Dear Referee #2,

We sincerely thank you for the constructive assessment of our work. We also thank you for the feedback provided, especially for highlighting areas where the manuscript can be more informative.

We will include specific suggestions from Referee #2 in the text, though in this document we address some specific and technical comments in detail (note that missing comments will be directly corrected in the manuscript). Referee's comments are written in italics, and point-by-point responses are written in purple.

- General comment

This manuscript presents a multi-proxy palaeoecological record from a subalpine lake in the Pyrenean mountains. The authors combine pollen and charcoal analysis with a previously published sedaDNA record to reconstruct vegetation and fire dynamics for the last 12000 years, however their pollen analysis reaches back further. The combination of different proxies and the comparison with existing climate records allows the authors to discuss the different drivers of vegetation change and disentangle the impacts of climate and land use on the vegetation. They propose that cooling during the Neoglacial led to an opening of the vegetation, which was exacerbated by anthropogenic activities. Overall, the data is of high quality, the analyses support their statements, and the manuscript is well prepared. However, I do have some comments, suggestions and questions I would like the authors to address before publication.

We are grateful for the relevant comments that Referee #2 has made to our work. It has expanded our scope and helped us to produce a clearer version. We answer each suggestion in depth in the following lines.

- Geographical setting:

It would be interesting to expand the information regarding the geographical setting with information on today's temperatures (summer, winter, mean) and the altitude of the tree- and timberline. This would allow readers to better assess some of the discussed changes.

The timberline ecotone in the Upper Gállego Valley is situated at 1700-1800 m, and the treeline reaches 2000-2200 m. We agree with adding information about today's temperatures and the treeline and timberline.

- Methods comment 1:

It is unclear from the methods how the 5 sections (1U-5U) were assigned. It this purely based on changes in the lithofacies or was a statistical method used?

Sections 1U-5U were assigned according to the extraction operations using the UWITEC platform. This approach allows several sections to be extracted, penetrating the sediment 1.8 m at a time. In Tramacastilla, we could perform 5 extraction operations, obtaining 5 sections (1U-5U) that reached 9 m depth. We will include this information in the manuscript in order to enhance clarity.

- Methods comment 2:

Do you think that the sections 1U and 2U are the result of the damming of the lake?

Actually, we do not believe that sections 1U and 2U are the result of the damming of the lake, as the damming happened in 1956, and both sections reach about 800 m. However, the damming could have caused the sediment of those sections to mix, and so would be the cause of the absence of an accurate chronology.

- Methods comment 3:

You describe the creation of a master core, but based on the rest of the results it seems you stayed on one core drive for the pollen and charcoal analysis and used the other core drive for the sedaDNA analysis. Did you use the parallel drives (TRAM21-1A and TRAM20-1A) at all for core correlation and master core building?

Due to the lack of some parts of the sediment in the parallel drives (TRAM20-1A and TRAM21-1A), we finally did not create a master core. We will delete that part from the manuscript.

- Methods comment 4 (line 383) and line 215:

In Line 383 you mention a hiatus in the lower section of your cores, but this hiatus is not clear in any of the figures, nor modelled in your age-depth model. I would recommend including the hiatus in your bacon model, if you are sure, it is there. As that would create a better agedepth model. Furthermore, in some of the figures in the supplemental material, the hiatus is included in the age/depth axis, but in the manuscript it is never. […]

Do you think the lake wasn't frozen for most of the time before the period 22-15 ka BP? Also, this interpretation is in stark contrast with the later mentioning/interpretation of a hiatus for this section of your core. Please stick to one interpretation, either a hiatus or low sedimentation rates. Then all the figures, discussion, but also supplemental figures should reflect the final interpretation.

Thank you for the meaningful comments. We agree that both interpretations are contradictory, so we will stick to one of them, giving coherence to the data.

- Methods comment 5:

Could you clearly specify for which section of the core (xxx cm- xxx cm) you constructed the age-depth model?

We conducted the age-depth model for the sediment between 390 and 880 cm. We will include this information in the manuscript to enhance clarity.

- Methods comment 6 and comment in results:

Why did you choose to date bulk samples? Where there no terrestrial plant macrofossils available? […]

Did you also consider using proxies such as conifer stomata or macrofossil analysis? Especially conifer stomata could have been analysed on the same slides as the pollen analysis and could confirm the local presence of conifer trees.

We dated bulk samples as the sediment lack of any terrestrial plant macrofossils. We will include this specification in the manuscript.

In fact, no conifer stomata nor plant macrofossils were found in Tramacastilla lacustrine sediment, though it would have been interesting to be able to study them.

- Methods comment 7:

Table 1: I would add some additional info to the table including the calibrated age range of the 95% confidence interval, plus the mean or median calibrated age.

We are grateful for this relevant comment regarding dating information. We will include everything in Table 1, as it will enhance the clarity of the table.

- Methods comment 10:

Is the charcoal analysis contiguous? Would be nice to mention.

Yes, charcoal analyses were performed in 202 continuous samples. We will include that for clarification in the text.

- Line 191:

It is interesting you have indications for low lake levels, as I would expect the lake levels to be much higher due to the damming of the lake. Do you have an explanation for this?

It is true that after the damming, the depth of the lake increased from 4 to 13.5 meters. Indeed, low lake levels do not correspond to the period after damming, but for the period between 800 BP and the damming.

- Comment on Figure 4:

Why is this figure not plotted on age, it would make it much easier for the readers to see when things are happening? If you would prefer to plot on depth, could you at least add an age axis.

It would also be nice to add a summary diagram, so changes in trees, shrub and herb vegetation are easier to see.

We would prefer to keep the results' figures in depth rather than age, as it retains the core reference as a geological sediment. We will add an age axis on Figures 2 and 4.

Regarding the summary diagram, we fully understand its potential usefulness. We will include that summary diagram in Figure 4.

- Comment on Figure 5:

Maybe you could add some more labels to this graph. For example, that e and f are coniferous trees, g and h deciduous species. I would also show the results for domesticated animals from the sedaDNA here. It would enhance your discussion. In the text a chironomid temperature reconstruction is mentioned. Maybe this could be shown as well?

We believe that adding labels would not enhance the clarity of the figure. Indeed, note that e and f are not only coniferous trees, but include *Fagus*. Regarding animal *sed*aDNA, we thank you for that valuable insight. We will include it, as long as this addition does not reduce its clarity or makes the figure more complex. Note that the chironomid temperature reconstruction does not correspond to Tramacastilla lake, but to Basa de la Mora. Besides, some data are missing in that record, so we believe Mendukilo temperature reconstruction is more useful in Figure 5, and widely refer to in the text.

- Line 349:

You mentioned that the low taxonomic resolution of pollen analysis could lead to an overestimation of human impact on the landscape, and you use the example of Plantago, which I don't think is a good example. It is possible to distinguish several Plantago pollen types including Plantago lanceolata type, which is a strong indicator of anthropogenic impact (see Beug 2004, Behre et al. 2023).

Thank you for your meaningful comment. We will replace that Plantago example with Trifolium type.

- Lines 359-363:

They hypothesis that excrement from animals could bring DNA into the lake is interesting, but I can't imagine this to be a large contributor to the sedaDNA signal. Are there any studies that have shown a contribution of excrement to the sedaDNA signal in a lake? To further study this hypothesis the inclusion of dung fungal spores in the palynological analysis would be very valuable. Increases in dung fungal spores such as Sporormiella would show if there was an increase in herbivory around the lake, and if this is related to change in herbs/grasses. Furthermore, it is not surprising there is a difference between Poaceae pollen and Poaceae sedaDNA representation. Poaceae pollen are wind-pollinated, very abundant and always well represented in pollen records, whereas grass biomass is usually not very high and Poaceae do not seem to work so well with sedaDNA metabarcoding.

We acknowledge that excrements from animals are unlikely to be a major source of the *sed*aDNA signal. We are not aware of studies that directly quantify this contribution, and we have therefore reframed this point more cautiously, presenting it only as a secondary possibility.

We also agree that coprophilous fungal spores (e.g., Sporormiella) would be highly valuable for assessing herbivory. Regrettably, this analysis falls outside the scope of the present revision, but we have explicitly noted it as a promising avenue for future research.

Regarding the Poaceae discrepancy, we fully agree with the reviewer's explanation and will clarify this point in the revised text.

- Lines 366-375:

Did you also look at the modern surface sample (pollen and sedaDNA) to better understand the connection between the pollen, sedaDNA and vegetation? This could help with understanding the results.

We agree that it would be very interesting to look at the modern surface sample. However, we were not able to carry out that analysis. We will consider to do it in the future.

- Line 403:

You mention the plant communities were not very diverse during the Late Glacial. Did you think about calculating richness for the sedaDNA and the pollen, that could have been a nice addition to the discussion about plant diversity. Do you think it is possible for the Late Glacial vegetation to also have a rich herbaceous vegetation composition? Some sites in the Alps do suggest this (e.g. van Vugt et al. 2022).

Thank you for your meaningful comment. While plant diversity analysis would add valuable insight to our data, we believe it is beyond the scope of this manuscript. However, we will consider it for further research. Regarding Late Glacial richness, we do not believe that herbaceous vegetation was richer during the Late Glacial compared to the Late Holocene (ca. 4 ka BP). However, it could be greater during that period compared to the Early Holocene, when dense forests were dominant.

- Lines 454-460:

Could continentality have played a role in the Betula and Corylus dynamics? In the Alps the dominance of Corylus during the Early Holocene is often related to high summer insolation and continentality (e.g. Aregger et al. 2025).

Actually, we had previously consider that explanation. However, similar vegetation dynamics of *Betula* and *Corylus* were found in Basa de la Mora (Pérez-Sanz et al., 2013), a place with higher continental influence. Besides, a different situation was found in nearby Portalet (González-Sampériz et al., 2006), which is located in the same valley than Tramacastilla and thus has similar climate. This evidence led us hypothesise that local environmental features were responsible for those differences in *Betula* and *Corylus* dynamics.

- Lines 473-476:

Couldn't differences in dispersal also lead to this pattern. The winged fruits of Betula are more easily dispersed than the heavy hazel nuts of Corylus.

We are grateful for the meaningful comment. Indeed, dispersal differences could explain the different patterns between *Betula* and *Corylus*. We will include it in the text.

- Line 483-484:

So ground fires instead of crown fires?

Thank you for the detailed term. We will include this specification in the text.

- Lines 518-521:

Could the pollen or sedaDNA data even record hunting activities. The anthropogenic taxa are not related to hunting activities, but show arable and pastoral farming.

Actually, we do not know whether there are ways of discerning hunting from other human-related activities through pollen or *sed*aDNA data. However, hunting practices at that time would not have a considerable impact on ecosystems, as archaeological evidence point to a low impact of hunter-gatherers groups.

- Lines 549-552:

Where is the treeline today? Do you see any indications for a lowering of the treeline? Or are there any records from region that looked at treeline ecotone dynamics?

The treeline currently reaches 2000-2200 m asl. The absence of plant macrofossils prevents us from reconstructing treeline ecotone dynamics, and no studies from the valley have focused on that question. However, it would be interesting to explore it through different approaches, and we will consider it for future research.

- Line 568-571:

People could also have opened the niche for Abies and Fagus?

As we mentioned in the manuscript, we believe that natural climatic conditions (supported by the known biogeography of both taxa) initially triggered the expansion of both *Abies* and *Fagus*. After it, anthropogenic activities may have subsequently facilitated their spread, providing a competitive advantage over previously dominant taxa. No evidence was found that pointed to human activities initially triggering *Abies* and *Fagus* expansion, and other Pyrenean sequences record similar chronologies for their expansion, supporting the idea of climate as the main responsible of it.

- Comment on Figure 7:

Would it be possible to also plot the charcoal records for the records? So it's nicer to see the vegetation-fire dynamics?

Thank you for pointing that out. We will include charcoal records from all the records plotted in Figure 7, so a better idea of regional vegetation and fire dynamics.

- Comment on discussion sections:

The subchapters of the discussion are called greelandian, northgrippian etc. but in the text Early Holocene, Mid Holocene etc. is used. Is there a particular reason to switch between these different names?

There is no particular reason for using different names. We will unify the terms so as not to cause confusion.

- Line 45:

I have never heard of transterminance, is this the same as transhumance?

Transterminance is defined as the pastoral mobility only in altitude, while trashumance is long-distance pastoral mobility. This is a strategy used in mountain ecosystems in order to take advantage of subalpine and alpine pasturelands during summer (Carrer and Migliavacca, 2019; García-Ruiz et al., 2020).

- Line 341:

Pollen can be extra-local to regional, depending on catchment size. What do you think is the pollen catchment for Tramacastilla?

Considering the catchment area of Tramacastilla lake, we think the pollen reconstruction corresponds to local rather than regional scale. However, it will always have a more regional scale compared to *sed*aDNA vegetation reconstruction.

References

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