Dear Referee #1, we thank you a lot for very constructive suggestions. In the following we response (in bold) to all of your detailed comments (in italics).

Although this is a good methodological exercise, the objectives, methodological implications of this study are not clear to me. I believe the main purpose when applying Bayesian statistics to perform an age-depth model is to combine as much chronological and stratigraphic information as possible to get the best dating and probabilistic estimates of age uncertainties. According to that, the conclusions of the study i) all the Bayesian models improve the accuracy and precision of previous age estimates and ii) Method D (the one which includes more detailed chronological and stratigraphic information) is the best approach, were fairly predictable results. On the other hand, if the main objective is to transfer an existing chronology to a new composite sediment profile as indicated in the title, the high-resolution stratigraphic correlation using marker layers should be enough, especially in varved sediments.

Our study compares different methods to integrate radiocarbon dates and varve-dated marker layers using a Bayesian approach with the Bacon package. However, we did not conclude that all of the presented models improve accuracy and precision of the previously published varve chronology VT-99 (i), especially not in the youngest part and in parts with less radiocarbon ages (as shown by Model D, section 3). We also disagree, that the good performance of Model D was predictable (ii), as Model B, C and D contain varve information and radiocarbon ages merged in different ways.

Holzmaar is one of the best studied varved records in the world and ongoing studies of these sediments (e.g. Garcia et al., 2022) are an example of the use of new methodological approaches in palaeolimnology with potential for significant impact on regional palaeoenvironmental and palaeoclimate research. I strongly support the publication of a new improved and robust chronology for this site but, in my opinion, the manuscript needs some changes in the structure and content before publication. Below are my suggestions:

(1) I really think the manuscript would benefit from a better description of the objectives and I propose two options to do so that, I hope, can help:

Option 1 (the most sensible to me). The main goal is to improve the existing Holzmaar chronology and to transfer it to the new composite profile. In this case, I would focus on a better description of the correlation between the old and new composite profiles. I miss a figure showing the two composite profiles with the position of the marker layers, radiocarbon dates, tephra layer and prior information used in Method D. I would focus on the comparison of the VT-99 chronology, the radiocarbon chronology (Method A) and the integrated Bayesian chronology (Method D) and I would discuss the new chronology (Method D) reporting age uncertainties and new age estimates for the LST, UMT and climatic transitions based on Method D as described in Section 3.2.4. This information might be relevant for other researchers working on this region.

Option 2. The main goal is to discuss the best approach for Bayesian age-depth modelling in varved sediments in general and Holzmaar in particular. This option implies additional work. I would suggest a comparison of Method D in Bacon with a Bayesian age-depth model in Oxcal using the same chronological information. This would allow discussing the pros and cons of the two approaches for varved sediments, which would be a significant contribution to the community.

Thank you for these two options, which we appreciate. We agree with the need for a figure showing the composite profiles from before and after applying the Bayesian modelling. The aim of our study was to compare different varve and radiocarbon integration methods, to find the best way of adapting and updating an existing varve chronology to a new profile. We are aware of the highly specialized topic of this research, but we strongly believe that in the future more projects will face situations like this. Therefore, we do not agree excluding any of the tested approaches here, because only this approach allows future researcher to compare their data directly instead of testing them for their own and once again. We completely agree with OxCal being an additional option. In our case, we want to give an overview of the different approaches using Bacon. A comparison of OxCal with Bacon was in our minds. However, implementing this into our study would increase the size of the manuscript distinctly.

Therefore, we will implement a new figure comparing HZM-B/C with HZM19 that shows the marker layer positions, depths of radiocarbon ages, tephras and other chronological markers used in our study. However, we prefer not to change our general approach. Additional arguments are presented below.

(2) The structure of the manuscript needs improvements as follows:

Introduction: the introduction does not provide sufficient background information to understand the issue addressed and the significance of this study. I found the missed information in other parts of the manuscript though, so I think this is just to move some paragraph into this section.

We appreciate your thoughtful suggestions and address each individual point as followed:

- *Paragraph 1, 2 and 3 (line 37-61) need to be supported by references.*

  We agree with your suggestion and will add more references (highlighted in yellow) to lines 37-61:

  "Terrestrial archives from lakes have the potential to provide information about climate and the human history of its catchment area beyond instrumental and historical data (Berglund, 1986; Last and Smol, 2001a, b; Cohen, 2003). In the late 1980s, gravity coring (Kelts et al., 1986) piston coring (Nesje et al., 1987; Wright et al., 1984) and freeze coring techniques (Renberg and Hansson, 1993) for lacustrine sediment records have improved tremendously allowing a better quality of sediments to be recovered from modern lakes. Since then, the new fields of limnogeology and paleolimnology flourished with increasing demand of societies for documentation of natural background data related to questions around acid rain (e.g. Battarbee et al., 1990), environmental pollution (e.g. Renberg et al., 1994) and more and more with a focus on global climate change (e.g. Jenny et al., 2019).

To provide such information not only on local scales but also on larger regional to global scales, investigations from different sites need to be compared and linked. However, such correlations are only successful if the contributing archives are based on robust chronologies. Therefore, precise and reliable age-depth models are the basis for sedimentary investigations and reconstructions of environmental and climatic changes of the past, as they ensure intra-site comparability and enable recognition of larger scale patterns. A reliable chronology should be based on a combination of different dating techniques (multiple dating approach) such as radiometric dating, well-known events such as tephra layers (Turkey and Lowe, 2001), historic data (e.g., flood events) or varve counting. The term "varve" (Swedish: layer) was first introduced by De Geer (1912) for outcrops with proglacial sediments and describes finely laminated sediment structures with annual origin. The alternating pale and dark layers are driven by seasonal changes in temperature and precipitation that cause different chemical and biological processes within the lake and its catchment area. When anoxic conditions at the sediment-water-interface are given at least seasonally, i.e. no bioturbation destroys laminations, varves are preserved and provide high-resolution and precise chronologies in calendar years (Zolitschka et al., 2015; Lamoureux, 2001).

Until the 1980s, varve chronologies were the only option for calendar-year chronologies for sediment records, while AMS radiocarbon dating was still in its infancy and calibration of radiocarbon ages was restricted to tree rings of the Middle and Late Holocene, if at all applied (Pearson et al., 1977; Olsson, 1986).“

- *Sub-subection 2.3.4 "Bayesian age-depth modelling" (in varved sediments?) should be added to the Introduction (line 65). And after that, I would add the sentence in line 94-99. I would provide more details about the main reasons to choose Bacon based on the information about Bacon and Oxcal you give in sub-subsection 2.3.4.*

We agree of rearranging these chapters, but will implement it in line 71 instead of 65. We include the first part (lines 239-264) of chapter 2.3.4, as the remaining part contains too detailed information for an introduction. We attached lines 94-99 to the end of it and added more details about our decision as followed:

"In this study, we focus on varve-counting integration methods using Bacon (rBacon version 2.5.7; Blaauw et al., 2021; Blaauw and Christen, 2011) for the R programming language (version 4.1.1; R Core Team, 2021), as it is one of the most often used software package in paleo studies and provides many different ways for implementing information."

After lines 94-99 we continue:

“As Bacon provides many different options to incorporate information into the age-depth model, in the literature only few approaches are provided integrating varve and radiocarbon ages (Bonk et al., 2021; Vandergoes et al., 2018; Shanahan et al., 2012). For that reason, we summarize these approaches and compare them directly with each other. This will lead to faster decisions for future studies facing a comparable situation.”

- *Information provided in line 70 -82 is duplicated in Section 2.3.1. I suggest to removed it from the introduction.*

We agree and removed it from the introduction.

- *Aims and Objectives are not clear (see comment 1 above)*

Thank you for this clarification. We added our aims and objectives by formulating the last part of the introduction as follows (line 100-107):

“The aim of our study is to transfer and optimize the existing varve chronology from HZM-B/C to the new sediment record HZM19. In addition, we offer an overview about different approaches for age-depth modelling and their effects on model outcomes to researchers who face comparable challenges, thus supporting their decision making.

For this reason, we discuss the possibilities of integrating and improving the chronology by combining the varve chronology with modelling approaches using Bacon. This is accomplished by testing and comparing integration methods with regard to accuracy and precision obtained from the interpolated varve chronology itself and from a Bayesian model without any varve information relying on radiocarbon dates only.

With this integration of all age information we produce the most reliable age estimations for the HZM19 record: VT-22. Based on this best model outcome, this master chronology of VT-22 serves as the chronological backbone for ongoing and future biological, geochemical and geophysical investigations conducted with the new Holzmaar sediment cores (e.g. García et al., 2022).

Material and Methods:

- *Subsection 2.1 “Regional Settings” should be under an independent section. I suggest a new Section 2 on “Regional settings and the Holzmaar sediment record”. which includes (1) the current subsection 2.1 “Regional settings”, (2) subsection 2.2. “Holzmaar lithology” where you provide information about the published lithology from old cores (Zolitscka 1998 a and b) as described in subsection 3.1. And (3) Subsection 2.3 “Previous Holzmaar chronology” which corresponds to the current su-subsection 2.3.1. Material and Methods would be Section 3 then.*

We completely agree with the rearrangement of these chapters and adapted them as suggested. The new chapter structure will be as followed: … -

2. Regional setting and the Holzmaar sediment record
- **2.1 Regional setting**
- **2.2 Holzmaar lithology**
- **2.3 Previous Holzmaar chronology**

3. Materials and Methods
- **3.1 Sediment core collection**
- **3.2 Chronology**
  - **3.2.1 Pb-210 and Cs-137 dating**
  - **3.2.2 Bayesian age-depth modelling**

4. Results and Interpretation
- **4.1 Transfer of VT-99 to HZM19**
- **4.2 Pb-210 and Cs-137 dating**
- **4.3 Age-depth modelling**
- **4.4 Comparison of model output with VT-99**
- **4.5 Comparison of model output with the common isochrones**

… (as before).

- *Line 152: please provide information of the length of the cores, how many parallel cores you collected, distance between them and the sediment depths they cover.*

We provided the requested information as follows:

"The coring locations are distributed evenly along a 12 m-long transect with 4 to 4.4 m distance between coring locations. The recovered sediment cores have lengths of 2 m (HZM19-07, -08, -10) and 3 m (HZM19-11), which have been split in the field into 1 and 1.5 m-long sections, respectively. In total, HZM19-07 covers a sediment depth of 15.5 m (0-15.5 m), while the other sites provided different depth ranges: HZM19-08 (0.25 – 10 m), HZM19-10 (4 – 14 m) and HZM19-11 (1 – 19 m)."

- *Line 157: please say how many marker layers you have used for correlation*

For correlation of the cores we used 48 distinct correlation marker layers. We will include this number into line 157 and include a table with related sections depths into the appendix.

- *I would say that Sub-subsection 2.3.2 "Transfer of VT-99 to HZM19" should be part of the results.*

We agree and added subsection 2.3.2 to the result section (see above).

- *Line 265-266. Reference is needed.*

We added four different examples from the literature providing methods of varve and radiocarbon integration with Bayesian modelling approaches: Bonk et al., 2021; Vandergoes et al., 2018; Shanahan et al., 2012; Fortin et al., 2019

Results and Interpretation:

- *It makes more sense to me that the lithozones are described as previous work (see my comment above re a new Section 2). Subsection 3.1 should focus on the correlation of the HZM 99 and HZM 19 composite profile and the transfer of the varve chronology (current subsection 2.3.2). It would be good to see in a figure the two composite profile, the stratigraphic position of the marker layers, radiocarbon dates, hiatus, etc and both the VT-99 varve age-depth profile and a 14C chronology.*

We completely agree with this suggestion. With the new structure (see above), the Results and Interpretation will become chapter 4. Thus, chapter 4.1 will focus on the transfer and correlation of VT-99 from the old cores as recommended. To achieve this, we combined previous chapters 2.3.2 "Transfer of VT-99 to HZM19" and 3.2.2 "Varve time and independent chronology". We will also add a figure to supplementary material showing the old composite sediment profile HZM-B/C and the new HZM19 together with positions of marker layers:

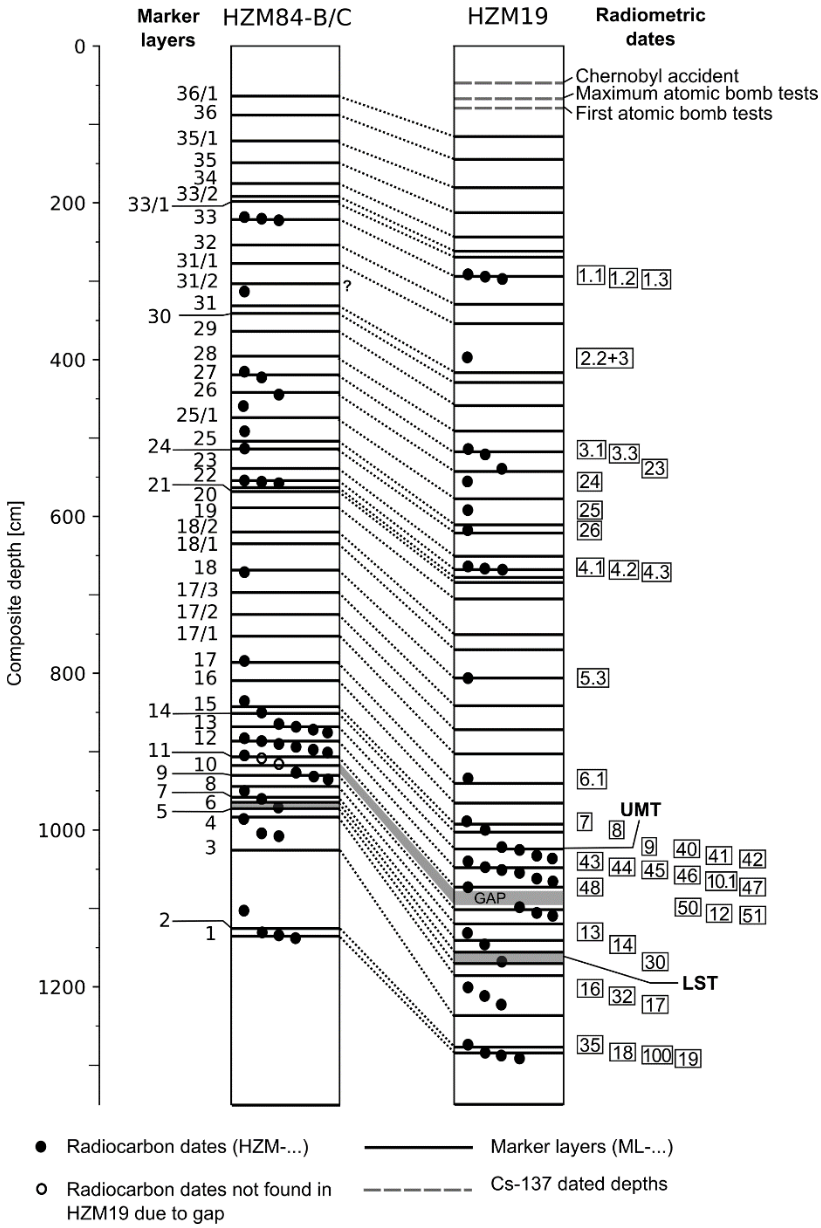

Figure A1: Correlation of HZM84-B/C and HZM19. Positions of marker layers (ML indicated to the left) are marked as solid lines and connected by dotted lines between both profiles. Positions of radiocarbon dates (numbers indicated in rectangular *boxes to the right) are marked as solid circles. Grey dotted horizontal lines refer to Cs-137 dated depths. Positions of Ulmener Maar Tephra (UMT), Laacher See Tephra (LST) and the technical gap are indicated.*

- *I would call subsection 3.2 "New chronological information" and make sub-subsection 3.2.3 and new subsection 3.3 "Age-depth modelling".*

Due to the rearrangement of chapters mentioned above, chapter 4.2 will "4. 2 Pb-210 and Cs-137 dating".

- *Sub-subsection 3.2.4 and sub-subsection 3.2.5 should be subsection 3.5 and 3.4, respectively. Foucssing on Method D only (I would delete Mehod B and C from the manuscript), first describe the improvements in dating and age uncertainty using the best Bayesian model (Method D) with respect to the varve chronology (VT-99) and radiocarbon chronology (Method A) (using the text in sub-subsection 3.2.5). Second, report new age estimates for the tephra layers. As these tephra layers, especially the LST, have been used for synchronising records and the estimation of the duration on the YD in different European sites (e.g Wulf et al., 2013), a revised age estimate with a reduced age uncertainty from HZM might be very useful.*

We rearranged the chapters to: 4.4 Comparison of the model output with VT-99 and 4.5 Comparison of model output with the common isochrones. We do not exclude Model B and C for reasons mentions above. We agree with the statement that tephra layers are very important chronological marker layers for several studies in related fields. However, we incorporated the latest LST age estimation into the calculation for all models. Thus, our date is very close to the published age by Reinig et al., 2021. As we used this age for our modelling, the new LST age is not independent. We reported our outcome for both tephra layers but will focus on the age difference between both isochrones. This was also recommended by Reviewer #2.

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