Tree height uncertainty biases aboveground biomass estimation more than wood density in miombo woodlands

1) Overall feedback:

Well written, relevant topic. Overall, the paper is carefully presented. The method section requires more detail imo, for the manuscript to be more deeply reviewed. Right now, because of a lack of information on some accounts it was not possible to correctly review it imo (therefore I also did not read the discussion in too great detail at this stage). I suggest a major revision.

-Authors should provide recommendations for how to improve agb measurements given the practical implementation and scope of their article, and this agb measurement methodology (e.g. forest carbon projects).

-Authors should clarify and potentially rephrase/concretize their objectives (L103-107)and then link it better to the methodology and data collection that was necessary for reaching their objectives.

-Authors should consider whether the introduction and article in general should speak about a larger context of tropical forests (or even 'and savannas' as they mention in first line of intro), or specifically target miombo woodlands as the title suggests. Though I understand that tropical forests in general might be relevant since equations are used in miombo from tropical forests more widely, it is important to clarify in the text the distinction imo, and also clearly introduce miombo as a specific type of dry forest at some point in the intro already. I also think the authors should acknowledge and provide info on the available other destructive tree datasets / equations for miombo systems. Please see my specific feedback on that.

-Authors should provide more information on how they tackled the fact that their data comes from three different sites (statistically / ecologically)?

-Authors should provide more detailed information on the methodology used for the forest inventory data. See specific comments.

-Authors should explain why other allometric equations from miombo (destructive tree harvest datasets) have not been included in the comparison and/or include them throughout the analysist o make it more robust and exhaustive.

2) Specific feedback:

ABSTRACT

L30 What do you mean with 'generic information'? Please clarify in the abstract.

L30 Not sure that 'in particular' fits well here as a wording, since you haven't given anything else before that in terms of error demonstration?

L32 Is 'intuitive' the correct word here? (defined as 'using or based on **what one feels to be true** even without conscious reasoning; instinctive.')

The final sentence of the abstract reads odd to me. What is the takehome message from your results? What should people calculating biomass in miombo do now based on what you found? Not all of us will be able to partition errors if we do not have destructive tree data so do you recommend a middle way solution to limit the errors but still have the potential to monitor without cutting trees… Is the recommendation about using specific height measurement methods, or measuring

height more repetitively to lower bias? Is it about needing more wood density values from actual trees in the field?

Shouldn't the keywords be new words compared to the title and not repetitive?

INTRO

L47-52 Though I do not think addressing my comment would need to be done exactly here in the article, I think the authors should also address the uncertainty/bias in carbon projects where numbers from ecosystem- or site-specific contexts are transferred to a completely different context, out of the assumption that variation in the biomass amounts will be negligible. Large variation in small-scale environmental conditions as well as land-use history and ongoing management (eg. fire) in miombo eg might mean the biomass values can differ a lot between sites and regions. I could not find a review that has addressed this already (based on field data and not remote sensing only), but I think it requires touching upon this variation in the current paper at least as well. I think the sentence 'this is rarely the case even at the most basic level of the individual tree' made a nice jump for me to think about this, since you could then extend this to say 'even on the level of the site or region there is much room for bias/less room for simple comparisons'. Also with 'there are multiple sources of uncertainty that affect tree biomass estimation' → You could present here some of the 'other uncertainty' except for the ones you look at in your analyses (which are methodological), cfr. environmental, management variation etc.

L62 Should the authors touch upon some more recent efforts here and innovations towards the future, eg. ESA 2025 Biomass launch?

L65 I think there needs to be more depth provided here. What are the myriad of equations? Can you provide a table with full overview? Are you referring only to equations for tropical forests (cfr 2nd part of your sentence), or all biomes? How do you demonstrate that the most widely used is the ones by Chave? Do you mean they are most widely used in science or in forest carbon monitoring & reporting, where other equations might be used than the published ones but this information might not be publically available (?), despite it being used to monitor carbon stocks as well across many different areas.

Related to this comment, I miss information on which previous datasets exist that target similar research questions for miombo specifically (destructive tree harvesting) though maybe that will come later on in the article. Eg referring to some of these studies (probably non-exhaustive).

https://www.sciencedirect.com/science/article/pii/S0167880912001892

https://www.sciencedirect.com/science/article/pii/S0378112713005306

https://www.sciencedirect.com/science/article/pii/S0378112712007074

https://onlinelibrary.wiley.com/doi/full/10.1111/j.1744-7429.2010.00713.x

https://www.sciencedirect.com/science/article/pii/S0378112717308071 -- including one of the authors to this current article, so please clarify how this dataset links to the current article's dataset?

L70 Please explain 'measured inputs', I did not understand this contradiction with the line before.

L69-74 On several occasions, I miss scientific backing. Eg here, there is a lack of references to support your statements. Please introduce these.

L86 Interesting, I wonder if the authors can give concrete examples for the availability of wood density for miombo ecosystems, since their article targets this biome. How much % of the species wood density is available for this biome? Have there been efforts to sample wood density on a large scale?

The introduction in general is very broad on ecosystems the authors seem to cover with their article (tropical forests and savannas in first line of intro), while the article is supposed to talk about miombo. I think this needs clarification as to whether the authors will stick in the introduction to broad context, tropical forests, or whether miombo should be more specifically mentioned from the start.

L94 Can the authors touch upon what previous work has been done in the same context? Have there been other quantitative assessments like this and what have they found?

L98 I'm not sure if comparing miombo area to the size of the UK is super helpful in a global context. Could the authors find a better comparison related more to the study area/biome's location?

L104 Please clarify 'new biomass allometric models fit to the data' to make it more clear. Please explain or introduce earlier the availability of 'local biomass models' cfr my previous comment.

L106-107 It would be useful at this stage to get more information on what types of approaches you tested on imputing H and wood density. Is it about different measurement methods/protocols, or only different computer based methods?

<u>METHODS</u>

2.1

L110 'Multiple datasets' – does it cover multiple study areas/regions? It should be clarified, which comes later in 2.2 and Table 1 but ideally is already mentioned here more concretely and in the introduction when the authors introduce 154 trees were used. It seems important information that there is also a site-level variable that may need to (have been) addressed in the statistical analyses. Cfr also my comment on 'other uncertainty drivers' where I touch upon site/region level variation in agb estimates.

L111 Please provide a reference

L114 A map would be helpful, for the reader audience that is not familiar with miombo and their region of occurrence

L115 Can you make this concrete, 'long dry seasons', 'months of intense rainfall', 'fire playing a key role'? Can you touch upon the difference between dry and wet miombo as well?

L117 Can you provide references for the statement 'trees in this region … are able to recover remarkably quickly from wildfires and other forms of disturbance…'?

2.2

L132 Can you provide argumentation why the outliers were excluded?

Table 1: it clearly shows you have looked at the site level variation because you include elevation, MAP and MAT – where in the article do you touch upon how you have addressed the fact that combined dataset comes from 3 different sites and how you accounted for this potential influential factor in your analyses and results?

2.3

Can the authors provide more information on the measurement methodology of the forest inventory data? As well as the spatial locations of the destructive harvesting vs. the inventory data? This seems like crucial information to understand and assess how robust the comparative analyses in that is the key of the article (how does height and wood density measurements influence the biomass quantification with field data vs harvesting data). If this data has been published, the authors can refer to the specific publication for detailed methodology information.

L146 What was the reasoning for excluding the outliers?

There is a section explaining H-D dataset, but what about what was done for wood density? Where can we find information on it? Also, for Height, what exactly has been compared in terms of testing the influence of H imputation on biomass quantification?

2.4

Would be helpful to know what the different packages are used for, as now it is just a summation of many different packages which gives limited information.

Overall this section seems invaluable for me right now. It is not clear what was done as part of data harmonization and analyses in relation to the two research objectives*. At this stage, it became clear for me that the authors should clarify and potentially rephrase/concretize their objectives and then link it better to the methodology and data collection that was necessary for reaching their objectives.

*L103-107

*Using these data, we set out to address **two key research objectives**. First, we compared AGB estimates obtained using new biomass allometric models fit to the data with those of existing local and pantropical biomass models. Second, we systematically assessed how different approaches to imputing H and ρ affect tree-level AGB estimates.*

2.5

The authors should work towards improving this section to be very clear and linked to their research objectives. Please specify here already what it means 'newly developed biomass models', despite explaining it later on in this section.

L164 Can the authors reflect upon the other available allometric equations from Miombo woodlands (cfr previous comment)? Why was the Ilua 2016 equation included here as comparison and not the other available allometric equations?

Can the authors also reflect upon the following article https://www.mdpi.com/1999-4907/7/2/13 ?

L170 Why these two options were selected, combined rho diameter^2 height vs. diameter alone? Please explain. It is unclear to me why in figure 1 there is then also a correlation shown with rho or height alone? Please also explain how the other available miombo allometric equations fit into your storyline and why they were not mentioned or compared as well.

L181 Please provide a backing for your statement (larger trees, largest errors). Please specify 'absolute terms of what'.

Figure 1: can the authors also give information on the tree inventory dataset? I'm not sure if figure 1 is not better fit for incorporation into the results since you are including this tree harvest dataset model as a part of your comparison or research objective 1? (L167-171). Can the authors argue why it should be in methods and is not a result?

2.6

L216 Shouldn't this decision of which model to use for the height and wood density influence be based on what your previous analyses showed as the 'best model' for your dataset, rather than the most commonly used model?

L229 Which 4321 trees?

L231 I think the authors should state clearer throughout the paper how the uncertainty from height/wood density was assessed, by referring to the Bayesian technique at some more occasions. This aspect remained very unclear for me until this point in the article, and it would help readers to clarify that more from the start. Also the separation and methods of the two distinct research objectives and why the authors focus on both should be better clarified I think.

I believe I understand it like this but it took me a while to figure it out and the authors could help the readers to clarify that easier: First there's the comparison of 2 existing (based on destructive tropical forest as well as miombo woodland harvest data) and 2 new models (based on their own destructive miombo data) to see how the regression models perform in terms of predicted vs observed (field inventory data) and when including combinations of predictors vs single predictors. Then there's the check of the field based height and wood density are influencing the uncertainty in the model based on field inventory data and Bayesian modelling, using only the chave model.

RESULTS

It is problematic for me to see that the site variation has not been tackled or addressed in this analysis. The destructive data comes from three different sites – where is the argumentation from the authors that state/show that they can be used as a combined dataset?

3.1

L264-265 Please explain in caption the three numbers what they refer to each time (RMSE 160.5 vs 210.6 vs 217.9 eg.). Why are you only showing it for 3 of the 4 models?

Figure 2

Can the authors specify the model formula in a and b as well like they do for c and d?

Can they explain in caption what a, b stands for?

Can e be shown in the same order as they show the models (ILUA2, Chave, Fitted1, Fitted2)?

L266 Please explain how the ILUA2 model was developed more clearly in the methods where introducing this model. If not, it would at least be expected to be in the discussion, considering the underestimation.

3.2

L297 More information is needed on the field inventory dataset and measurement protocol to understand what height and rho values were measured (how many replicates, which instrument etc)?

L302 I think you should rephrase it so it's clear that it's the difference (higher values) that leads to the possible reduction in underestimation, not the fact that they're correlated.

It would be good throughout this section to reiterate what species-specific vs regional level estimates meant in terms of method. That's really the key difference in the paragraphs here so should be 100% clear for readers.

Some of this end section in results already read more like discussion (compounded errors etc).

Figure 3

Can you make it more visual clear the different scenarios? Eg by showing on the left = measured H all three panels, then middle is Species H, right is Regional H (and similar for top to bottom the differences)? Maybe also by using color codes or size for variation in the RMSE and PE (so we can easily see which ones have smaller or larger errors?)

It isn't mentioned that Bayesian modelling was involved – could this be mentioned in the figure caption of those figures that involved it (?figure 4).

L307-320 This section involved 3 figures as output and the information is not separated clearly enough for readers to digest it. Please try to make this clearer what you found in every step and every figure.

The abstract should become more clear and concrete when having read the results now. You mention in L30 'using generic information' – please make this specific and linked to how you name the 9 scenarios in the actual article, eg measured, species, regional, …

DISCUSSION

L385-387 Please explain more carefully why this priority stems from the previous lines of text

I miss a section where the authors zoom out on their results and bring forward 'lessons learnt' for people measuring and utilizing numbers on carbon stocks in practice. Generally, the discussion ends on a very specific statement and no any conclusion is made.