

Referee #1

We are extremely grateful for the comments provided, which have led to a considerable improvement of the current manuscript, and have contributed to enhancing its clarity, scientific rigor and scope.

In general, we will include the references mentioned in various parts of the manuscript, as well as the suggestions made by the reviewer regarding typographical and grammatical errors in the text. In this document, we answer to specific and technical comments in detail, with especial emphasis on some of them. *In this document, referee's comments are written in italics, and point-by-point responses are written in purple.*

- General comment:

This manuscript presents a novel multiproxy palaeoecological record from a high-elevation lake located on the southern slope of the Pyrenees, which combines pollen, charcoal and sedaDNA to reconstruct vegetation changes and their drivers during the Lateglacial and the Holocene. The main novelty is the integration of the previously published sedaDNA dataset with the more "classic" palynological record. The fire regime reconstruction of the local fire regime based on the peak detection analysis adds further value to this study. The combination of datasets allows a novel interpretation of the landscape transformation at high elevation in the Pyrenees during the second half of the Holocene that proposes that human intervention was a major driver but was strongly supported by changing climatic conditions associated with the Neoglacial. I consider that the manuscript is overall well prepared, the data are complete and valuable and the discussion of the results is comprehensive and interesting to a broad audience. However, I also have some comments, suggestions, questions and concerns that the authors may consider before their manuscript is published. I provide them in an annotated pdf version of the manuscript that I attach.

We would like to express our sincere gratitude to the referee for your insightful and encouraging comments on our manuscript. We believe that the modifications derived from the comments will help to improve the quality of the work.

- Line 11:

Do you mean short- and long-range transhumance and other forms of livestock management? Some of them have been very important but have been declining for the past few decades.

It is true that, over the last century, the Pyrenees have seen a significant decline in traditional practices. We will include this detail in the abstract.

- Line 16:

Check the timing, because I would say that the Neoglacial mostly extends over the Late Holocene.

We will specify we refer to the initial phase of the Neoglacial period, that started ca. 6 ka BP, according to García-Ruiz et al. (2020a), as it is true that the Neoglacial extends over the Late Holocene.

- Line 46, comment in the word "transterminance":

This is a loan from Spanish, in English "short-distance transhumance" or "short-range transhumance" are commoner.

We coincide that others terms such as “short-distance transhumance” or “short-range transhumance” are commoner. However, we would like to keep the original, as we feel it is more adequate to what we are referring to, and follows the same criteria as García-Ruiz et al. (2020b), where they use the term “transterminance”.

- Line 82:

What about Abies and Fagus forests? These taxa are abundant in some sections of the palaeobotanical record and it would be good to mention which role they play in present-day vegetation.

We will include a sentence talking about current distribution of *Abies* and *Fagus* forests, that are of great importance in the palaeoecological record.

- Line 84:

I was wondering whether the authors could provide an indication of the elevations of the current timberline (or forest line) and treeline ecotone so the readers have a better idea of the local vegetation.

The timberline ecotone in the Upper Gállego Valley is situated at 2200-2300 m, and the treeline reaches 2700 m. We will include this information in the manuscript.

- Line 102:

Please, specify which are the mentioned sedimentary features. Do the authors have an explanation for this?

Uppermost sections (1U and 2U) from selected cores displayed sediments that are a product of high-energy depositional processes without in-lake organic production that may include reworked organic material into the sediment, resulting in a non-coherent chronology. We will include this information in the manuscript.

- Lines 107 and 336:

Line 107: *Did the authors search for terrestrial plant macrofossils? Bulk can be problematic even if the bedrock is not calcareous.*

Line 336: *plant macrofossil analysis and/or the identification and quantification of conifer stomata would have added great value to the palaeoecological record discussed here. These proxies would have enabled assessing the local presence of tree taxa in the catchment, allowing inferring shifts in the treeline and timberline position, for instance.*

In this regard, we appreciate the suggestion, as it would have been interesting to analyse plant macrofossils and/or conifer stomata. However, the absence of any of these remains prevented us from carrying out these analyses. Consequently, we based radiocarbon dates on bulk samples.

- Comments on table 1:

The authors may consider following Stuiver and Polach (1977) to round the radiocarbon dates [...]

Probability distributions of calibrated radiocarbon dates do not follow a normal distribution. Therefore, I recommend to indicate the 95% confidence interval and the median or the mean of such distribution. That would mean adding another column to the table [...]

Additionally, the authors may add another column showing the "Age in the figures", which would be that assigned to the corresponding depth from the age-depth model.

We are grateful for these relevant comments regarding dating information. We will include everything in Table 1.

- Line 123:

Did the authors try to identify and quantify spores of coprophilous fungi as indicators of grazing (by wild or domestic ungulates)?

We agree that this is an important question. Regrettably, this analysis falls outside the scope of the present manuscript, but we will consider it for future research.

- Line 143:

Asteraceae is a huge family and each of the listed pollen taxa includes species living in very different habitats, not just in steppe-like grasslands [...] Same with Caryophyllaceae.

We agree that both are big and complex families. However, we would like to keep that classification, as we followed pollen classification from González-Sampériz et al. (2006), that is focused on El Portalet record, and is the nearest sequence from Tramacastilla.

- Comment on Figure 2:

Here and elsewhere: Perhaps it enhances visualisation and is more correct (please, see my comment in the radiocarbon dates table) to add a secondary Y axis showing the age (obtained from the age-depth model).

Thanks for the valuable insight. We will include an age scale in both Figures 2 and 4.

- Comment on Figure 5:

I would suggest the authors to add the most relevant information got from sedaDNA concerning livestock, as it is an important topic in the Discussion section.

Indeed, animal sedaDNA information is widely referred to in the text. We will include that information in Figure 5, as long as this addition does not reduce its clarity or makes it more complex.

- Line 349:

Precisely Plantago is not the best example, because several well characterised pollen types have been described within this genus (check for instance The Northwest European Pollen Flora or Beug).

Thank you for the meaningful comment. We will replace that example with *Trifolium* type.

- Line 359:

Well, Poaceae pollen is produced in high loads and transported by the wind, that is why it is one of the most abundant herbaceous pollen types in most European records.

Indeed, what we wanted to point out in that sections is that we would have expected the representation of Poaceae pollen and sedaDNA to be more equivalent, as animal excrements would result in an over-representation of palatable plants in the sedaDNA record. The little difference between both analysis discards this idea.

- Line 411, on "Pllan d'Estan":

Typo, revise.

We appreciate the detail, although we confirm it is not a mistake, as that is the local name to refer to the area.

- Line 413:

Two of the records referred are from the Cantabrian Range, where the influence of the Mediterranean Sea must have been quite limited compared to the North Atlantic. I would rather look in this direction.

We thank you for the meaningful comment, and will look for more cites that support our results.

- Line 461 (in “continuous though not frequent fires”):

I am not sure that I understand what the authors mean; please check.

Thanks for the appreciation. We will change this part in the manuscript, with: “regular low intensity fires”.

- Line 469:

The connection between these two processes I am afraid is not clearly made here. Forest expansion during the Early Holocene also happened in other areas of Central Europe where glacial refugia were not particularly close. I am not questioning that glacial refugia were located nearby, but the evidence presented here is not conclusive in that regard.

We thank the reviewer for this perceptive observation. We agree that rapid forest expansion during the Early Holocene is not in itself conclusive evidence for the proximity of glacial refugia, as similar patterns are observed in regions of Central Europe that lack nearby refugial areas. Our intention was not to present the forest expansion as proof of refugia, but rather to note that the observed pattern is consistent with the hypothesis of regional refugia previously proposed for this area. We will revise the text to make this distinction clearer and to avoid any over-interpretation of our data.

- Line 547:

This explanation seems plausible, and similar to what apparently happened with agricultural practices at the beginning of the Neolithic on the Eastern Mediterranean (please, see van Vugt et al.'s publications). However, I would recommend the authors to avoid overstatements given the evidence presented. Actually, I miss a summary pollen diagram in both percentages and accumulation where one can get a better idea of the shifts in the abundances of trees, shrubs and upland herbs. In the figures shown in the manuscript, I am not fully able to assess such changes adequately.

Thank you for your thoughtful comments and for the suggestion to consider the parallels with the Eastern Mediterranean Neolithic. We also appreciate your caution regarding overstatements. We will carefully re-read the final paragraph of our discussion and take you point that some phrasing could be perceived as too assertive. We have therefore revised the text throughout to ensure that our interpretation is presented with the appropriate degree of caution, avoiding any suggestion of definitive causal links and making it clear that our data are consistent with, rather than conclusive proof of, the proposed scenario. We trust that these adjustments adequately address your concern.

Regarding your request for a summary pollen diagram showing trees, shrubs, and herbs, we fully understand its potential usefulness. We will include that summary in Figure 4.

- Line 560:

Well, Abies was actually disfavoured by human activities in many areas of Europe, you may look at Tinner et al. (2013) Ecol. Monogr., Henne et al. (2013) Landscape Ecol. or Morales-Molino et al. (2021) Ecosystems.

We thank you for pointing out this important nuance regarding the effects of human activities on *Abies*. We were aware that the evidence is not unanimous, and we agree that in many regions of Europe *Abies* was indeed disadvantaged by anthropogenic disturbances. We will therefore incorporate the references you suggested into the revised manuscript, and we will nuance our phrasing to better reflect this complexity.

References

- García-Ruiz, J.M., Palacios, D., Andrés, N., López-Moreno, J.I., 2020a. Neoglaciation in the Spanish Pyrenees: a multiproxy challenge. *Mediterranean Geoscience Reviews* 2, 21–36. doi:10.1007/s42990-020-00022-9
- García-Ruiz, J.M., Tomás-Faci, G., Diarte-Blasco, P., Montes, L., Domingo, R., Sebastián, M., Lasanta, T., González-Sampériz, P., López-Moreno, J.I., Arnáez, J., Beguería, S., 2020b. Transhumance and long-term deforestation in the subalpine belt of the central Spanish Pyrenees: An interdisciplinary approach. *CATENA* 195, 104744. doi:10.1016/j.catena.2020.104744
- González-Sampériz, P., Valero-Garcés, B.L., Moreno, A., Jalut, G., García-Ruiz, J.M., Martí-Bono, C., Delgado-Huertas, A., Navas, A., Otto, T., Dedoubat, J.J., 2006. Climate variability in the Spanish Pyrenees during the last 30,000 yr revealed by the El Portalet sequence. *Quaternary Research* 66, 38–52. doi:10.1016/j.yqres.2006.02.004