RESPONSES TO REVIEWER 2
"Peatland development reconstruction and soil complex biological responses to permafrost thawing in Western Siberia"

Reviewer comments are black boxes, the authors responses are blue, and parts of the manuscript are *blue and italicized*.

General comments

The revised manuscript "Peatland development reconstruction and complex soil biological responses to permafrost thawing in Western Siberia" represents high-quality and original study addressing an important question of permafrost mire dynamics in Western Siberia of the last two centuries. This scientific question is relevant withing the scopes of BG journal. The authors present new paleoecological data and try to interpret them using original concepts. As a result, authors reach substantial conclusions on the dynamics of the studied permafrost mires revealing complex interactions among permafrost, fire regime, local surface wetness and vegetation. The dynamics is interpreted in the context of climate changes. The applied scientific methods and assumptions are valid and in most cases are clearly outlined. My main concern is that sometimes authors go beyond their results in the interpretations and conclusions (see my specific comments), but this can be easily corrected by more precise phrasing or by removal speculative parts (which are not numerous). The structure and the language of the manuscript can be also improved to more concise (see my specific comments). The same concerns the title and the abstract of the manuscript. I think that the manuscript can be accepted for publication after minor revisions.

We thank the reviewer for the positive and encouraging assessment of our manuscript. We are pleased that the reviewer finds the study to be of high quality and scientific relevance, and that the applied methods, data, and interpretations make meaningful contributions to understanding permafrost mire dynamics in Western Siberia.

We acknowledge the reviewer's concern that in a few instances our interpretations may go beyond the direct support of our results. We have carefully reviewed all relevant sections and revised the manuscript to ensure that our phrasing is more precise and that any speculative statements are clearly indicated as such or removed when not sufficiently supported. We have also addressed all specific comments in detail and made appropriate changes to improve the clarity, conciseness, and structure of the manuscript, including revisions to the title and abstract as suggested.

We appreciate the reviewer's constructive feedback, which has helped us improve the manuscript, and we hope that the revised version meets the expectations for publication in *Biogeosciences*.

Specific comments

Title "soil" is quite unexpected here. It would be better to stick to one term here permafrost soils or permafrost mires. I think the latter is more relevant to the study. The word "soil" can be completely removed from the title.

Thank you for this helpful suggestion. Following the reviewer's comment, the word “soil” will be removed from the title and other parts of the manuscript where “soil biological response” is mentioned.

Revised title:
Peatland development reconstruction and complex biological responses to permafrost thawing in Western Siberia

Abstract

“an increased abundance of fungal communities” I do not see such data in the ms.

We respectfully suggest retaining this statement in the abstract, as data from core Kh-K1 (Figure 5B) clearly show an increase in the abundance of *Microthyrium* type fungal fruit bodies (types HdV-8 and HdV-8B) starting after 1979 CE, with a more pronounced rise after 1985 CE continuing until around 2008 CE. These trends are described in the Results section (4.2.2 and 4.2.3) and further discussed in the Discussion (5.2).

“Our study reveals that thaw-induced terrain subsidence was remarkably subtle, yet it underscores the intricate and multifaceted nature of permafrost degradation, which may potentially lead to dramatic consequences.” This sentence is very general.

We agree that the original sentence was too general. To address this, we will revise the sentence to be more precise and informative, emphasizing the spatial variability and ecological complexity of thaw-induced terrain subsidence. The revised sentence will be incorporated into the abstract for greater clarity.

Revised part of the Abstract:
Our study reveals that thaw-induced terrain subsidence was subtle and spatially variable, yet these localized surface changes triggered complex hydrological, vegetational, and microbial responses highlighting the nonlinear and multifaceted nature of permafrost degradation.

Introduction

40 I do not really see the difference between these two ways. I think that you are trying to say that increased temperatures will lead to release of the organic materials either through it leaching/removal or decomposition. Why is this negative impact? Or negative for whom? It seems to be a positive relation, the greater the temperature the greater the loss of organic materials. Moreover, at 45-50 you say that increased temperatures lead to other changes in permafrost peatlands such as greater surface wetness and active layer thickness. Why are these effects are not counted in those “negative impacts”? I think that more precise phrases and structure of the introduction can easily solve the issue.

Since permafrost peatlands are very complex ecosystems, it is difficult to determine with certainty whether the impact of increasing air temperatures and related thawing will be positive or negative, and for how long. For example, as the reviewer mentioned, greater wetness was not accounted for as negative in our manuscript, since it is not entirely negative. Releasing additional water boosts plant productivity, as we mentioned in the further paragraph (line 72), but whether this enhanced productivity

will last, and for how long, remains uncertain. As Ogden et al. (2023) state in their study from northwestern Canada, greening in Arctic–Boreal regions was strongest where permafrost had recently thawed. However, this increase in plant productivity was not sustained with prolonged thaw, especially once the thaw exceeded rooting depth. Their results suggest that the positive effects of thaw on vegetation may be temporary and vary with the extent of active layer thickening. Another important factor influencing the positive/negative impact of permafrost thawing is the vegetation composition of post-thaw peatlands (shrub-dominated or graminoid-dominated), because this will also impact net CO_2 flux in peatlands (Gong et al., 2024).

In conclusion, we agree with the reviewer that it is not appropriate to clearly label the impact of temperature increase on permafrost peatlands as negative, since this oversimplifies the complexity of interactions within these ecosystems. The sentence about the impact of temperature increase on permafrost peatlands will be revised (see revised Introduction part below). We will also refrain from characterizing these impacts as positive or negative in the rest of the introduction given the complexity of the processes that take place in the permafrost peatlands ecosystems.

References:

Ogden, E. L., Cumming, S. G., Smith, S. L., Turetsky, M. R., and Baltzer, J. L.: Permafrost thaw induces short-term increase in vegetation productivity in northwestern Canada, Global Change Biology, 29, 5352–5366, https://doi.org/10.1111/gcb.16812, 2023.

Gong, Y., Wu, J., Roulet, N., Le, T. B., Ye, C., and Zhang, Q.: Vegetation composition regulates the interaction of warming and nitrogen deposition on net carbon dioxide uptake in a boreal peatland, Functional Ecology, 38, 417–428, https://doi.org/10.1111/1365-2435.14480, 2024.

Revised Introduction:

Increased temperatures impact permafrost peatlands by inducing permafrost thaw, which leads to the release of little decomposed organic matter, and by triggering the activation of anaerobic decay processes (Jeong et al., 2018; Karlsson et al., 2021). The microbial decomposition of accumulated peat contributes to an increase in carbon dioxide (CO_2) and methane (CH_4) emissions from peatlands, which have positive feedback in the climate system (Jeong et al., 2018).

60 “The surface of permafrost peatlands often consists of microhabitats” It is not clear for what kind of living organisms these microhabitats. Perhaps, it would be better to refer to them here as “complex surface topography”. And then explain why this topography represent different microhabitats.

We appreciate the suggestion and would like to clarify that the peatland surface is indeed composed of distinct microhabitats or microforms, commonly described in the literature as hummocks, lawns, hollows, and pools (Rydin et al., 2013; Belyea and Clymo, 2001). These microforms create different conditions based on microtopography, water table depth, oxygen availability, and nutrient levels. These environmental gradients, in turn, shape the composition of plant assemblages as well as the occurrence of diverse microorganisms, including testate amoebae (the focus of this study), microalgae, bacteria, and fungi. We acknowledge the suggestion to use *complex surface topography* and agree it captures the physical structure well. However, the term *microhabitats* is widely used in peatland ecology to emphasize the biological and ecological significance of these microforms in shaping organism communities and we would like to keep this term in our text.

References:
Belyea, L. R. and Clymo, R. S.: Feedback control of the rate of peat formation, Proc. R. Soc. Lond. B, 268, 1315–1321, https://doi.org/10.1098/rspb.2001.1665, 2001.
Rydin, H., Jeglum, J. K., and Bennett, K. D.: The Biology of Peatlands, OUP Oxford, 397 pp., 2013.

75 "Studied Khanymei permafrost peatlands are located between *greening*-dominated and *browning*-dominated zones of Western Siberia." It does seem like a right place for this sentence because the readers do not know anything yet about the study site.

We agree with the reviewer that this sentence introduces the study site too early, before providing sufficient background information. We have removed this sentence and replaced it with a more general statement about the transitional zone between *greening*-dominated and *browning*-dominated regions. This revised text still provides the broader geographical context of our study area while avoiding premature mention of the specific site. The study site itself is now introduced later in the manuscript, after the regional context is fully established.

Revised Introduction section:
The transitional zone between these greening-dominated and browning-dominated regions is of particular interest, as it may reflect early signals of ecosystem change. Our study focuses on the permafrost peatlands, located within this transitional zone, which may indicate that some parts of these peatlands have already surpassed the period of post-thaw beneficial enhanced plant productivity (Ogden et al., 2023; Phoenix and Bjerke, 2016).

Study area

115 "precipitation patterns have altered significantly" perhaps have been altered?

Thank you for pointing this out. We agree that "have been altered" is more appropriate in this context, and we will revise the sentence accordingly.

Material and methods

Figure 2. Please give more detained descriptions of the cores, otherwise it is not clear from which part of the mire they were extracted (the reader needs to go back to the text). Please, check the other figure legends as well.

To clarify the origin of the cores, we will update the caption for Figure 2 to include more detailed descriptions of the sampling locations (revised Figure 2 caption below). We will also modify the figure itself to include labels "A) peat plateau" and "B) lake edge" to improve readability and ensure consistency with other figures in the manuscript. Additionally, we will review the captions of all other figures and make similar adjustments where needed to enhance clarity.

Revised Figure 2 Caption:
Figure 2. Age–depth models based on radiocarbon dating for peat cores: A) Kh-K2 – peat plateau and B) Kh-K1 – lake edge. The dark and light blue areas represent the 68.3% and 95.4% confidence ranges of the model, respectively.

205 How the fresh sample volume was determined?

The fresh sample volume was consistent for all samples and set to 1 cm^3, as stated in the Methods section 3.1 (Coring and sediment sub-sampling).

215 "For the peat core, Kh-K1, four (Kh1-A-D) and for Kh-K2, six zones (Kh2-A-F) were distinguished and used in the result description." This sentence belongs to the Results section.

Thank you for this comment. We will remove the sentence from the Methods section and add it at the beginning of the Results section, where it better fits the context.

Added text at the beginning of the Results section:
This section presents the outcomes of the multi-proxy analyses of two peat cores, Kh-K1 (lake edge) and Kh-K2 (peat plateau). The results are organized according to stratigraphic zones identified based on changes in testate amoeba (TA) community structure and associated fluctuations in depth to water table (DWT). For the peat core Kh-K1, four zones (Kh1-A to Kh1-D) were distinguished, and for Kh-K2, six zones (Kh2-A to Kh2-F). These zones provide a framework for describing and interpreting past hydrological and ecological dynamics.

225 It is not clear why NMDS analysis was performed for one core only?

Thank you for raising this important point. We will add an explanation to the Methods section to clarify why NMDS analysis was performed only for the core Kh-K1. While both cores contribute to the overall reconstruction of peatland development, Kh-K1 captures a particularly dynamic and ecologically informative period, which we wanted to explore in greater detail using NMDS. In contrast, for core Kh-K2, our focus was on broader stratigraphic and compositional changes, and we felt that CONISS zonation was sufficient to present these patterns effectively. Since the manuscript is already quite extensive, we chose not to include an additional NMDS analysis in order to maintain clarity and focus.

Revised Method section:
The NMDS was performed only on core Kh-K1, as this core captures the most dynamic ecological transitions, and CONISS was considered sufficient for summarizing patterns in Kh-K2.

Results

240 Perhaps, it would be better to place the images of the unidentified testate amoeba to the supplementary materials, as this is not the main focus of the paper. I would recommend structuring the paragraph from the most reliable to the least reliable statements. It would be better to report the abundance and to interpret the hydrological preferences of well-known taxa first, and then mention the presence of the unidentified species. The reconstructed WTD should be reported after the description of testate amoeba assemblages. The same is for the descriptions of the other zones.

We understand that organizing the assemblage descriptions from more to less taxonomically resolved taxa is important for clarity. However, we decided to list species based on their relative abundance, and in our opinion relegating unidentified taxa (which are sometimes among the most abundant in key

periods of the record) to the end of this list would risk confusing the reader and disrupting the ecological narrative of the assemblages.
We agree with the reviewer that the zone descriptions need more transparent structure, and we will revise the descriptions of all zones so that: each zone starts with the testate amoeba assemblage (listed by relative abundance) and then the reconstructed depth to water table will be reported after the assemblage description, as it is derived from the species composition – see proposed changes on the example of the zone Kh2-A (4.1.1.)

Regarding the image of the unidentified testate amoeba, we believe it is important to retain this figure in the main text, rather than moving it to the supplementary material. This study relies on hydrological reconstruction based on testate amoebae, and the abundant presence of this morphotype during the thawing period is a significant and distinctive feature of the dataset. Providing the image will help future researchers recognize and compare this morphotype in similar palaeoecological contexts. Therefore, we consider it relevant to the core scientific message of the article.

Revised Results section (4.1.1. example)
In the first zone Kh2-A there is a dominance of Unknown TA_Khan, Difflugia pulex type, and the presence of Centropyxis aculeata type (Fig. 3A, Fig. 4) – indicators of wet conditions (Halaś et al., 2023). Bigger TA aperture size, higher shell biovolumes, and more spherical shells also suggest wet conditions. TA species with agglutinated shells are the most abundant in this zone. Based on TA, this zone was characterized by wet conditions, with DWT around 4 cm and a pH of 5.1.

"Wetter conditions favoured bigger TA aperture size, higher shell biovolume, and more spherical shells." The inversed logic here, because water conditions have been reconstructed on testate amoebae. You can say that the predominance of TA with large and spherical shells also indicate wet conditions.

We agree that the logic in the original sentence was misleading. We will revise this sentence, as well as similar ones in the Results section, to clarify that the predominance of specific testate amoebae traits is indicative of particular environmental conditions as given in an example in the previous comment.

"A less acidic pH (5.1) was reconstructed at the start of the record." Less acidic compared to what?

To avoid ambiguity, we will remove the phrase "less acidic" from the sentence and simply report the reconstructed pH value.

Revised sentence
Based on TA, this zone was characterized by wet conditions, with DWT around 4 cm and a pH of 5.1

330 "Peat plateaus with lichen-moss-shrub cover have been a characteristic feature of the Khanymei peatlands' landscape in recent years (Volkova et al., 2019)." This sentence seems to belong to Discussion.

We agree, this sentence will be removed form Results section.

Discussion

410 “During this period, the dominance of *Betula* pollen in the region confirmed moist conditions. *Betula* is a pioneer species that prefers wetter environments but is sensitive to both floods and droughts (Beck et al., 2016; Lanta and Hazukova, 2005).” I agree that birch is a pioneer species, but I am not sure that it can indicate moist conditions. Why do you think so?

We agree that the interpretation of *Betula* as an indicator of moist conditions is debatable. To avoid overinterpretation, we have decided to remove this sentence from the manuscript.

555 “releases additional moisture” Thawing permafrost can release additional water or increase substrate moisture

We agree that the phrasing could be more precise. The expression “releases additional moisture” will be revised to more accurately reflect that thawing permafrost increases peat moisture. This change will be implemented in the indicated location as well as in other instances throughout the manuscript where similar wording was used.

Revised sentence

Wetter conditions reconstructed on the peat plateau resulted from low-lying permafrost ~27 cm (Fig. 1D), which, during the thaw, increase peat moisture, influencing TA assemblages.

565 To my mind this paragraph is quite speculative and vague. I think it can be removed completely

We appreciate the reviewer’s comment and understand the concern regarding the speculative nature of this paragraph. However, we believe the observation of increased abundance of *Microthyrium* type fungal fruit bodies during the period of permafrost thaw and high *Sphagnum* spore production may offer a potentially meaningful ecological signal, even if the interpretation remains tentative. There is no consensus in the literature on a clear interpretation of increased spore production, and fungal fruits bodies are still poorly studied in paleoecology. Nevertheless, we would like to retain this paragraph as an indication of a possible ecological response worth noting and potentially exploring in future research. To address the reviewer’s concern, we have revised the paragraph to clarify its observational nature and to reduce speculative language. We now emphasize that the interpretation is cautious and that further research is needed to understand the role of fungal fruit bodies in peatland carbon dynamics.

Revised paragraph

Another important observation was that together with permafrost thawing we noted an increased abundance of several Microthyrium type fungal fruit bodies (type HdV-8 and HdV-8B) (Fig. 5B). In our study the highest abundance of HdV-8B fell in the period preceding the highest accumulation of peat and carbon but coincided with the greatest production of spores by Sphagnum. Given that fungi are involved in organic matter decomposition (Mitchell et al., 2003), this pattern may reflect a phase of active decomposition that preceded maximum peat accumulation. While we refrain from drawing firm conclusions, we consider this an intriguing signal that may warrant further investigation, particularly in light of the currently limited understanding of the ecological significance of these fungal remains.

610 “The described critical thawing zone (Fig. 8B) is dynamic and rapidly changing, and occurs in a small area most often perpendicular to the previously thawed and collapsed depression and is about 1-2 meters wide with much influence of lateral hydrological drainage (which is difficult to determine).” I do not any description of the critical zone in the text, it is just marked on the figure. Even from the figure I do not see that the zone is “perpendicular” to anything, so these spatial relationships are not persuasive for me. Overall this paragraph seems to be speculative. Are there any other studies, which would report similar patterns?

We thank the reviewer for pointing out the lack of textual description of the "critical thawing zone." We agree that the term “perpendicular” does not adequately describe the spatial relationship we intended to present. We will add a short description of this zone in subsection 5.2 and correct fragment in the subsection 5.3 (see below). We will also adjust the discussion to ensure consistency with the updated sections.

We acknowledge that our interpretation is based on reconstructions rather than direct observations. However, similar patterns of lateral degradation and marginal thaw have been documented in other studies. For example, Borge et al. (2017) showed that lateral erosion is a dominant pathway for degradation of peat plateaus and palsas in northern Norway, driven by thermal undercutting from adjacent standing water. Zuidhoff (2002) documented block erosion and edge-related thermokarst processes contributing to the rapid collapse of a palsa dome in Sweden. Likewise, Jones et al. (2016) found that 85% of forested permafrost plateau degradation in south-central Alaska occurred along lateral margins. These studies support our interpretation that lateral processes at the margins of thawed features are important contributors to ongoing permafrost degradation.

References:

Zuidhoff, F. S.: Recent decay of a single palsa in relation to weather conditions between 1996 and 2000 in Laivadalen, northern Sweden, Geografiska Annaler: Series A, Physical Geography, 84, 103–111, https://doi.org/10.1111/1468-0459.00164, 2002.

Borge, A. F., Westermann, S., Solheim, I., and Etzelmüller, B.: Strong degradation of palsas and peat plateaus in northern Norway during the last 60 years, The Cryosphere, 11, 1–16, https://doi.org/10.5194/tc-11-1-2017, 2017.

Jones, B. M., Baughman, C. A., Romanovsky, V. E., Parsekian, A. D., Babcock, E. L., Stephani, E., Jones, M. C., Grosse, G., and Berg, E. E.: Presence of rapidly degrading permafrost plateaus in south-central Alaska, The Cryosphere, 10, 26732692, https://doi.org/10.5194/tc-10-2673-2016, 2016.

Added description in subsection 5.2. - end of the paragraph (line 526)

These changes mostly occur in a lateral part of peat plateau, where data from the lake edge core (Kh1) allowed us to identify a critical thawing zone (Fig. 8B).

Corrected fragment of subsection 5.3.

The described critical thawing zone (Fig. 8B) is dynamic and rapidly changing and occurs in a small area most often parallel to the previously thawed and collapsed depression with much influence of lateral hydrological drainage (which is difficult to determine).

Technical corrections

180 Lycopodium should be in italic

Will be corrected in the text.