

## REVISION 2 - Joanna L. Corimanya

Dear reviewer, thank you for your valuable revision and insightful comments. We have carefully considered your feedback and tried our best to address each point accordingly. On behalf of the authors,

Lorena Baglioni

The manuscript presents a valuable and timely contribution to the study of forestline dynamics in mountain ecosystems under the influence of climate and land use change. The authors propose an automated, reproducible method to detect the uppermost forestlines in the Alps and Apennines, and evaluate long-term trends in greenness and wetness using Landsat time-series and the Contextual Mann-Kendall (CMK) test. The combination of robust spatial datasets, a long temporal window (1984–2023), and a detailed comparison of canopy cover classes adds substantial weight to the conclusions. The literature review is quite thorough, and the flexibility and scalability of the proposed method enhances its utility across global mountain ranges. In addition, the integration of multiple spectral indices (NDVI, EVI, NDMI, TCW, etc.) offers a nuanced perspective on ecological processes such as tree encroachment and canopy densification.

### Major revisions:

The manuscript would benefit from a careful linguistic edit. There are numerous typographical and grammatical errors (e.g., "threfore", "rispectively", "forestline uo ti 200 m") that impede readability. Sentence structure could be simplified in some sections for clarity and flow.

Thank you for your suggestions. We edited the manuscript according to your useful indications

While the methodological design is sound, a more explicit discussion of the sources of uncertainty (e.g., compositing effects, spatial mismatch between TCD and Landsat, potential overestimation of greening trends due to observation frequency) would improve the robustness of the conclusions.

Here we discussed some points you have mentioned.

- **Compositing effects:**

At lines 160-162 we added the following text: *"We preferred the medoid compositing technique over traditional compositing approaches because it is more robust to outliers and noise. In fact, it consists of the closest value to the median"*.

- **Spatial mismatch between TCD and Landsat:**

We considered the TCD for i) the forestlines detection and ii) the definition of the canopy cover class of each greenness and wetness trend points during the spectral analysis. In both cases, the spatial mismatch between TCD and Landsat did not affect our analysis. Infact, the detection was independent from the Landsat time series and we analysed spectral trends along a spatial buffer after the definition of the forestlines. In addition, we assigned the canopy cover classes resampling the TCD to 30 m of spatial resolution. A possible spatial mismatch between the Landsat pixel and the modified TCD should not have affected the following analyses as we did not consider the absolute value of canopy cover, but we assigned a class to each point within a range.

At lines 203 -204 we added the following text: *“Because of the large canopy cover classes ranges to which the points were allocated taking into account a mean TCD value, a possible spatial mismatch between the resampled TCD and the Landsat data was ignored”*.

- **Potential overestimation of greening trends due to observation frequency:**

The use of the medoid as a reducer of the values sampled each year during the growing season enable us to minimise overestimation. In fact, the influence of possible outliers along each pixel-based time series was limited and the most representative value among those sampled was considered (as already pointed out in lines 160-162 for the “Compositing effects” discussion). Pixels with missing values for several consecutive years in the time series were not considered and therefore did not affect the trend analysis.

A risk of overestimation has been assessed in the use of the maximum seasonal NDVI as greening proxy (Bayle et al. 2024), but we did not adopt it.

The authors correctly report that GAMs relating TAU values to elevation and forestline distance were not statistically significant. However, this result could be better contextualized—what does this imply about the spatial consistency or heterogeneity of trends?

The elevation and forestline distance were not statistically significant drivers of greenness and wetness trends for both the Italian mountain ranges. This result is probably due to a combination of topographic, climatic and anthropogenic drivers that must be considered to assess which are the main ones of these spectral trends, considering the relevant environmental differences between the Alps and the Apennines discussed in the study area section.

We added this information in the revised manuscript.

**Minor revisions:**

Line 15: Should say “carried out,” instead of, “carried on.”

Corrected.

Line 16: I am not sure what is meant by “..and avoided to fix..” Please clarify.

We clarified the sentence. We did not use a predefined minimum elevation threshold for the forestlines detecting method, because other mountain chains can have different altitudinal ranges. For this reason, an established threshold could have affected the replicability in different geographic contexts.

Line 22: There is an extra space between ‘respectively’ and ‘in’.

Corrected.

Line 29: Remove paragraph break.

Removed.

Line 40: Begin a new paragraph at “The ongoing development of remote.”

Begun.

Line 43: Remove ‘an’.

Removed.

Line 44: Should be 'treeline monitoring' instead of 'treelines monitoring'.

Corrected.

Line 44: The authors should mention the strengths of aerial photography as well, similarly to how they describe the strengths and weaknesses of other methods. For example, aerial photography allows for broader temporal scales compared to satellite-based remote sensing.

We changed the text as follows (lines 42-44): *"At the local scale, aerial photography is commonly used (Ameztegui et al., 2016; Hansson et al., 2020; Nguyen et al., 2024) since it provides older images than satellite ones, although image quality and availability are limiting factors (Morley et al., 2018)."*

Line 57: The clarity of this sentence could be improved with a rewrite. I would suggest changing the sentence to, *"..and to study alpine treelines by applying greening proxies like vegetation indices."*

We have modified as suggested.

Line 60: A comment appears to be left in by mistake? Remove sentence of a different font color which states, *"Fare clic o toccare qui per immettere il testo."*

Removed.

Line 68: Spelling error. 'Overcaming' should be 'overcoming'.

Corrected.

Line 75: Change 'photosintetic' to 'photosynthetic'.

Corrected.

Line 78: 'This' should be 'these'.

It refers to "kind".

Line 87: 'Forestlines' should be 'forestline'.

Corrected.

Line 97: Remove paragraph break.

Removed.

Line 98: This sentence should be rewritten for clarity. I suggest, *"..while wetness indices are better for detecting gap-filling processes by intercepting the the spectral signal of lower leaf strata."*

We have corrected as suggested.

Line 104: Remove one of the periods after 'SE'.

Removed.

Line 105: Should be 'ranges' not 'range'.

Modified.

Line 107: Change 'and/or' to 'and'

Modified.

Line 108: Should be 'ranges' not 'range'.

Modified.

Line 109: Should be 'elevations' not 'elevation'.

Modified.

Line 113: Remove 'A' from, "Alps and Athe Apennines."

Removed.

Line 118: Fix typo in 'affected'.

Corrected.

Line 121: 'Others' should be 'other'.

Amended.

Line 122: Remove 'of'.

Removed.

Lines 133 - 134: Rewrite the sentence for clarity and grammar.

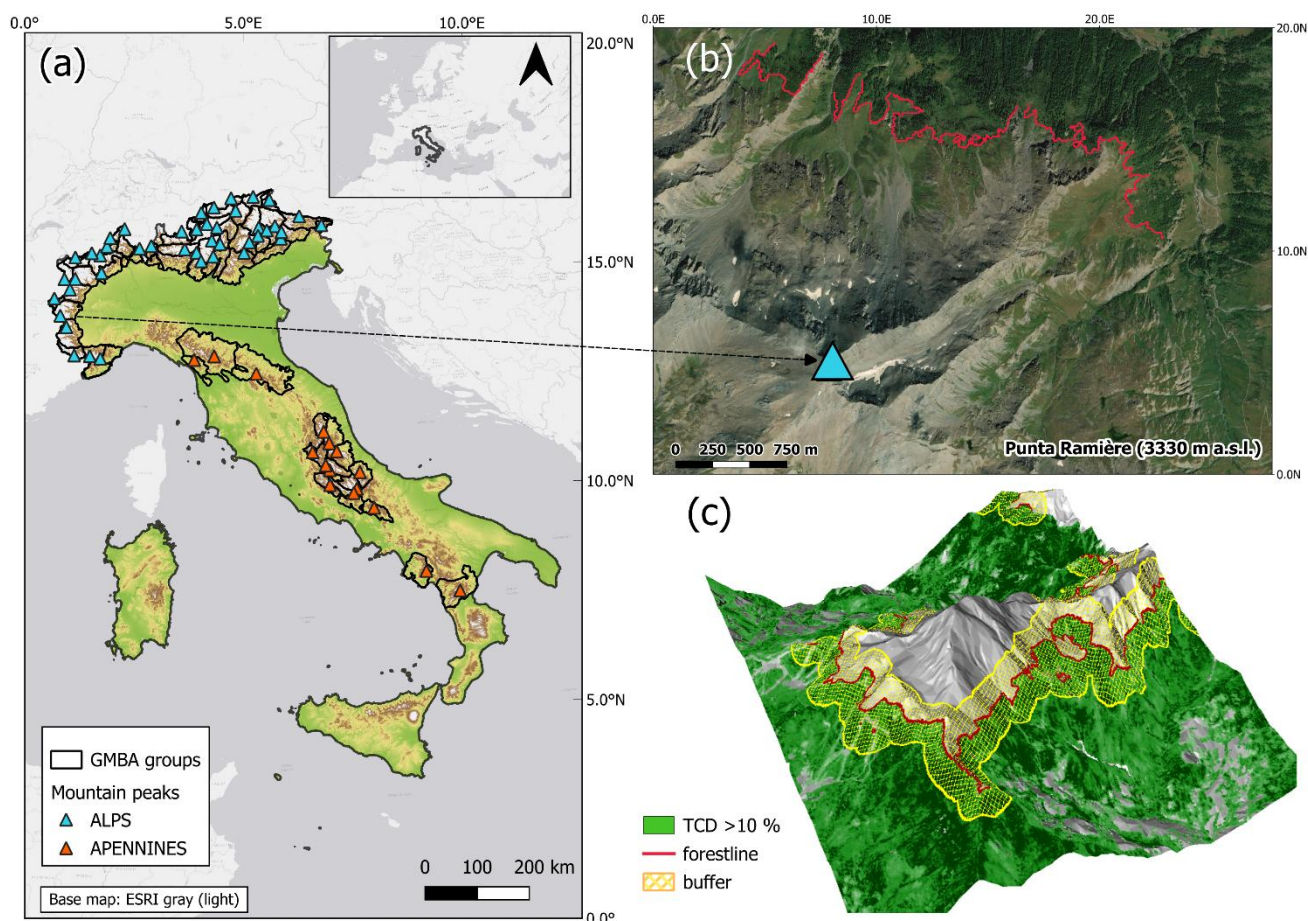
We modified as follows: "We avoided a minimum elevation threshold for the forestlines detection to facilitate the replicability of the method in geographic regions with different altitudinal ranges."

Line 138: Are the points every 10m? If so, authors should increase clarity by stating the points are at 10m intervals instead of 10m distance.

We modified the sentence as suggested.

Figure 1 (c): Yellow is difficult to read in legend. I suggest changing to a different color to indicate the buffer.

We changed it to a dark yellow.



Line 178: Explicitly state the predictor variable(s) that were compared with greenness and wetness to evaluate significance.

The significance (p-value) is not referred to a predictor variable of the detected trends. In the CMK trend test, the p-value of each pixel represents the probability of observing a significant trend in the analysed time series.

Line 195-196: The authors would benefit from increased clarity and specificity in this sentence. Why did they choose two sets of only 40 points? Or is it two sets of 40,000 points, and there is a typographic error? How were the points randomly sampled? Are these different points than the points discussed earlier in the paragraph? Splitting this up into two sentences and providing more detail will greatly improve the readability of the manuscript.

Yes, thank you for pointing out the error. We sampled 40,000 trend points for each mountain range and it is a subset of the previously described points. We modified the sentence as follow: "After this characterisation of the trend points, we randomly sampled two sets of 40,000 points for each mountain range by the "slice\_sample()" function of the "dplyr" R package (Wickham et al., 2023). Each set contained an equal number of greenness and wetness significant trend points."

Line 196: 'a' should be 'an'.

Corrected.

Figure 3: This diagram is excellent! It is very thorough and communicates the analysis well.

Thank you, we enjoyed that you appreciated this diagram.

Line 297: There is an extra space before 'Italian'.

Amended.

Line 297: 'emisphere' should be 'hemisphere'.

Amended.

Line 305: 'forestlines' should be 'forestline'.

Lines 311 - 312: Clarity would improve by rewriting the beginning of this sentence. I suggest, "Overall, rising greenness and wetness trends were recorded at both mountain ranges in line with the ongoing natural reforestation processes." The authors should also note that, in my suggested rewrite, I corrected a typo in 'reforestation'.

Thank you for the correction, we modified it.

Line 321: Add a comma after 'general'.

Added.

Line 326: Change 'plant' to 'plants'.

Changed.

Line 327: Change 'associated to' to 'associated with'.

Changed.

Line 331: Remove the comma after 'Apennines'.

Removed.

Line 352: Add a comma after 'Furthermore'.

Added.

Line 363: Change 'climate' to 'climatic'.

Changed.

Line 381: Remove the extra period at the end of the last sentence.

Removed.