Rev. 1 – 2nd version

>Dear Editor,
I have reviewed, for the second time, the manuscript entitled "Quantifying the impact of groundwater fauna and temperature on the ecosystem services of microbial carbon degradation: a proof-of-principle approach" by Schmidt, Rutz, and Marxsen.
I would like to thank the authors for having carefully and positively addressed all of my previous comments. I found the manuscript substantially enriched and improved, also thanks to the incorporation of the suggestions raised by the second reviewer. My overall evaluation of this work therefore remains strongly positive.

Thank you very much for the repeated evaluation and the positive feedback!

I would also like to emphasize that this contribution is particularly timely in light of the adoption by the European Commission in May 2026 of Directive (EU) 2026/805, amending the Water Framework Directive (WFD), the Groundwater Directive (GWD), and the Environmental Quality Standards Directive. Recital 20 of the new directive explicitly acknowledges that groundwater bodies are ecosystems and highlights the need for further research—supported, where appropriate, by EU funding—to improve our understanding of the characteristics and functions of groundwater ecosystems, particularly in the context of climate change.
The present study, which the authors honestly and appropriately describe from the title onward as a proof-of-principle approach, aligns closely with these emerging policy priorities by modelling real-world data. Admittedly, the study relies on several approximations, some of which may be substantial for certain variables. However, these limitations largely reflect the current scarcity of available data and studies on this topic. To the best of my knowledge, the existing literature is still limited and mainly represented by the work of Saccò and Mermillod-Blondin and their collaborators.
In my opinion, the authors have made a convincing effort to reason critically and rigorously with the available data and the existing body of literature. The resulting models generate interesting scenarios that encourage important reflections on the effects of climate change on the ecosystem services provided by groundwater ecosystems.
Perhaps the most striking outcome of the model is the prediction that, in the absence of stygobiotic fauna, the amount of residual organic matter would be 6.6 times higher than under conditions where groundwater fauna is present. This finding deserves careful consideration, particularly because of its potential implications for groundwater quality and drinking water resources. I believe that this result may stimulate colleagues in the field to design targeted experimental studies aimed at testing or challenging the model's predictions.
In light of these considerations, I recommend the manuscript for publication.

Thank you very much for this detailed and encouraging feedback and the hint to the EU Directive 2026/805. We further detail below how and where we incorporated this important directive. We believe that we are already citing the existing literature by Sacc Saccò and Mermillod-Blondin and their collaborators that you refer to. If not, please kindly indicate which further work should not be omitted here.

I only noted a few minor typographical issues and have the following suggestions for the final revision:
Introduction: The authors may wish to consider citing the new directive and specifically Recital 20, as this would place their study within a highly relevant and evolving policy framework.

Thank you again for pointing out that a citation of this new directive belongs in the introduction. We have placed it in the third sentence of the new first paragraph of the introduction: '*Groundwater, i.e. sensu lato the water beneath the surface (Winter et al., 2003), is also an ecosystem (e.g. Malard et al. 2023a; Directive (EU) 2026/805).*' (lines 30ff .in the pdf of the new track-changed version).

And we have placed it also at another point of the introduction:

'*The new directive (EU) 2026/805 demands in recital 20 'to reduce the level of purification treatment required in the production of water'. This is only possible if humankind makes sure that groundwater remains at or is developed towards a productivity of the whole food web that reduces organic matter most efficiently.*' (lines 62f .in the pdf of the new track-changed version)

and in the discussion, heading 4.5: '*Here, we focused on degradation of BOC as a main ecosystem service relevant to drinking water production for humankind, as also demanded in Directive (EU) 2026/805*.' (lines 605f .in the pdf of the new track-changed version)

Lines 25–34 (tracked manuscript): I suggest adding supporting references for several of the statements made in this section.

Based on feedback by the second review we have completely changed the first paragraphs of the introduction, while at the same time making sure to cite more references. The first two paragraphs now read:

'*Ecosystems deliver services that humankind depends upon (Daily et al., 1997). On the surface, such services include pollination (Landis et al., 2017), production of nutrition (Leclère, 2020), transformation and decomposition of dead biomass (Blouin et al., 2013), recreational opportunities (Eigenbrod, 2016), and water purification (Mori et al., 2025), which is a prerequisite for drinking water production (Tockner, 2021). Groundwater, i.e. sensu lato the water beneath the surface (Winter et al., 2003), is also an ecosystem (e.g. Malard et al. 2023a; Directive (EU) 2026/805)alive. Microorganisms are found almost everywhere in groundwater, adapted depending on to different conditions (e.g. Lueders and Griebler, 2008). They produce biomass (e.g. Magnabosco et al., 2018) which may be the food source for other organisms such as protozoa and fauna (Mermillod-Blondin et al., 2025). Groundwater ecosystems, although still often ignored, deliver, among others, the ecosystem services reworking of sediments (Stumpp & Hose 2013) which hinders colmation, i.e. the clogging of sediments (Descloux et al., 2013), and water purification (Avramov et al., 2010). When undisturbed, this purification is believed to reach drinking water quality (Avramov et al. 2010) through e.g. pathogenic microorganisms being removed (Tufenkji et al. 2004), pollutants being biologically degraded (Meckenstock et al., 2015), and naturally occurring carbon being transformed (Marxsen, 1981; Herrmann and Taubert, 2022). Such purification takes time and is only possible in groundwater flowing slowly (probably maximum 1 m per day) through sediments or fractures with small pore sizes. In this contribution, we focus on such relatively deep and relatively old groundwater, i.e. not the subsurface water in continuous exchange with the surface and the atmosphere.*

The entire food web in groundwater (Malard et al., 2023b) may be involved in groundwater purification through its processing of carbon. The groundwater food web is often truncated (Gibert and Deharveng, 2002), but may encompass several trophic levels (Ercoli et al., 2019; Malard et al., 2023b), depending on the respective environmental conditions. Some groundwater food webs are

qualitatively well described, in terms of e.g. "who eats whom" (Bradford, 2009; Bradford et al., 2010; Ercoli et al., 2019; Francois et al., 2016; Leijs et al., 2015). Quantitative evaluations are a lot scarcer (but see e.g. Foulquier et al., 2011, Mermillod-Blondin et al., 2025). However, this function of purification or self-cleaning in groundwater, i.e. degrading carbon compounds (Becher et al., 2022) to ultimately the gases CO2 or CH4, is probably most relevant to humans. These functions are one prerequisite for sustainable drinking water production, which is one of the 17 goals (goal 6) of the 2030 Agenda for Sustainable Development (United Nations General Assembly, 2017). Where groundwater communities decline or vanish, this may lead to deteriorating groundwater health (Koch et al., 2024a), compromising an aquifer's ecosystem and its function. The new directive (EU) 2026/805 demands in recital 20 'to reduce the level of purification treatment required in the production of water'. This is only possible if humankind makes sure that groundwater remains at or is developed towards a productivity of the whole food web that reduces organic matter most efficiently.' (lines 25-41).

Line 114: A semicolon is missing between references.
Thank you very much for spotting this oversight! Now corrected.

Line 133: I would remove the comma after "further."
I intended to stress that the sentence is true for the indicated reasons, but for more reasons as well, but I admit that the comma might hinder the reading flow, so the comma is deleted now.

Line 204: A semicolon is missing between references.
Thank you very much for spotting this oversight! Now corrected.

Line 189: "Iannelli et al al." should be corrected to "Iannella et al."
Thank you very much for spotting this oversight! Now corrected.

Line 316 and elsewhere: Please verify that the citation is consistently reported as "Avramov et al. (2013)" rather than simply "Avramov."
Avramov (2013) refers to Maria Avramov's thesis, included in the Bibliography:
Avramov, M.: Sensitivity and Stress of Groundwater Invertebrates to Toxic Pollution and Changes in Temperature, PhD, 2013.

Some of the statistics and model parameters we use here, can only be found in the thesis. We rechecked to make sure that at each place the correct reference is given, and indeed changed to the 2013 paper in one place (line 52f.).

Report #2, reviewer 3

Dear Editor, Dear Authors
I have revised the current manuscript version, considering also the comments by two previous reviewers and the editor, as well as the authors response and revisions made.

Thank you very much for this enormous effort!

Agreeing with both previous reviewers, I also consider the topic of the manuscript important and timely. As the authors acknowledge, their modelling approach relies on numerous assumptions and simplifications, which can of course be discussed, as well as criticized. Despite these inherent limitations, I am convinced that the work provides a valuable and courageous (agreeing with reviewer 1) contribution to the field of groundwater ecology by presenting a solid proof-of-principle approach to model groundwater microbial carbon degradation under varying temperature and fauna presence-absence scenarios. Considering the concerns and comments by the previous reviewers, I think that the revised version of the manuscript now clearer points out that the modelling results are based on (many) underlying assumptions and that this is a proof-of-principle approach. I particularly appreciate that this is now explicitly stated in the title and in other parts of the manuscript.

We are glad that we were able to convince with the updated version.

Generally, I recommend acceptance of the manuscript, yet I have some additional comments which the authors might consider before publication:

Thank you very much for this constructive criticism.

Abstract
L. 21: "Sustainable drinking water production is more reliable and less costly, the more active the groundwater fauna in the production area is." I recommend the authors set this statement in a more precise context. Is it a hypothesis based on your results? If yes and given the intensive discussion about limitations of the modelling approach, I would recommend a more careful phrasing.

Thank you for pointing out this lack in clarity. Since indeed this sentence is neither a hypothesis nor a direct outcome of these preliminary results, we deleted the sentence from the abstract and ended the first paragraph of the conclusion with the slightly modified phrase: '*We hypothesize that sustainable drinking water production which is foremost based on reducing organic carbon is more reliable and less costly, the more active the groundwater fauna in the production area is.*' (Lines 732f. in the pdf of the track-changed version).

Introduction
Generally, I think the structure of the introduction could still be improved. The editor suggested a more clearly "funnelled" structure from the broad problem to the specific research question which I still see lacking in some parts.

We are sorry that we did not convince with the restructuring of the introduction and will follow the recommendations, as detailed in the following points.

For example:
L. 25ff: The introduction now starts with explaining very specifically the faunal components of groundwater ecosystems (stygobites, stygophiles, stygoxenes). In my opinion starting on more broad topics such as ecosystem services -> groundwater food webs -> carbon degradation (or similar) would be a more suitable structure.

We are sorry that we still jumped ahead too quickly and did not understand from which broad viewpoint to funnel towards the research question and made too many assumptions. We have now started with ecosystem services in general, moving towards groundwater, and then their food web,

and then carbon degradation as one ecosystem service in groundwater. We hope that this convinces more now, in the introduction:

'*Ecosystems deliver services that humankind depends upon (Daily et al., 1997). On the surface of the Earth, such services include pollination (Landis et al., 2017), production of nutrition (Leclère, 2020), transformation and decomposition of dead biomass (Blouin et al., 2013), recreational opportunities (Eigenbrod, 2016), and water purification (Mori et al., 2025), which is a prerequisite for drinking water production (Tockner, 2021).*

Groundwater, i.e. sensu lato *the water beneath the surface (Winter et al., 2003), is also an ecosystem (e.g. Malard et al. 2023a; Directive (EU) 2026/805). Microorganisms are found almost everywhere in groundwater, depending on different conditions (e.g. Lueders and Griebler, 2008). They produce biomass (e.g. Magnabosco et al., 2018) which may be the food source for other organisms such as protozoa and fauna (Mermillod-Blondin et al., 2025). Groundwater ecosystems, although still often ignored, deliver, among others, the ecosystem services reworking of sediments (Stumpp & Hose 2013) which hinders colmation, i.e. the clogging of sediments (Descloux et al., 2013), and water purification (Avramov et al., 2010). When undisturbed, this purification results often in drinking water quality (Avramov et al. 2010) through e.g. pathogenic microorganisms being removed (Tufenkji et al. 2004), pollutants being biologically degraded (Meckenstock et al., 2015), and naturally occurring carbon being transformed (Marxsen, 1981; Herrmann and Taubert, 2022). Such purification takes time and is only possible in groundwater flowing slowly (probably maximum 1 m per day) through sediments or fractures with small pore sizes. In this contribution, we focus on such relatively deep and relatively old groundwater, i.e. not the subsurface water in continuous exchange with the surface and the atmosphere.*

The entire food web in groundwater (Malard et al., 2023b) may be involved in groundwater purification through its processing of carbon. The groundwater food web is often truncated (Gibert and Deharveng, 2002), but may encompass several trophic levels (Ercoli et al., 2019; Malard et al., 2023b), depending on the respective environmental conditions. Some groundwater food webs are qualitatively well described, in terms of e.g. "who eats whom" (Bradford, 2009; Bradford et al., 2010; Ercoli et al., 2019; Francois et al., 2016; Leijs et al., 2015). Quantitative evaluations are scarcer (but see e.g. Foulquier et al., 2011, Mermillod-Blondin et al., 2025). However, this function of purification or self-cleaning in groundwater, i.e. degrading carbon compounds (Becher et al., 2022) to ultimately the gases CO_2 or CH_4, is probably most relevant to humans. These functions are one prerequisite for sustainable drinking water production, which is one of the 17 goals (goal 6) of the 2030 Agenda for Sustainable Development (United Nations General Assembly, 2017). Where groundwater communities decline or vanish, this may lead to deteriorating groundwater health (Koch et al., 2024a), compromising an aquifer's ecosystem and its function. The new directive (EU) 2026/805 demands in recital 20 'to reduce the level of purification treatment required in the production of water'. This is only possible if humankind makes sure that groundwater remains at or is developed towards a productivity of the whole food web that reduces organic matter most efficiently.' (Lines 25 - 65 in the pdf of the track-changed version).

We deleted the paragraph on stygobites, stygophiles and stygobionts, for reasons that we detail in the reply to a further comment on this topic, further down.

L. 122: You refer to the river Fulda floodplain, yet the actual introduction of that study data comes much later.

Thank you for spotting this inconsistency which was the result of moving sections and thus disrupting the sequence of introductions of terms and places. We have corrected the respective sentence in the following way: '*While we do not know whether these two species were among those*

present in the study area of this contribution (introduced below), until we have better data, we assumed the parameters from Brielmann et al. (2011) to be representative enough for a modelling study.' (Lines 149f. in the pdf of the track-changed version).

L. 159ff: This paragraph is very detailed – maybe something to move to the methods part of the manuscript?

We appreciate that it might seem tedious to read this paragraph with detailed area descriptions already in the introduction. We die believe that this is necessary to introduce the area in which this "proof of principle" study took place, and in what ways it may or may not be representative for other areas. However, since it may indeed hinder the reading flow too much, we have considerably shortened it and moved most of if to the methods section, so that it now reads as follows in the introduction:

"*Since it is hard to derive the relevant data sets on the required temporal and spatial resolution, while controlling for different environmental settings globally, one way to approach answers to these questions are models. Here, we present a model, as a proof-of-principle approach, based on data from one of the most comprehensive data sets on a groundwater ecosystem, in the River Fulda floodplain (Husmann and Marxsen, 1988; Marxsen et al., 2021). While many groundwater taxa are ubiquitous, neighbouring aquifer zones may differ markedly in fauna taxa composition (Di Lorenzo et al., 2025a), and so it was for the River Fulda data set, although of small size (3 km^2; Marxsen et al., 2021). The River Fulda data set thus enables us to study reactions to scenarios of increased temperatures and / or setting fauna biomass to 0 as if after a calamity, in different environmental exchange conditions, under the same climate. The data set allowed to check whether the developed model represented a range of measured field conditions. Fauna being absent might also be a consequence of climate change, since, as described, fauna does not survive well elevated temperatures.*", (Lines 187-202)

and in the methods section:

"*Marxsen et al. (2021) had performed a k-means cluster analysis on the physical and chemical properties of the River Fulda data set (locality: Johannisaue), assuming four groups. One group combined wells near the river Fulda and in intense exchange with the river ("R"), one group covered wells that were characterized by a plume of a carbon source from the near-by village ("P"), one group was characterized by agriculture with elevated nitrogen and phosphorus concentrations ("A"), and the fourth group represented wells of a mixing zone being situated in-between the other three zones and combining characteristics of all zones ("M"; Fig. 1). The data set allowed checking whether the developed model represented a range of measured field conditions. Once satisfied with the model, it is possible to change parameters and / or exclude fauna biomass to run scenarios representing warmer climates, and comparing ecosystem functions (here: degradation of organic carbon) when fauna is present versus absent. Fauna being absent might also be a consequence of climate change (see above). Admittedly, the data from the Johannisaue within the narrow zone of river-near aquifers, might not be representative for many aquifers. However, we lack data that are representative for those aquifers relevant to our drinking water resources, and thus, we decided to take the data from one of the most comprehensive studies and made further assumptions relating to more secluded aquifers with a low range in temperatures and low adaptation of fauna to higher and lower temperatures."* (Lines 222-235)

One sentence of the former introduction was moved to the Conclusions so that the now second paragraph reads :

« *The fauna's role in groundwater purification might in general still be underestimated. This has implications for drinking water production which will locally have to compensate the lack of fauna's ecosystem services by increased treatment which raises costs and insecurity. We hypothesize that sustainable drinking water production which is foremost based on reducing*

organic carbon, is more reliable and less costly, the more active the groundwater fauna in the production area is. « (lines 730 – 733).

Additional comments on Introduction:
L. 29ff: I recommend the authors re-check their definition of stygobites, stygophiles and stygoxenes. Noting the temperature for stygobites for example, that statement seems a bit out of place. Furthermore, stygophiles can temporally or during part of their life cycle be associated with groundwater ecosystems – thus I think from a biological perspective the definition in the manuscript can be improved. See definitions in Gibert et al. (1994) Groundwater ecology, p. 11ff and Malard et al. (2023) Groundwater ecology and evolution, p. 114.

We realize from your reply that, concerning stygobites versus stygophiles, the figure originally by Gibert et al. (1994) and reproduced e.g. in Culver et al. (2023), one chapter in Malard et al. (2023), is understood by some researchers very differently from how we understand it. We will give an explanation for why we see it differently below, but first, after reconsidering, we deleted the paragraph on stygobites et al. in the beginning of the introduction, because we now realize how controversial the notion of stygobites is, and how little a discussion on that helps the actual aim of the contribution. Further down in the introduction, former line 114, at the next mention of stygobites, we reworded in order to avoid the term:

« Organisms adapted to the surface and its daily influence, i.e. stygoxenes and stygophiles, will cope with surface temperature ranges, while fauna adapted to the groundwater without daily influence, i.e. usually at least meters and months away from surface influence, are usually not adapted to temperatures deviating from groundwater temperatures." (lines 139-146).

The changes concerning ecosystem services in general and in groundwater, were referred to above in the context of a new structure of the introduction.

L. 37: Personally, I would be careful with stating that stygoxenes and stygophiles "do not play a role in most groundwater systems". In shallow aquifers, they can be very abundant, making up a substantial part of the faunal biomass. Yet, I guess you refer to groundwater that is less connected to surface systems (i.e., group III in Schmidt & Hahn 2012 Limnologica). I recommend to state more clearly what you refer to.

Indeed, when talking about « true » grroundwater fauna or stygobites, we very much have conditions in our minds as in group III in Schmidt & Hahn (2012), based on the observations below.

As commented above, the figure originally in Gibert et al. (1994) is obviously understood in several ways. We will first explain how we understand it and then give a concrete example which in our opinion supports this understanding.

We definitely agree on stygoxenes spending their entire lifecycle on the surface, and not in sediments. If they are found in a sediment sample, this is either a sampling error or a site where surface-bound organisms are washed passively by rather strong currents into the sediments. Simuliids as depicted in the figure for stygoxenes, spend most of their larval stage attached to the surface of e.g. stones and collect plankton from the flowing water. For them to be washed into the sediments, the currents must have been so strong that they would have pushed any groundwater away, if indeed there was any groundwater. Just because water flows into the sediments, does not immediately change its quality and there is no point calling it anything different than surface water,

even if flowing for a short time subsurface. Not all water without light is automatically aquifer water. Instead, its properties should be checked and compared with aquifer groundwater and surface water. Subsurface water may be completely disconnected from any aquifer. Otherwise, you would have « aquifers » within concrete-lined channels harbouring some sediments at the bottom.

Once the surface water's residence time in the subsurface has been sufficiently long for it to change physically and chemically (first of all : temperature and dissolved oxygen / redox state), it should in our opinion be called a hyporheic habitat, i.e. a habitat that is physically and chemically distinct from that of surface water and thus, offers different conditions to all organisms. Dissolved oxygen is limiting to many surface organisms from small deviations from saturation on. This is one reason for surface organisms not being able to spend their life cycle in the subsurface. These physical and chemical living conditions which stay different from those of the surface for an extended period, offer a habitat for what we would call hyporheic fauna, i.e. stygophile fauna. Since these are adapted to the lower dissolved oxygen, and thus may be slower both physically and metabolically than the surface organisms, the stygophiles cannot easily compete with surface organisms and usually spend a considerable part at least of their larval stage in the sediments, as depicted by the cycles in the figure at least partially entering the sediments. The left cycle next to the « permanent hyporheos » *Acanthocyclops* seems to indicate that *Acanthocyclops* may spend its entire lifecycle in the permanent hyporheos, which does not turn it into a stygobite, or it may spend its entire life cycle at the surface, which does not turn it into a stygoxene.

We completely agree that stygophiles may reach high densities and high biomasses in the subsurface. But this is the subsurface immediately underneath the surface, i.e. surficial sediments, where enough nutrition is available for organisms to reach high densities. The only other place for subsurface fauna to reach similar high densities is at springs and in and around wells. At both places, aquifers interact with the atmosphere, particularly when wells are not closed off well – which is the usual case. Just because you find ants and leaves and fir seeds in well water does not turn these organisms into stygobites – they enter the « groundwater » accidentally and provide hotspots of allochthonous food. Only under those circumstances do even aquifer-bound organisms reach higher densities which they would never reach in those sections of the aquifer not cut open. This may also be the case in many caves with high populations of bats bringing in nutrients and carbon, or with dynamic watercourses entering from the surface. However, such caves and surface springs are rarely used for drinking water production, for the reason that they are indeed sensitive to pollution. At springs, you drink the water flowing out of the rock, i.e. only seconds after it saw light – you do not drink the water from the spring pool, in which debris floats. Drinking water production from river sediments is called "bank-filtered drinking water" (e.g. Schubert, 2002) versus drinking water from groundwater, although in both cases the water is subsurface. Completely different organisms and processes are involved.

We clarified what we need by « groundwater », particularly used for drinking water production, in the introduction: "*Such purification takes time and is only possible in groundwater flowing slowly (probably maximum 1 m per day) through sediments or fractures with small pore sizes. In this contribution, we focus on such relatively deep and relatively old groundwater, i.e. not the subsurface water in continuous exchange with the surface and the atmosphere.*" (Lines 38-41).

The example which in our opinion underlines this separation of subsurface surface water representing the hyporheos versus the longer term aquifer water with stygobite assemblages is situated in a 60 km^2 catchment. The groundwater / surface water gradients showed virtually no overlap between subsurface in-stream fauna and fauna in wells just a few meters away (L and W transects in Schmidt et al., 2007a, b). At another transect in the same catchment (S transect), stream sediments were populated while no fauna was found in four upgradient groundwater wells during monthly sampling over a whole year. While this catchment is of course not representative of

groundwater wells the world over, it remains one of the most detailed and longest-running studies of groundwater/ surface water gradients. To us, it seems to suggest that subsurface fauna in stream sediments might be merely that: subsurface. But when the subsurface is physically and chemically driven by the surface water, and not so much by groundwater, the inhabiting fauna should in our opinion not be called "groundwater" fauna but hyporheic fauna. There is no argument why fauna that is adapted to live permanently under the sand and stones and vegetation as stygophile in a surface water body, should not be blind and devoid of pigmentation. Thus, blindness and low pigmentation is not necessarily a marker for a "true" groundwater taxon or stygobites, but for its life cycle taking place hidden from irradiation, i.e. permanently subsurface. Since we do not see a convincing way to distinguish subsurface 'groundwater' fauna in streams from 'groundwater' fauna in wells just a few meters apart, when they are taxonomically and mostly also visually morphologically clearly different from each other, we prefer to make the distinction between the very surface-influenced hyporheos as a habitat for stygophiles, and at the same time distinct from the aquifer zone that is largely not influenced by exchange with the surface, as a habitat for stygobites. There are of course sites in gaining streams in groundwater upwelling sections (Winter, 2000) where the hyporheos underneath a surface water body is more driven by the surfacing groundwater than by surface water. In that case, actual groundwater fauna will be found in stream or river sediments. But until it is physically, chemically, and hydrologically indicated to show such strong upwelling, and ideally a continuum of taxa from groundwater to stream sediments, I would always assume the subsurface fauna in stream sediments to be hyporheic, i.e. blind permanently subsurface stream fauna, rather than groundwater stygobite fauna.

We are happy to continue this discussion, maybe elsewhere.

L. 146: There are also contrasting findings, for example Di Cicco et al. (2023) Journal of Thermal Biology.

Thank you for pointing out this paper obviously still missing from introduction and discussion. Di Cicco et al. (2023) point out that "groundwater is a thermally stable environment". Concurrent with our lengthy explanations of our viewpoint of stygophiles' versus stygobites' habitats above, groundwater with a thermal stable environment cannot be close to the surface and cannot be in intense exchange with the surface, as the hyporheos is. The hyporheos will show considerable variation in temperature, even if dampened compared with surface temperatures (e.g. Schmidt et al., 2006, Fig. 3). A stable temperature is an indicator for aquifer groundwater and is usually only found at a considerable distance from the surface in water of an age older than days or even weeks.

The authors of this study say that "*Niphargus longicaudatus* is a complex of groundwater obligate amphipod cryptic species with one of the broadest geographic ranges among the genus, being found in Corsica, Italy, the eastern Adriatic coast and Greece (Barnard and Barnard, 1983), its geographic range spanning over 1500 km (Lefebure et al., 2007; Borko et al., 2023)."

If it is a cryptic species, it is possible that it actually consists really of several species for which the species-specific characteristics have not yet been found. The wide distribution could be one indicator for several species hiding under one name. It is possible, even if not very likely, that the studied specimens showing the wide temperature tolerance were a mixture of species. However, this is of course only one possibility of many.

We added the sentence: "*However, the groundwater taxon* Niphargus longicaudatus*, with a wide geographic distribution, showed a wide temperature range in laboratory experiments (Di Cicco et al., 2023)"*. (Lines 145 f.)

Material & Methods

Generally, I am not very experienced with modelling approaches as the one applied here and thus cannot comment in detail. Yet, the derivation of the underlying modelling parameters and the process model seem to be in detail explained and documented in the Supplement. Maybe include somewhere in the text the size of the study area or the maximum distance among two sampling sites. It is theoretically visible in Fig. 1 from the scale, but I think it is good to be transparent about the data coming from wells that are all extremely close to each other.

We added the sentence "*The size of the studied region was 3 km^2 (Marxsen et al., 2021), with the distances among wells ranging from 100 to 2028 m from each other.*" in the methods section (Lines 219f.).

The complete distance matrix in meters is shown below. If the reviewer and editor deem it important, we will include it in the Supplementary Materials.

	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32	P33
	Distance [m]																																
P01		170	100	739	543	442	555	338	128	289	304	249	346	502	698	507	889	1053	725	544	731	340	377	204	407	452	661	569	792	1081	949	749	945
P02	170		251	882	702	612	669	471	291	455	438	290	349	557	755	487	803	910	618	443	574	237	217	185	434	329	590	439	622	923	1106	850	1061
P03	100	251		730	517	380	579	356	134	209	204	199	305	423	615	467	878	1083	730	551	779	362	436	302	486	551	758	667	863	1127	919	778	960
P04	739	882	730		233	451	272	412	613	598	762	919	1026	1058	1196	1181	1607	1790	1458	1278	1455	1078	1099	751	617	980	952	1073	1466	1803	267	288	296
P05	543	702	517	233		220	280	265	415	366	530	698	803	825	963	955	1387	1595	1247	1068	1273	875	917	604	545	863	906	969	1312	1623	406	425	516
P06	442	612	380	451	220		453	317	329	182	329	528	626	616	745	767	1207	1456	1086	912	1158	738	813	572	607	847	962	962	1234	1506	570	628	736
P07	555	669	579	272	280	453		223	446	523	680	778	884	972	1140	1046	1444	1577	1276	1096	1230	889	880	513	348	718	682	806	1218	1572	539	200	392
P08	338	471	356	412	265	317	223		224	323	469	555	661	755	929	823	1226	1381	1063	882	1043	677	687	346	296	598	657	704	1060	1391	649	422	607
P09	128	291	134	613	415	329	446	224		208	292	332	438	550	736	600	1004	1181	846	665	858	465	503	252	375	525	685	642	911	1208	821	644	830
P10	289	455	209	598	366	182	523	323	208		165	347	446	463	618	591	1029	1276	904	730	983	559	645	458	564	729	892	846	1072	1329	747	718	863
P11	304	438	204	762	530	329	680	469	292	165		229	310	298	461	440	882	1161	774	610	897	467	587	505	667	752	960	868	1017	1234	899	878	1028
P12	249	290	199	919	698	528	778	555	332	347	229		107	268	467	268	689	935	557	386	669	242	378	431	654	618	875	725	801	1004	1092	976	1157
P13	346	349	305	1026	803	626	884	661	438	446	310	107		230	418	162	584	854	465	303	616	214	374	511	746	665	939	765	774	938	1193	1082	1264
P14	502	557	423	1058	825	616	972	755	550	463	298	268	230		199	231	647	1001	596	476	815	442	603	696	907	884	1143	987	993	1112	1179	1171	1326
P15	698	755	615	1196	963	745	1140	929	736	618	461	467	418	199		359	678	1083	686	609	952	622	785	894	1100	1080	1341	1182	1150	1217	1284	1336	1475
P16	507	487	467	1181	955	767	1046	823	600	591	440	268	162	231	359		443	770	365	252	596	290	449	661	901	782	1069	870	791	882	1337	1244	1425
P17	889	803	878	1607	1387	1207	1444	1226	1004	1029	882	689	584	647	678	443		441	206	360	508	566	647	987	1235	999	1299	1046	743	614	1776	1637	1833
P18	1053	910	1083	1790	1595	1456	1577	1381	1181	1276	1161	935	854	1001	1083	770	441		405	552	359	722	697	1068	1292	960	1229	957	509	191	2000	1749	1966
P19	725	618	730	1458	1247	1086	1276	1063	846	904	774	557	465	596	686	365	206	405		181	326	388	446	799	1046	794	1093	840	562	531	1646	1464	1668
P20	544	443	551	1278	1068	912	1096	882	665	730	610	386	303	476	609	252	360	552	181		344	208	297	627	875	655	956	719	548	640	1469	1285	1487
P21	731	574	779	1455	1273	1158	1230	1043	858	983	897	669	616	815	952	596	508	359	326	344		430	357	717	935	602	879	608	237	350	1678	1396	1616
P22	340	237	362	1078	875	738	889	677	465	559	467	242	214	442	622	290	566	722	388	208	430		163	422	671	495	788	580	564	772	1280	1077	1281
P23	377	217	436	1099	917	813	880	687	503	645	587	378	374	603	785	449	647	697	446	297	357	163		373	610	359	659	429	431	706	1322	1054	1270
P24	204	185	302	751	604	572	513	346	252	458	505	431	511	696	894	661	987	1068	799	627	717	422	373		249	275	457	391	715	1059	995	682	899
P25	407	434	486	617	545	607	348	296	375	564	667	654	746	907	1100	901	1235	1292	1046	875	935	671	610	249		377	363	459	889	1263	881	472	698
P26	452	329	551	980	863	847	718	598	525	729	752	618	665	884	1080	782	999	960	794	655	602	495	359	275	377		301	117	518	906	1237	848	1074
P27	661	590	758	952	906	962	682	657	685	892	960	875	939	1143	1341	1069	1299	1229	1093	956	879	788	659	457	363	301		272	745	1148	1220	743	960
P28	569	439	667	1073	969	962	806	704	642	846	868	725	765	987	1182	870	1046	957	840	719	608	580	429	391	459	117	272		479	880	1334	919	1145
P29	792	622	863	1466	1312	1234	1218	1060	911	1072	1017	801	774	993	1150	791	743	509	562	548	237	564	431	715	889	518	745	479		403	1709	1361	1587
P30	1081	923	1127	1803	1623	1506	1572	1391	1208	1329	1234	1004	938	1112	1217	882	614	191	531	640	350	772	706	1059	1263	906	1148	880	403		2028	1731	1954
P31	949	1106	919	267	406	570	539	649	821	747	899	1092	1193	1179	1284	1337	1776	2000	1646	1469	1678	1280	1322	995	881	1237	1220	1334	1709	2028		528	424
P32	749	850	778	288	425	628	200	422	644	718	878	976	1082	1171	1336	1244	1637	1749	1464	1285	1396	1077	1054	682	472	848	743	919	1361	1731	528		227
P33	945	1061	960	296	516	736	392	607	830	863	1028	1157	1264	1326	1475	1425	1833	1966	1668	1487	1616	1281	1270	899	698	1074	960	1145	1587	1954	424	227	
max.	**1081**	**1106**	**1127**	**1803**	**1623**	**1506**	**1577**	**1391**	**1208**	**1329**	**1234**	**1157**	**1264**	**1326**	**1475**	**1425**	**1833**	**2000**	**1668**	**1487**	**1678**	**1281**	**1322**	**1068**	**1292**	**1237**	**1341**	**1334**	**1709**	**2028**	**2028**	**1749**	**1966**
overall maximum [m]				2028																													

Supplement S3: Do you mean µm in the table (instead of µmm)?

Yes, indeed, of course it should all be µm. Thank you for spotting this! Now corrected.

Results

Fig. 2c: Why is the model so far off from the underlying data points at zone "P"? Or did I miss it in the text?

Indeed, this warrants more words. We added in the methods section: "*For BOC, the highest discrepancy between measured values and the modelled development, and the worst fit parameters, were found for the polluted zone "P".*" (Lines 334f.)

In the discussion, we changed one sentence and added one: " … *less of the biologically available carbon pool was taken up by microorganisms than was refilled from precipitation, physical breakdown, and import from the soil in the zones "M" and "A". In contrast, in the polluted zone "P", where measured values were as high as in zone "R", the modelled curve however approached 0 and did not rise visibly. One reason may be that the numbers of prokaryotes were high in the measured value, and were the highest in the model. Thus, similar amounts of carbon present in the area were taken up faster and to a higher degree in zone "P" by higher biomasses.*" (Lines 484 – 489).

Fig. 3: In such a graph I would usually expect some sort of confidence intervals.
If the line in Fig. 3 was fitting measured points, indeed, a confidence interval could or should be given. Fig. 3, however, is a 1D reduction of the multidimensional modelled pattern in Fig. 2. So, the 1D line is not about creating confidence in the model, but to show the overall trend of the respective model. At this point, the overall trend is independent of the measured data. We considered giving the first and last value of the modelled value development instead of the overall trend, but this would neglect whether the model started and ended at a minimum, maximum or rather average section of the modelled development and would not indicate the overall development. With this figure we do not want to show how well the model fits the data, because that was done by error measures given within individual plots in Fig. 2. Instead, Fig. 3 merely should indicate the overall trends, comparing the different model runs, in a more abstract way. If reviewer 3 is not convinced by this explanation, we had rather exclude Fig. 3 than splitting it into enough sub plots to show distinguishable "confidence" intervals.

Discussion
L. 416ff: "Thus, the choice and development of appropriate parameters is crucial but virtually impossible based on the available field and laboratory data without far-fetched assumptions. If the reference case is not appropriately parameterized, using it as a base for further scenarios is not reliable." This could be misunderstood as you considering your assumptions far-fetched. Maybe reformulate to something like "are to-date necessarily speculative"? Please re-check.

It is not completely wrong to call the assumptions "far-fetched" because we have so little indication on what would be a more trustworthy data base. However, these are to our knowledge the best data on which to start. Thank you for the proposed phrase which we now replaced the old one with, so that it now reads:
"*Thus, the choice and development of appropriate parameters is crucial but virtually impossible based on the available field and laboratory data and to-date have to necessarily remain speculative*." (Lines 468 ff.)

L. 423ff: This sounds more like methods than discussion to me.
We found it important to give the background for the ensuing discussion at this point again, but indeed, these two sentences are methods – the actual discussion only starts in the following paragraph. We moved these two sentences to the methods section, now Lines 261-263.

L. 550: "In many scenarios, including the "no fauna" scenarios of the "M" and "P" zones, BOC concentration increased, i.e. the remaining carbon increased, which is an indicator of a reduced ecosystem service." I recommend being more specific here. Do you mean that in many scenarios BOC increased over time in general (-> why?)? Or do you mean at reference

temperatures the "no fauna" compared to fauna scenarios had higher BOC in two out of four zones? But then I would not call that "many scenarios".

Yes, indeed, "many" was perhaps exaggerating a bit. We did not only mean the two out of four zones, but also three out of five scenarios or manipulations, compared to the reference case. Indeed, the "no fauna" scenarios in the "M" and "P" zones showed the strongest differences, compared to the temperature manipulations. Now, rephrased to: "*In some scenarios, including particularly the "no fauna" scenarios of the "M" and "P" zones, the trends through the modelled BOC concentration increased more than the reference scenario over the study period. In other words, based on the fitted trends, the remaining carbon increased, which is an indicator of a reduced ecosystem service.*"
(Lines 606 ff.)

Conclusion
L. 663 You write "lacking fauna increased remaining BOC up to 660-fold". Yet in the discussion (L. 508) it is written that the increase in BOC without fauna was up to more than 6.6-fold. This is a very large difference (and already pointed out by reviewer 1). Please check.

Thank you so much for picking up this repeated oversight - already pointed out the first time by Rev. 1. Unfortunately, when addressing the comment during the preparation of the first revision, I must have - without double checking - mistaken the former L. 553 for a place in a sub chapter that was deleted during the revision anyway. I now realize that the comment had been about the conclusion all the time - now corrected, of course.

L. 666 There is a very strong statement about how the lack of fauna will affect drinking water provision. But then followed by an explanation why the data used in the current analysis might not be representative. This is quite contrasting and I recommend the authors re-check and possibly revise their statement.

Thank you for pointing out this stark contrast. We changed the first two sentences of the last paragraph as follows: "*To address such hypotheses, particular efforts will have to be spent on the variables and parameters. Those used in this modelling exercise will have to be confirmed and adapted by more detailed field studies to ascertain transferability of the model to other regions, other biogeochemical conditions, and other resident fauna.*" (Lines 733ff.)

References (all references in the sentences cited from the main paper, i.e. given above in italics, can be found in the main paper)

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