1. Author's response to reviewer 1

We thank the reviewer for their comments, which we have discussed in the responses below and which we believe have significantly improved the manuscript.

1.1 Regarding the methods, I am afraid that the authors have overlooked a significant part of the recent scientific literature on the subject. The voxel-based approach which is presented, tested and discussed in the manuscript is not an undisputed reference method and has a number of known drawbacks.

We agree with the reviewer's view that a "best approach" to voxel-based PAI estimation remains contested. However, the aim of this paper is not to evaluate all possible voxel methods, but rather use a method with broad applicability to multiple TLS configurations. We chose the voxel-based method used in this study for clear reasons. First, we wanted to use full plots and segmented trees, so methods developed with single scans were inappropriate. Further, many radiative transfer methods require information on scanner location and beam direction limiting use to single scans or individual trees with known scan locations around them – not available in many TLS datasets. In addition, our preference, where possible, is to use methods that have been thoroughly and independently validated – in this case the voxel method chosen has been validated with destructive sampling. Finally, we only use methods that were open source and easily reproducible, excluding many insufficiently documented, GUI-based or proprietary approaches. Further discussion of our choice is given in our answer to the following comment.

We note that efforts to move towards a best practice consensus are building within the community requiring a dedicated effort and we believe our study provides direction for ways forward. We also highlight that methods should be compared across sensor and forest types to draw robust conclusions. As the data used in this study are published, we would be delighted to see further exploration of this topic making use of different voxelisation schemes but see the testing of these different methods to be beyond the scope of this study.

1.2 L103-106 the authors briefly mention that there are different approaches to voxel-based estimation of PAI/LAI and they opt for one that treats elementary voxels as either empty or full (opaque). Unfortunately, there is no obvious justification for such a choice being made. The emerging consensus in the recent literature seems to be in favour of what the authors refer to as "simulating radiative transfer within each cube". One significant advantage being that the laser scanning geometry is considered, and hence the variable sampling intensity and occlusion effects on PAI estimated can be accounted for.

While we appreciate the reviewer's comment that significant recent progress has been made in the field, our view is that a consensus on best approach is yet to be reached and the approach proposed by the reviewer is still contested (and please see the proceeding comment). In particular, there is increasing recognition that voxel size significantly influences PAI/WAI/LAI estimates, and many methods do not provide clear guidance on how to deal with this. For example, You et al., (2022), published after the submission of this manuscript, argue that voxel-based methods are highly sensitive to voxel size and present a morphology-based method to obtain LAI from the surface area on envelope fitting to extracted leaf points. A key benefit of the voxel-based approach used in this study is the clear justification for matching voxel size to point cloud resolution, as evaluated in Li et al., (2016) and validated using destructive samples. Using a radiative transfer approach PAI estimates are highly unstable over varying voxel sizes and there is no clear guidance from the literature on how to choose the correct one. Evaluating the many potential methods for calculating LAI from TLS data are well beyond the scope of this study, however, we hope that the work presented here will contribute towards a future consensus in the field.

As discussed in our response to reviewer 2 (comment 2.9), we have amended our discussion of voxel size in section 1.3 to reflect the debate around voxel size choice.

We have added to section 2.4 to clarify our justification for use of a voxel classification approach over a radiative transfer approach, also commented on by reviewer 1.

1.3 In addition, degrading point cloud resolution down to the voxels resolution is likely to degrade the quality of point cloud segmentation into leaf and wood as well as the PAI estimates.

Downsampling is a critical step in *treeseg* (Burt et al., 2019) to handle computational loads associated with segmenting point clouds. We thank the reviewer for drawing attention to our lack of clarity over the justification for down sampling data and have added statement to section 2.5.

The requirement of individual tree point clouds in *TLSeparation* means downsampled individual tree point clouds are necessary without upscaling the resolution of individually segmented trees. The scale of this study (2472 trees, 33 plots) means using a raw data resolution is computationally impracticable and consequently, downsampling is common practice in studies using large datasets of individual tree point clouds. We believe choosing a *knn* based on the point cloud resolution is a robust approach to optimising wood leaf separation under the constraints associated with large datasets. We explain the *knn* in section 2.5 of the proposed manuscript.

We chose point cloud resolution as a trade-off between computational demands while retaining the structural information contained in each tree. We then matched voxel size to point cloud resolution rather than down sampling point cloud resolution to desired voxel size. This is in line with recommendations for the method we chose; many voxel-based methods provide no clear guidance on this. We thank the reviewer for drawing attention to our lack of clarity here and have reworded the explanation in section 2.4.

1.4 For these reasons, I believe the conclusions drawn are not well grounded. The general conclusion that "Our results demonstrate the challenges that stand in the way of large scale adoption of TLS for vegetation indices monitoring" which refers to the large discrepancies observed between methods in their study contradicts recent papers such as (Béland and Kobayashi, 2021; Nguyen et al., 2022). Obviously, there are still challenges to address but this study does not seem to identify the real caveats associated with the use of TLS in vegetation studies.

From the cited literature we assume the reviewer is referring to (1) voxel size and (2) occlusion.

Regarding voxel size, we agree that there is a major problem in choosing voxel size with little consensus on how to choose the correct one for a range or forest types and ecosystems (see responses above). Separate analysis performed within our group shows unstable results over a range of voxel sizes using a radiative transfer approach, with a wide range of derived indices for one scan across relatively small variation in voxel size, suggesting high model sensitivity to this input parameter. The method we chose matches the voxel size to the resolution of the point cloud, and while the reviewer has pointed out there are "a number of known drawbacks" with this method, we feel that in the absence of well justified methods this is a pragmatic approach to accurately choosing the correct voxel size, and has been validated with destructively sampled data.

Regarding occlusion, Béland and Kobayashi, (2021) have chosen a very dense scanning density (5 m between scans), which is impractical in large-scale forest plots, and greater than the suggested scanning density in Wilkes et al., (2017), making such a dataset rarely available. Béland and Kobayashi, (2021) also suggest site specificity for their results, focusing on broadleaf trees, limiting the applicability of findings to our mixed Mediterranean forest.

Finally, the conclusion reached in our paper that "challenges stand in the way of large scale adoption of TLS" are drawn from a comparison of three TLS methods with conventional DHP. Neither papers cited (Béland and Kobayashi, 2021; Nguyen et al., 2022) test a voxel-based method against other widely used TLS PAI derivation methods (e.g. LiDAR pulse, 2D intensity image) and DHP, rather they are focused entirely on a voxel-based approach. We therefore argue the novelty of our findings and believe they do not contradict these papers.

1.5 Both theory and algorithms have advanced significantly in recent years and convergent approaches to PAI/LAI estimates from lidar (both TLS and ALS) are emerging. Maybe the authors will want to check the following references

We thank the reviewer for the references provided, however, argue that our dataset is significantly different from the data used in these studies. Methods suggested by the reviewer have been developed with individually scanned trees or branches (e.g. Béland et al., 2011; Soma et al., 2018), or with simulated data (e.g. Grau et al., 2017; Pimont et al., 2019, 2018; Soma et al., 2020). Individually scanned trees or branches can be scanned with a set of known scan positions allowing the precise location, distance, and beam angle from the scanner to be derived. Further, Béland and Kobayashi, (2021) focused on broadleaf trees functionally and physiologically different to those in our study, used a prohibitively dense scanning strategy (5 m), and lack validation from destructive sampling. Our dataset comprises 2472 trees scanned from 528 locations. To derive point-level information containing scanner location and beam angle would add significant complexity and computational load to the study. While an important question, understanding the necessity for this added complexity is beyond the scope of this paper.

As stated in the proposed manuscript L26-28: *"Our findings highlight the value of TLS data to improve fundamental understanding of tree form and function, but also the importance of rigorous testing of TLS data processing methods at a time when new approaches are being rapidly developed.",* we argue that the purpose of this paper is not to evaluate the latest methods, rather to take a step back and test existing methodologies with a large dataset.

1.6 the authors refer to Beland et al. 2014 when noting the potential role of voxel size in the voxel-based approach, but that paper uses a voxel-based approach which is not the one used by the authors

Thank you for pointing out this inappropriate reference to Béland et al., (2014); we apologise for this mistake and have corrected it, changing the reference to Li et al., (2016) who found voxel size to have significant effect on PAI estimates using the same voxel-based approach used in the study.

1.7 Regarding the ecological insights, the clearest result seems to be that the alpha parameter (WAI/PAI) decreases with tree size (figure 6). The interpretation of what may appear as a paradox is largely speculative. It is interpreted as the result of competition but no data supporting this is presented. One might have tried to explore how alpha evolved in relation to the local competition index for instance.

We thank the reviewer for the suggestion of exploring how alpha evolves with local competition, which is a key finding of this paper that we have not sufficiently highlighted. Figure 6b shows how alpha changes in relation to plot-level crown area index (CAI), a measure of the plot area covered by tree crown, and one that we have used as a proxy measure of local competition.

To clarify the use of CAI as indicative measure of local competition, we have changed the wording in section 2.6.

1.8 There is abundant literature (and theoretical arguments) that indicate that LeafToWood biomass ratio of trees growing in stands will tend to decrease with size (Bartelink, 1997; Forrester et al., 2017; Mensah et al., 2016). In the present study, the WoodToLeaf area ratio is found to decrease with tree size (for the four species for which there is a significant trend in figure 6). This could be an artefact as the authors point out (l. 387-394). The issue might indeed have to do with the leaf/wood filtering.

We agree with the reviewer that there is abundant literature that argue leaf to wood biomass ratio will tend to decrease with size, however, the literature cited by the reviewer differ fundamentally from our study in ways that may explain differences in results. For example, the focus species, *Fagus sylvatica* in Bartelink, (1997) is functionally different to species analysed in this study; Forrester et al., (2017) evaluate leaf biomass rather than wood to plant ratio and Mensah et al., (2016) omit correction for competition in their models while also excluding the largest trees from the study possibly introducing bias. This means that the arguments presented may not hold in our dataset measured in a mixed Mediterranean forest.

We agree that wood to plant ratio could be influenced by an artifact of wood – leaf classification, and have elaborated on this point in L418-425 of the proposed manuscript: *"Wood may be harder to accurately classify than leaves in TLS data (Vicari et al., 2019a), resulting in a higher occurrence of false positives in wood clouds, potentially leading to an overestimation in WAI, and therefore underestimation of α, especially in trees with small leaves which are prevalent in dry, Mediterranean environments (Peppe et al., 2011). The problem of misclassification will increase in taller trees due to TLS beam divergence, occlusion and larger beam footprint at further distances (Vicari et al., 2019a), suggesting that WAI overestimation could be more pronounced in tall trees. Although our dense scanning strategy (Owen et al., 2021) was designed to mitigate some of these effects, it is possible our findings could underestimate the slope of the negative relationship between α and tree height.".* Based on this, we would expect to be underestimating the negative slope of the relationship between alpha and tree height if it was an issue of misclassification.

1.9 This is also a field where progress has been made in recent years and maybe the authors would want to test alternative algorithms to TLSeparation which might perform better on their data. Some pointers are given below

We agree that there has been progress in the field of wood – leaf classification, however, we argue most progress has been focused on scaling wood – leaf classification from individual trees to whole scan or plot data (e.g. Krisanski et al., 2021; Wan et al., 2021; Wang, 2020; Wang et al., 2018; Wu et al., 2020) rather than major improvements in the classification framework itself. In the case of LeWoS (Wang et al., 2020), the tool has been tested only with tropical trees and, although, distributed as open-source, is either in the form of Matlab code or a pre-compiled executable, substantially limiting wider applicability. Testing the multitude of available approaches to wood – leaf classification would be invaluable to the field, however, is beyond the scope of this study – not least because such a test should use destructively sampled validation data, which we do not have access to. Here we are interested in using well-established methodology that has been validated with a range of tree types, so based our choice on that criteria.

1.10 My overall appreciation is that the data collected is very significant and could indeed contribute some new insights in terms of tree/forest ecology but more work is needed prior to publication.

We thank the reviewer for their comments and appreciate that the reviewer recognises the significance of our data and results. We are confident that following their and the other reviewer's comments that the manuscript has been significantly enhanced.

1.11 Reprocessing the TLS data already segmented using an open source freely available code incorporating much of the latest theoretical improvements should not take long. This analysis may profoundly alter the reported results (i.e the large overestimation of PAI with a voxel-based approach and the unexpected negative trend in WAI/PAI with increasing tree size). This may help clarify whether leaf/wood segmentation may be an issue and require further scrutiny or not.

Whilst additional analyses are always possible, in this case we believe our methodological choices are defensible, and these have been discussed in previous responses. We use well-established and tested leaf separation and PAI estimation methods that were tested, in the case of voxel-based method, with destructive samples. The scope of this study is to benchmark the most rigorously available methods, not testing all available methods but taking the conservative approach. Further, all the methods tested in this study are either open source in common programming languages, or, where we have written code this has been made freely available. Not all the methods suggested by the reviewer are open source or easily integrated into automated workflows. We believe that running the analysis again would introduce new, different biases, and don't believe this would enhance manuscript without changing scope.

2. Author's response to reviewer 2

We thank reviewer for acknowledging the impact of this paper and their comments which we have discussed below and think have significantly improved the manuscript.

2.1 I think this article's first and foremost improvement point is that the research goal is not clear and in-depth enough.

We apologise for a lack of clarity here, and agree that the twin goals of methodology comparison and ecological insight are not presented in as clear a manner as they could be. We have edited the wording in section 1.3 to improve their readability and enhance the communication of their importance.

2.2 The presentation of the results is not complete, which makes it difficult for readers to capture their needed information, such as the WAI variation trend (functions) among 5 tree species related to their height and density.

We apologise that our analysis of WAI was not clear to the reviewer. We chose to compare methods based on PAI estimates, and not WAI or LAI, to avoid introducing additional processing steps and complexity and therefore to more directly compare the chosen methodological approaches. Differences in PAI between different TLS and DHP estimates can be attributed to differences in processing approaches, whereas comparison of WAI introduces additional error from separation approaches. To improve clarity, we have added a statement to section 2.6

See also our response to comment 2.4 below.

2.3 Referring to the DHP results, authors evaluated the error of WAI and PAI analyzed by point clouds. I would like to know if the authors use the TLS data to improve the LAI evaluation accuracy. TLS can support assessing the single tree and plot-level WAI more accurately.

We agree completely that the combination of TLS and DHP might improve analyses, and this has been developed in methods not tested in this paper (e.g. Kamoske et al., 2019).

Here we did not use the two datasets together, preferring instead to retain the ability to compare them as independent estimates of the indices of interest. We note that neither should be viewed as the 'truth', and therefore using them in combination could introduce additional biases that would be challenging to disentangle. Nevertheless, others could use our data to perform the analyses suggested.

2.4 More importantly, whether the WAI of different Mediterranean trees has similarities between the same species, as well as providing specific information (maybe list in thematic tables to show the relationship among species, tree height, density, and PAI), will make readers benefit greatly. I think the measured data of this study can support this research goal, while they are not fully presented in the current edition.

Although these are not the focus of this study, we agree that additional information could prove useful to some readers. We thank the reviewer for their suggestion of including WAI analysis, which we think has significantly improved the manuscript. We have added Figure C2 and Tables C3, C4 to the supplementary information and refer to this in the main manuscript, section 3.4.

2.5 In addition, the presentation of the results is incomplete. I did not find the location, site conditions and tree species appearance of the measured plots shown in the manuscript.

We apologise for this omission. This information is presented in the cited study Owen et al. (2021), but we have added a detailed site map to the supplementary materials, Figure 1, which is referred to in section 2.1 of the main text.

Please see also our response to comment 2.14

2.6 The segmentation results of different tree species and the statistical information on PAI and WAI of trees grown in different site conditions were also not provided.

We thank the reviewer for their comment and apologise for lack of clarity around the segmentation process. Individual tree segmentation was carried out by the authors for a separate study (Owen et al., 2021). We have amended section 2.5 to clarify the segmentation process and have signposted (Owen et al., 2021).

Please see also our response to comment 2.17.

2.7 In addition, critical mathematical functions and quantitative conclusions are also lacking in the current edition.

We apologise for this lack of completeness. We are not entirely clear to which functions the reviewer refers, but for reasons of clarity and brevity we chose to primarily describe the various processing methods we used rather than repeat their original descriptions, which are extensive within the cited literature. Where equations have been used from other studies, we have cited the original equation number along with the paper in-text (but see response to 2.8 below).

2.8 I suggest authors reconsider whether it is necessary to study the CAI. This parameter can be easily analyzed using remote sensing images without using TLS.

In this study we used CAI as a proxy measure of stand density, which was a necessary within our model to both understand and correct for the effect of stand density on wood to plant ratio, α. Controlling for stand density (using CAI as a proxy) is important as trees growing in dense plots have lower water availability per tree (see section 1). We chose to use CAI as Owen et al., (2021) showed that the metric is also indicative of plot-level competition and the metric accounts for crown overlap which cannot be estimated from imagery in closed forests. Furthermore, Coomes et al., (2012) showed CAI to be better than traditional metrics such as basal area, as it is more intuitive to non-specialists and strongly predicts productivity.

We apologise for the lack of clarity when describing this metric and its intended use in the study, which was also commented on by reviewer 1 (comment 1.7).

We have therefore amended our description of the key metric, CAI, for quantifying stand density and local competition in section 2.6.

2.9 Furthermore, is it applicable to use a fixed voxel size when analyzing WAI? After all, different tree species have various canopy shapes and branch structure features. Adaptive adjusting the voxel size according to the point cloud density and the branch distribution trend may be more reasonable.

We thank the reviewer for their comment on voxel size and agree that finding an appropriate voxel size a complex problem (discussed extensively in the response to the other reviewer). We chose the method of voxel classification rather than a radiative transfer approach as it has a definitive method for choosing voxel size based on matching the voxel size to the resolution of the point cloud, which was tested against voxel sizes based on individual tree leaf size, and distance of beam, using destructive samples in Li et al., (2016). Using a radiative transfer approach, the methodology for choosing the “correct” voxel size is not clear, and others’ work (and our own additional, unpublished analyses) has shown that estimated PAI values are highly sensitive to voxel size choice.

We have amended our discussion of voxel size in section 1.2 to reflect the contentious debate around voxel size choice.

To clarify our justification for use of a voxel classification approach over a radiative transfer approach, also commented on by reviewer 1, we have added to section 2.4.

2.10 Optimizing the TLS-based WAI assessment methods, summarizing the regulation of interspecific WAI variation, and using these rules to improve the LAI assessment will make this article more attractive to better support research in related fields.

We thank the reviewer for their suggestion of including analysis of interspecific WAI variation, which we think is a valuable addition to the paper, and refer to our response to previous comments (2.2, 2.4, 2.11), where we have included these new analyses.

Here, we’ve focussed on interspecific variation in alpha and PAI, rather than WAI and LAI, but recognise that there would be value in such an additional set of analyses. We agree that developing new methods to correct for WAI in LAI estimates using approaches assessed in this paper would make for exciting work, however we think that to do this well we would require further testing and validation, ideally using destructive samples or multitemporal leaf on/leaf off remote sensing data, which is beyond the scope of this paper.

The following are some detailed points. I hope they will help improve the current edition.

2.11 I suggest authors clarify their research goal in the initial section of the manuscript. As a reader, I am more interested in how to use TLS to analyze WAI. However, authors did not briefly introduce the WAI extraction methods in the abstract but focused on comparing point cloud extraction methods of PAI and LAI.

We apologise for the lack of clarity in explaining our research goals. As in our response to comment 2.1, we have restated our primary and secondary research goals in section 1.3.

We thank the reviewer for their suggestion of analysing WAI, which we think has significantly improved the manuscript. As for comment 2.4, we have now included this analysis. We have chosen to keep the focus on comparing alpha, as this value is widely discussed in the literature. We have added a statement to this effect to section 2.5.

2.12 They focused on the wood to total plant area (α). I wonder if it is feasible to measure the plant area because of the occlusion effect during scanning. TLS may be more suitable for analyzing WAI.

We apologise not clearly stating the reasons for comparing PAI rather than WAI. All remote sensing methods evaluated in this paper (three TLS methods and DHP) more directly measure PAI than WAI or LAI as sensors are measuring the whole plant. Correcting for wood/ leaf to derive WAI/ LAI requires additional processing steps, which vary according to sensor (wood/ leaf separation algorithms for TLS and image masking for DHP, as these systems are not deciduous, and therefore leaf-off scans can't be made), introducing bias and limiting our ability to compare output. We have added a statement to this effect to section 2.6.

Please see also our response to comment 2.2

We agree that occlusion is a known problem with TLS data in closed canopy forests, however we have minimised the potential occlusion effects by following a dense scanning strategy following the widely cited Wilkes et al., (2017).

2.13 Section 1.3 It will be more interesting to add some research topics on integrating the fine-scale WAI (or α) assessed based on TLS to correct the large-scale LAI extracted from the multi-source remote sensing images. Based on the high-quality field dataset, it should be feasible to use this research in optimizing the large-scale LAI distribution evaluation.

We agree this is an exciting idea and could be the focus of follow-on work. We think that the work presented and, as the reviewer points out, our dataset provides a foundation for a more robust comparison of LAI and new insights from multi-source RS datasets, but that this would be an additional methodological development beyond the scope of our current study.

Following your suggestion, we have added a comment to this effect to section 4.4 of the revised manuscript.

2.14 In Sections 2.1 and 2.2, the location map of study plots and some images showing the scene of plots should be provided. The pictures of tree species also need to be added to show their phenotypic characteristics, which is beneficial to evaluate their drought tolerance (L323-324).

We agree with the reviewer that a location map of the study plots would be beneficial to the manuscript and thank them for the suggestion. We have therefore added a new figure, A1 to Appendix A showing the locations of plots within the two field sites, Alto Tajo and Cuellar in central Spain.

We believe that the plots used in this study are well studied and documented in the literature and therefore a detailed description of individual plot characteristics would repeat information already available. We have added signposting to this is section 2.1.

The five focus species of this manuscript are widely studied and known species and therefore believe that adding individual images of each species is unnecessary.

2.15 L 191 When setting this threshold (> 0 points) to identify the filled voxels, did you filter noisy points out from the tree TLS datasets? It is not easy to identify and

filter all noise in TLS data. I am worried the noise would lead to a lower P_{gap} and cause inaccurate LAI and PAI.

We apologise for not making explicit the noise filtering process of our data. We denoised individual-tree point clouds using height dependant statistical filtering as outlined in Owen et al., (2021), and combined individual tree point clouds into whole plots. We have added a statement to this effect to section 2.4.

While any remaining noise may indeed lead to lower P_{gap}, we followed standard processing procedure for this voxel classification method outlined in Hosoi and Omasa, (2006) and tested using destructive samples in Li et al., (2016). Similarly, we followed standard protocol in the published literature for the other two methods (LiDAR Pulse and 2D intensity Image), and therefore consider that our work is a fair representation of each methods' ability to accurately derive PAI and allows a comparison of each methods' merits and drawbacks.

2.16 L203-204 Some structure features of woody and foliage materials can be analyzed based on the pointset-, height bin-, and patch-based models. Please revise this sentence.

We apologise for the lack of clarity in this statement, and thank the reviewer for their suggestion. What we meant to say was that the voxel-based approach was the only method compared in this study capable of analysing PAI, WAI and LAI of segmented individual tree point clouds. We have reworded the sentience in section 2.5 to make this clear.

2.17 L206 The principle of TLS segmentation methods needs to be briefly introduced before the voxelization step. It is beneficial to improve the readability of the manuscript.

We thank the reviewer for their suggestion of providing an explanation of the segmentation process. Trees were not segmented for this paper; we used data that had already been segmented by the authors for a separate study (Owen et al., 2021), and we apologise for the lack of clarity. We have amended the description of tree segmentation in section 2.5.

2.18 L216 How to analyze the WAI after voxelizing woody point clouds? Some details should be introduced, which is key to calculating É‘ .

We thank the reviewer for their comment and apologise for the lack of clarity in our methods for calculating individual tree WAI. Individual tree WAI was calculated in the same way (voxel classification method) as individual tree PAI, but using the wood-only cloud from the wood – leaf separation step. We have updated section 2.5.

2.19 L225 Why explore the relationship between PAI and CAI in this study? The CAI assessment seems to deviate from the research topic, as it is not highly related to LAI and WAI but to the crown projection area, except the canopy gap area. Moreover, using images for CAI analysis is sufficient.

We apologise for not clearly stating our justification for the use of CAI in this study. CAI is used in this study as an indicative measure of both stand density and local competition, and is included to both explore how PAI is affected by competition, but also to correct for anticipated competitive affects that would otherwise impact our conclusions on species' differences in alpha. We thank the reviewer for their comment, and have amended our manuscript section 2.6.

Please see also our response to comment 2.8.

In closed canopies or canopies with crown overlap imagery would not capture CAI, since CAI is calculated using the sum of all projected crown area, not only that visible from imagery. We used TLS to measure CAI as CAI estimates are generated from the sum of all tree crown projected area and so requires individual tree measurements, either from segmented TLS or from ground measurements.

2.20 L245 As shown in Figure 3, PAI estimated using the LiDAR Pulse method more strongly agreed with DHP PAI than the Intensity Image method. However, I found their correlation (R^2) is not particularly significant.

We believe this is a misreading of our meaning, and therefore apologise for not using clear language in reporting our statistical results. We have therefore amended our description of results in section 3.1.

2.21 L248 Please carefully recheck the description of the results is correct according to Figure 3. As shown in Figure 3a, the Pulse-based method overestimates the PAI, while the intensity-based method underestimates the PAI.

We apologise for the lack of clarity in explaining these results and meant to say that both methods underestimate relative to DHP at larger values. We have therefore amended the sentence in section 3.1.

2.22 L264 You did not label Voxel-Based PAI in Figure 3. Do you mean the TLS PAI

We apologise for the lack of clarity in this sentence. Section 3.2, this line is referring to whole plot plant area index (Figure 4), which does include Voxel-Based PAI. We have now removed the reference to Figure 3 from this sentence.

2.23 L269 Maybe you did not set a suitable threshold when defining blank voxels. Merely my speculation!

We thank the reviewer for their speculation on why we may be experiencing overestimation from Voxel-Based PAI estimates. We followed standard protocol as described in the published literature for the Voxel-Based, LiDAR Pulse and 2D Intensity Images methods, which has allowed us to draw a fair comparison between derived PAI values from each method. Although threshold values could be influencing PAI estimates, we have made a 'best choice' to classify non-zero point containing voxels as vegetation and believe that, while important research, further exploration of threshold values would be beyond the scope of this study.

Please see also response to comment 2.15.

2.24 L282 and 257 You forget to mark the 1:1 dash line in these figures.

This graph (Figure 4b) presents the variation in PAI against CAI in order to understand how competition and stand density affects PAI so we would not assume a 1:1 relationship. We apologise for the lack of clarity and have amended the caption of Figure 4 to make this clearer.

In Figure 3b, the dashed line represents 0, as this panel is showing the relationship between TLS residuals and DHP PAI. We apologise for the lack of clarity and have amended the figure caption.

2.25 Although authors used the published woody-and-foliage separation methods, it is necessary to display some examples of TLS separation results scanned from diverse plots grown with different species. Due to the lack of validation data, it may be challenging to evaluate the segmentation accuracy. However, presenting the separation results is still available to support visual evaluation.

We agree that showing an example visual assessment of wood/ leaf separation is beneficial to the reader and have included an example of a wood/ leaf separated *P. sylvestris* in Figure 2, panels a and b. We have now included signposting in the caption in Figure 2.

We also note that wood – leaf separation was carried out by the authors for a separate published study (Owen et al., 2021). We apologise for the lack of clarity and have changed our description of the wood – leaf separation process accordingly in section 2.5. Please see our response to comment 2.33 below.

2.26 It is not easy to accurately separate the branch and leaf point clouds of trees except those of broadleaf. More importantly, I am worried about whether it is applicable to use the same voxel size to calculate the WAI of different tree species, which is crucial to the conclusion.

Although we agree it may theoretically be more difficult to separate wood and leaf in needleleaf trees, we note that *TLSeparation* was developed with applicability to both types of trees, with separation difficulties attributable to scanning strategy rather than separation algorithm (Vicari et al., 2019b). We note that this problem was minimised to the best of our ability in our dataset, as we followed a dense scanning strategy as outlined in Wilkes et al., (2017). As for comment 2.25 above, we have included an example visual assessment of a wood – leaf separated (needleleaf) *P. sylvestris* and included signposting in the caption in Figure 2.

2.27 L294-297 These sentences are not clear. How to assess tree-specific drought tolerance? You would better add some description about its evaluation methods and list the metrics to evaluate the drought tolerance of different tree species in this figure and the related references.

We agree the source of drought tolerance rankings needs to be clear and apologise for omitting this in the figure caption. Drought tolerance are taken from the widely-cited Niinemets and Valladares, (2006). We have amended the caption in Figure 5.

2.28 In section 4.1, why did you discuss the plot-scale CAI variation? The topic of this section is comparing diverse approaches to deriving PAI.

We apologise for the lack of clarity around the role of CAI in this study. As CAI was used as an indicative measure of stand density and local competition, it was discussed in this section as plots with higher CAI (and therefore greater stem density) showed greater variation in estimated PAI values from each method/ sensor. We note that we have now updated our description of CAI and its role in this study in section 2.6 and hope that the discussion in section 4.1 is now more clear.

Please see also our response to comment 2.8.

2.29 The title of Section 4.2 is a phenomenon that you need to analyze. Sections 4.2 and 4.3 still belong to Section 4.1 to discuss the LiDAR-extracted metrics with that of DHP.

The titles of sections 4.2 and 4.3 were intended to emphasise findings of particular interest and relevance to the initial aims of this manuscript. We agree, however, with the reviewer that these sections belong with 4.1 and have removed these section titles to make this more clear.

2.30 L320 According to the field data and Figure 3, what is a very low PAI value? Providing a quantitative indicator will significantly improve the manuscript's readability than using adjective words.

We thank the reviewer for the comment and agree that more quantitative language would improve the manuscript. We have therefore amended this line.

2.31 L348 The highest R^2 does not show a strong correlation.

We thank the reviewer for their comment and agree that we have not used clear statistical language. We have therefore changed the wording.

2.32 L374 This sentence is not clear. "Although species explain some variation in α, tree height and plot CAI were stronger predictors for all species…." According to the principle of these parameters, it is hard for me to agree that CAI and WAI have a strong correlation.

We agree with the reviewer that we have not used clear statistical language. We have therefore changed this sentence in section 4.3 of the revised manuscript.

2.33 L390-392 This is an interesting point. I prefer you to provide some figures and statistical information to prove your finding, especially in different plots with variable growing patterns (growing density, CAI, and WAI related to the tree species, as you mentioned in the Conclusion section). It is beneficial to deepen this study topic.

We thank the reviewer for finding this point interesting and their suggestion of including quantitative results of wood – leaf separation. The discussion point the reviewer refers to is a reference to the published paper describing the wood – leaf separation algorithm. Due to the lack of validation data, evaluating quantitatively the effectiveness of the wood – leaf separation algorithm over the different tree sizes/ growing conditions is not possible for this study.

We note that the wood leaf separation process was carried out by the authors, for a separate study (Owen et al., 2021), in which the results are discussed in more detail and segmented tree files made available online, cited as Owen et al., (2022). We apologise for the lack of clarity here and have reworded our description of the wood – leaf separation process in section 2.5.

2.34 L 398 I agree that correcting WAI can improve the LAI assessment. The TLS-extracted data can support calibrating LAI based on WAI and PAI. The WAI may be similar among single trees of the same tree species. According to your results, the WAI shows a more evident relationship to tree height and stand density. I think the

assessed WAI and plot-level PAI can be used to correct regional LAI for the plot or large-scale forests that were growing with limited tree species.

We agree with the reviewer that interspecific WAI values will be of interest to some readers and thank the reviewer for their suggestion, which we think has significantly improved our manuscript. We have included these additional analyses in Appendix C as also discussed in response to comments 2.4 and 2.10. We hope this work sparks further research on improving LAI estimates at large scale.

Some text errors that needed to be corrected are listed as follows:

Thank you for pointing out these errors.

- **Do not use an abbreviation in the title of your manuscript, as many readers in other fields do not know the meaning of TLS.**

We agree with the reviewer that abbreviations should not be used in titles and have amended our title accordingly.

- **I suggest authors unify the reference format throughout their manuscript. Different citation formats appear in the same paragraph may confuse readers.**

We thank the reviewer for their comment and have checked and corrected referencing throughout.

- **L135 What are FunDIV plots?**

Added “Functional Diversity”

- **L142 I do not understand “altitudinal gradient 840 – 1400 m.a.s.l.”.**

Changed to “altitudinal range”

- **L167 compare –ï¼ž compared**

Changed to “compared”

- **L169 and 180 Please note the font size of the subscript in the Pgap. This abbreviation can also be used in line 162.**

Changed to subscript and moved abbreviation to first use.

- **L176 Please add a comma to this sentence.**

Comma added

- **L199 Where are the solid black voxels in Figure 2?**

Changed to “Coloured voxels (green represents leaf and brown represents wood) are filled voxels and grey lines are empty voxels.”

- **L209 wood only point clouds?**

Change to “separated wood cloud”

- **L210 TLSeparation classifies points as leaf or wood? This sentence is not clear.**

Changed to “*TLSeparation* assigns points as either leaf or wood”

- **L219 TLS PAI and DHP PAI? (Using PAI_{TLS} and PAI_{DHP} instead)**

Changed throughout.

- **L234 Please add a comma to this sentence.**

Comma added.

- **L246-248, L264-265 You can mark these metrics in the insets of Figure 3.**

We think it is important to refer to statistical results in the main text of the manuscript for emphasis, however have included them in the figure captions as well for completeness.

- **Points in Figure 3 can be denoted as different marks or colors, such as circles or crosses, red or blue, to make this chart clearer (like the style of Figure 4).**

Changed to circles and triangles.

- **L262 Please unify the term throughout the manuscript. I think TLS whole plot PAI means TLS PAI(PAI_{TLS}).**

Changed to “whole plot PAI_{TLS}”

- **L274-276 You would better mark these metrics in the subfigures of Figure 4.**

We think it is important to refer to statistical results in the main text of the manuscript, however have included them in the figure captions as well for completeness.

- **In Figures 3 and 4, please delete the unit of PAI. The PAI, LAI and WAI are all ratio-type parameters (no need to denote unit).**

  Removed units and changed axis labels to new subscript (PAI_{TLS} / PAI_{DHP})

- **L318 TLS – DHP comparisons?**

Changed to “studies comparing PAI_{TLS} with PAI_{DHP}”

- **In this article, authors used lots of open-source software to support their analysis. I suggest they list all applicable packages and download links to make readers easy to use these tools.**

We thank the reviewer for their suggestion of providing a summary of all open-source software used for this manuscript. We have cited all the software used in text and in the reference list at the end of the manuscript. We believe that citing packages in the main text, readers are able to get a more detailed and contextualised explanation of the use in individual software packages.

- **Please carefully check the format of all references according to the manuscript preparation guidelines and the latest published papers in Biogeosciences. The current reference format needs to be optimized.**

We thank the reviewer for their comment and have checked the references throughout.

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