Dipartimento di
Scienze Agrarie,
Forestali e Alimentari

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To whom it may concern

Review Report on the PhD Thesis titled:

A millennium-long blue ring record in bristlecone pine (*Pinus longaeva* D.K. Bailey) - establishment and paleoclimatic interpretation

PhD Candidate

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Supervisors

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Overview

This PhD thesis significantly advances palaeoclimatology through its detailed exploration of blue rings (BRs) in Bristlecone pine as sensitive indicators of past climatic conditions, specifically late-season cooling events and volcanic cooling. The thesis situates BRs as a more accurate and nuanced proxy for reconstructing short-term climate variability, particularly cooling episodes induced by volcanic eruptions, than traditional tree-ring methods. The research emphasises the limitations of conventional dendroclimatological methods such as tree ring widths (TRW) and maximum latewood density (MXD) and argues that BRs can complement these traditional proxies, offering more precise insights into ephemeral cooling events.

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Structure and Clarity

The thesis is well-structured, presenting its findings in two articles. The first focuses on BR classification and its relation to thermal and topographic factors, while the second examines the relationship between BRs and volcanic eruptions. The text is clear and logically organised, allowing readers to follow the complex interplay between climatic factors and BR formation. The conclusions are well-supported by a large dataset and rigorous statistical analyses, enhancing the credibility of the findings.

I have some specific comments I would like to raise the attention of the PhD candite to:

1. From the introduction of the thesis (especially from the first paragraph on page 16 and the first paragraph on page 18), I get the impression that external and internal factors affecting BR formation are treated in a somehow disconnected way. Instead, the ecophysiological link between what happens outside and inside the plant is strong, bounding our understanding of the causes and processes leading to the formation of BR in conifers. In this respect, there is no evidence that a BR is a "response" (line 8, page 18) to "external conditions" (i.e. low temperature) and not an adaptation to cold.

2. From both the first and second papers, it needs to be clear that Frost Rings (FRs) and BRs result from two completely different mechanisms; therefore, they show different signals. FRs are morphological disruptions of newly formed tracheids and ray cells. In contrast, BRs result from a lack of lignin deposition due to the disruptions of the long chain of events that starts with hormone production at the leaf level and ends with cell wall lignification after some intermediate steps occurring outside and inside the lignifying cell. Can this explain why "BRs provide earlier evidence of cooling onset than RWs due to their ability to capture cooling episodes after the radial growth phase in a particular year is complete." (Page 83)?

3. I am puzzled by the sentence, "As Bristlecone pine is highly adapted for survival in its marginal habitat" (page 37) because no species is ever highly adapted to a marginal habitat. All species are adapted to their optional climatic niche, which fades towards margins where the species still thrives.

4. "Because all cores used in this study came from mature trees" cannot be an explanation for why the study did not underline "any relationship between juvenility and an increased probability of BR formation" (page 38). This is because cores from mature trees (should have) also included a "juvenile" part.

5. The use of the distance to the (current) tree line is a confusing variable because, over the period covered by the study (almost 2000 years), the (potential) tree line fluctuated up and downhill.

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Methodological Strengths

The study's methodology is robust and meticulously detailed. The dataset includes 83 tree cores spanning nearly two millennia, with 57,816 rings pictured and analysed. Statistical modelling is used to explore the factors influencing BR formation, such as temperature and topography, which offers a comprehensive understanding of how these interact. Using generalised linear mixed-effects models to assess climatic influences is appropriate and ensures that conclusions are statistically sound.

Additionally, the classification of BRs into four intensity levels based on the degree of under-lignification provides a detailed framework for understanding the variability in BR formation. Extensive data and careful visual analysis of stained tree-ring Bristlecone pine samples support this classification for this species. The possibility to apply the BRs classification to other conifer species remains to be tested.

Key Findings

1. BRs as Indicators of Cooling: BRs are shown to form in response to temperature drops in specific months, particularly September. However, the research also reveals a more complex interaction between multiple months (April, June, August, February, and October) and BR formation. This multidimensional approach enriches our understanding of how BRs form and opens new research questions.

2. Topography and BR Formation: The findings highlight that elevation and proximity to the upper tree line significantly influence the occurrence and intensity of BRs, with fewer and weaker BRs appearing at lower elevations. Although the discussion of this finding could have been broader, it underscores the importance of sampling across diverse topographical settings for more accurate climate reconstructions.

3. Volcanic Eruptions and Cooling: The analysis demonstrates a strong correlation between volcanic eruptions and BR formation, with a significant percentage of BR events matching volcanic sulphate signals from ice cores within a three-year window. This supports the thesis claim that BRs can serve as early indicators of volcanic cooling, often appearing before sulfur deposition in ice cores.

4. BRs vs. Frost Rings: The study concludes that BRs are more sensitive than latewood frost rings (LWFRs) to less intense and later-season cooling episodes, offering a more detailed record of past climate variability.

Areas for Improvement

While the thesis is comprehensive and methodologically sound, there are a few areas that could benefit from further exploration:

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1. Microsite Variability: The discussion around microsite-induced temperature variations could be expanded. Although microsite conditions influence BR formation, their role remains somewhat speculative in this study due to the spatial resolution of the temperature data used. Further research could further explore these dynamics to clarify their role in BR formation.

2. Temporal Resolution and Climate Models: While the thesis successfully correlates BRs with volcanic events, additional integration with climate models would enhance the temporal precision of these correlations. More explicit comparisons with existing paleoclimate reconstructions could illustrate how BRs improve the accuracy of climate predictions, particularly regarding volcanic cooling.

Implications for Future Research

The findings open several new avenues for research. The potential of BRs as indicators of abrupt, short-term cooling events, particularly those not captured by TRW and MXD, suggests that future studies should incorporate BRs into broader paleoclimatic reconstructions. The complex interplay between temperature, elevation, and BR formation indicates that more high-resolution studies are needed across various elevations and geographical regions. The thesis highlights some new research avenues, which, even if focusing only on Bristlecone pine, are research questions to be explored by the scientific community. This call to action could have been addressed to the research community instead of emphasising what the author would do next.

Conclusion

This PhD thesis makes a valuable and innovative contribution to palaeoclimatology by confirming blue rings as a sensitive and reliable proxy for past cooling events. The research is thorough and methodologically rigorous and presents clear evidence that BRs can enhance our understanding of short-term climate variability, particularly volcanic activity. While there are areas for future exploration, the thesis sets a strong foundation for further studies on BRs and their role in dendroclimatological research. Overall, this work is a significant step in improving paleoclimate reconstructions' accuracy and resolution.

I suggest that the candidate be allowed to proceed to the next steps in the procedure, which will result in a doctoral degree.

Yours sincerely,

Prof. Dr Alan Crivellaro