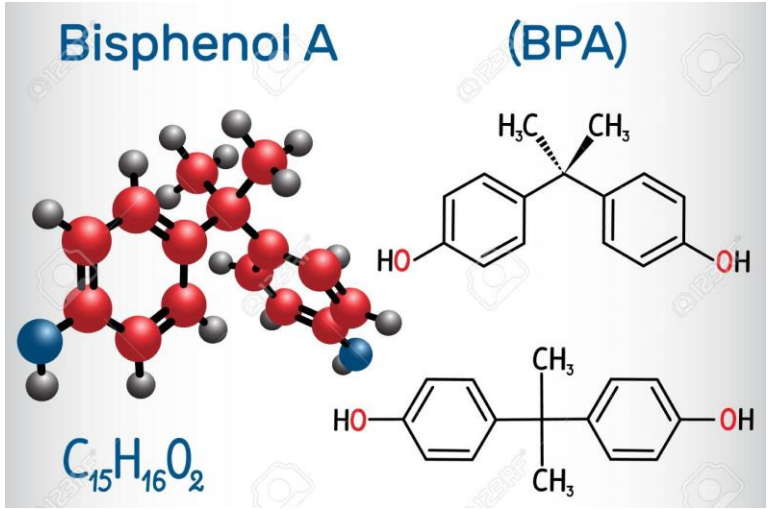
The Ecophysiological Index (EPI) synthetizing the **survival rates** and **energetic storage** decreased in wells with **low oxygen** and high nitrate concentrations, but only during the highest contamination period

Sentinel species are sensible to dissolved oxygen and nitrate concentrations.

Atrazine-related compounds may negatively impact sentinel health.

3. Plastic Additive Bisphenol A: Toxicity in Surface-and Groundwater Crustaceans

- Bisphenol A (BPA) - considered as a substance of very high concern (European Union)
- occurring worldwide - wide application in many plastic products, building materials, coatings, epoxy resins…



3. Plastic Additive Bisphenol A: Toxicity in Surface- and Groundwater Crustaceans

- acute (24 h) and chronic (28 d) toxicity - survival and spontaneous locomotory activity recorded in real-time in the Multispecies Freshwater Biomonitor (MFB)
- the most sensitive macro-crustacean species was the groundwater isopod *Proasellus slavus*, in both acute and chronic exposures
- *P. slavus* might be used for long-term monitoring of chronic low-dose exposures, e.g. in groundwater and drinking water
- groundwater crustaceans tend to react both faster and more sensitive to BPA short-term exposure than the surface water representative *Gammarus fossarum*
- groundwater species have a thinner and transparent cuticula - less protection from the surrounding aquatic environment

Current scientific debate

- do the standard aquatic test species, primarily daphnids, also protect groundwater invertebrate species or if there is a need to find groundwater test species and develop specific toxicity test guidelines for a safe risk assessment to fulfill the European Groundwater Directive?

4. Metal exposure

Ability to accumulate heavy metals

- epigean and hypogean amphipods differ in their ability to accumulate heavy metals
- ***Niphargus rhenorhodanensis*** and ***Niphargopsis casparyi*** (hypogean species) have been shown to have **higher Zn** and **Cu concentrations** than *Gammarus fossarum* (epigean species)
- correlation with longer life expectancy of species adapted to underground conditions, and thus longer exposure to heavy metals (Plénet, 1995)

Niphargus rhenorhodanensis

Zn **Cu**

Gammarus fossarum

4. Metal exposure

Tolerance to metal exposure

- greater tolerance of subterranean species to metal exposure has been observed compared surface species
- *N. rhenorhodanensis* is 2-20 times more tolerant of arsenic exposure than the surface *G. fossarum* species (Canivet et al., 2001)

Niphargus rhenorhodanensis

Gammarus fossarum

2-20 times more tolerant

Questions that remain unanswered?

- the impact of **climate changes** - the consequences of warming and changes in river hydrology on the hyporheic assemblages are <u>not yet predictable</u>
- the occurrence of **invasive species** - disturbing the hyporheic communities
- strong need for methodologies to estimate the hyporheic **biodegradation** of **pollutants** (xenobiotics, pesticides, trace metals)

Conclusions

- 60 years after the hyporheic zone was first defined, the study of its habitat, fauna, and the related ecological processes, have made significant progress making ecotone an essential element in river functioning knowledge
- despite these advances, several questions remain unsolved and require more effort in research and application for river management
- hyporheic organisms will be particularly impacted by climatic changes because of the combination of temperature rising and changes in river and groundwater hydrology


THANK YOU FOR
YOUR ATTENTION!