Response to anonymous referee #1

Ali et al. present a study on an interesting and important topic: biomass estimation for subtropical forests in the East Asian monsoon region. The study is generally well introduced and clearly structured. The data set is most probably appropriate to tackle the research questions raised by the authors. The choice of analytical methods, however, needs considerable reconsideration in some regards.

=> We are grateful to referee #1 for providing useful comments on our study. We have thoroughly revised our manuscript (MS) by following the reviewer's suggestions. According to the reviewer's constructive comments, we have reorganized the conceptual models (see Fig. 1 in the revised MS). In addition, we have re-analyzed our data with structural equation models (SEMs) and we believe that our MS has substantially been improved.

=> Please find our responses to your specific comments below.

1) Measurements and calculations of carbon stocks

- There are no measurements of carbon stocks, just calculations based on allometric equations, so please adjust the section title accordingly.

=> We have adjusted the section title. Thank you.

- I was not able to find eqn 1 in Brown et al. 1989, please indicate exact reference or modification if applicable.

=> Actually, we used the revised form of the equation in Brown et al. (1989), which had been published in FAO papers (1997). We apologize for the wrong citation. In the revised MS, we have calculated AGB using equations in Chave et al. (2014), and used the D and H model.

- 14% of variance in tree height are not explained by diameter. This information could be used to improve allometric estimates, since the diameter-height-allometry varies with environmental conditions, and might provide valuable additional information.

=> This is a constructive comment. In the revision, we have employed Chave et al. (2014) model by using DBH, H and wood density as predictors, and we believe that this model improved the estimation of AGB of large trees.

- However, there is no way of validating your AGB estimates, since no yield data are available. In the same regard, the comparison of eqn 1 with other allometric equations is not useful, since you never know the true AGB for the plots. If this comparison shall be kept, then please change it into some kind of uncertainty estimate. Rˆ2 values do not help much here, since all equations are based on the same parameter (diameter), so please report RMSE values. Related: in fig. S3, please provide equidistant scaling of the axes.

=> We agree with your comment that we cannot validate AGB estimates in the previous MS. We have used the most recent global allometric equation developed by Chave et al. (2014) for estimation of AGB (as recommended by referee# 2), as it has been found to be the most suitable and appropriate equation for tropical and subtropical forests. Therefore, there will be no need to compare AGB estimates from different allometric equations, as allometric equations in Chave et al. (2014) include subtropical forests. Thank you.

- L191 ff: To me, it is unclear how to relate the DBH of a single tree to area-based basal area estimate. Please elaborate here.

=> Sorry for the lack of clarity in the previous version of our manuscript. Tree basal area is calculated as pi*(DBH/2)^2, and stand basal area is the sum of all tree basal area. In the revised MS, we have deleted these sentences, as there is no need for comparison anymore. Thank you.

- L197: You are not using a D-H model.

=> We have clarified this in the revised MS, by using the D-H model for both big trees and small trees and shrubs. Thank you.

2) Calculation of structural diversity
- L210ff: Why do you optimise for a good correlation between H for DBH and height? If you so, you might as well use only one of these factors as a surrogate variable for general tree dimension diversity. I suggest comparing results for different discretization cutoffs instead. This would also interesting for the SEM approach: stand age drives structural diversity, but the direct link between stand age and C-stocks is stronger than the indirect one. One reason for this might be a mismatch in classification resolution.

=> We agree with the suggestion and have compared results for different discretization by employing SEMs and select the best SEM through AIC. Please see Table S3 for such comparisons and selection of best SEM. Moreover, in the revision, we have used stand structural diversity as a latent variable by incorporating both DBH and height diversity indices.

3) Statistical analysis

- You present a variety of linear modeling variants, when all you want to know is how a set of six parameters influences two response variables. The first set of analysis is contained in the second set, and the second set is a complicated way of doing an AIC based stepwise procedure (under the assumption that collinearity in the design matrix is manageable, which you suggest, but might want to reconsider given the explained variance of the single predictors sum up to > 160% (see L330ff)).

- The basic question, as I understand it, is: which set of variables is the best choice for predicting C-stocks. Following this logic, a validation approach would be suited to address the problem, either using a stepwise procedure, using explicit variants of multiple regression models (like already done for the second stream of analyses), or a learning routine that allows for inspection of relative variable importance (like random forests). 80 plots could well be enough for such a validation scheme.

=> Thanks for the constructive comments here. We have followed the comments on diversities and compare the results. Therefore, we have only use SEMs for comparing different models based on different combinations of DBH and height diversities of different discrete classes. In addition, we have provided bivariate relationships and Pearson's correlation coefficients in Fig. 2 and Table S2, respectively. Further, we have also refined our conceptual model in order to test the complex pathways in one SEM model, instead of in two models (as conducted in the previous MS).

The results are presented in a clear and concise fashion, and the discussion is consistent, comprehensible and linked to current literature, given the results based on the complex analysis scheme.

=> Thanks a lot!

Some minor corrections:

- *L339 "range" instead of "ranged"*
- *L480 "which was also found"*
- *L537 "to increase C storage"*
- *L187 "using Brown's"*

- *L190 why switch from DBH to D?*
- *L192 "using Brown’s“*
- *L194 "that Brown’s“*
- *L201 AGBt*
- *L247 "using equation 3“*

=> We have corrected all these mistakes in the revised MS. Thank you.

Response to anonymous referee #2

General comments

In general, I consider the MS has great potential in providing a strong contribution to ecological literature by assessing the relative role of different predictors and particularly of structural and species diversity on carbon stocks in subtropical secondary forests. This is a topic of active research today. However, I consider the current version is still away from publishable in Biogeosciences. I have five main comments on this:

=> We are grateful to referee #2 for providing constructive comments on our manuscript. According to the reviewer's comments, we have thoroughly revised the MS both in theoretical and analytical aspects. Please find our responses to your specific comments below.

1) First, Rather than providing a strong conceptual approach for framing their aim, that is, testing the role of structural diversity on aboveground biomass, authors made a long but not structured literature review of the many variables that could explain variation in AGC stocks, of course making particular emphasis on those the will further test. After such review, there are no clear stated hypothesis guiding the application of statistical methods and their prediction is so general and non-exclusive that it could be demonstrable almost with any result. I consider the conceptual model in Figure 1 is a good starting point, but such a model should be clearly sustained in the introduction. It could serve as the hypothesis to be tested. Another argument on favor of this critique is that soil carbon stocks are almost no introduced and furthermore, authors pretend to explain them with the same set of predictors than used for the AGC case. This shows a naive approach that does not take into account the vast literature on the factors influencing C stocks in (tropical) soils.

=> Thanks for these constructive comments. We agreed with your concerns that the research aims are not well structured in our previous MS. In the revision, we have clearly introduced our new conceptual models in the introduction for driving the specific hypothesis. In the introduction, we have argued that stand structural diversity contributes directly to AGB, but variations in stand structure may also enhance light capture and C storage. Hence, stand structural diversity may vary more strongly than species diversity within communities (due to disturbances) and across communities (due to environmental gradients), and may have a larger direct effect on aboveground C storage (Poorter et al., 2015). Therefore, we hypothesized that stand structural diversity would have a stronger and positive effect on aboveground C storage than species diversity, once the direct effect of stand age has explicitly been taken into account, in secondary subtropical forests (see conceptual models in Fig. 1).

=> After careful consideration, we feel that it may be best to exclude the SOC component since data associated with many drivers such as local site condition, past disturbance history as well as litterfall (leaves and roots) feedback for SOC are not available. We have used much of our efforts on aboveground C storage by testing 48 structural equation models (SEMs), in order to clarify the effects of stand age, stand structural diversity and species diversity on aboveground C storage. Therefore, the SOC component has been excluded from our revised MS. Thank you.

2) In accordance with the unstructured introduction, authors present a wide range of statistical tests for testing basically the same idea. They use simple linear regression, multiple regression and SEM to test the same predictors each time. If you have worked to present a conceptual model like that in Figure 1, why to use approximations do does not allow to test it? Moreover, simple and multiple regressions ended providing almost the same results that SEM, with the exception of two new significant interactions in the SEM model, which are then undervalued by the authors. So I would suggest that according to the idea of a very clearly presented unique hypothesis, a unique analysis should be presented, in which case SEM seems to be the best option.

=> We agreed with your comments about statistical analysis. We have used SEMs by testing different combinations of height and DBH diversities based on different discrete classes, and then select the best model through AIC. In this way, we believe that our proposed hypothesis and conceptual model have substantially been improved than the previous version of the MS. We have provided bivariate relationships for each hypothesized path in SEMs in Fig. 2 and correlation coefficients in Table S2.

3) There are some parts of the discussion where authors present possible explanations to their results, but they do not realize that their own results (particularly the SEM) provide no support for such explanations. I consider that a more careful interpretation of such a model should be done.

=> We apologize for the lack of clarity in the discussion section in the previous version of the MS. We have now clearly discussed our new model with sound evidences in this and other studies. Thank you.

4) Authors sometimes cite references that are not appropriate or even not refer to the point under discussion. See several specific comments below.

=> We have avoided such mistakes in the revised MS. We apologize for inappropriate citations.

5) I consider the inclusion of site productivity as a predictor should be reconsidered (see specific comments below).

=> Thanks for your constructive comment. We have followed your suggested paper (Grace et al., 2016) for making a new conceptual model (see Fig. 1). By considering one of your comments below, we have excluded site productivity as a predictor, in the revised models.

Line 54. Replace ", and store" by "by capturing ". Yu et al 2014 highlight the capture capability rather than the currents C stocks.

=> We have corrected it in the revised MS. Thank you.

Lines 58-59. Authors assert site productivity impact C stocks. However, Lohbeck et al. did't tested the effect of site productivity on biomass or carbon stocks, they tested the reverse. A recent test of the effect of productivity on biomass can be found in Grace et al. 2016 Nature for grasslands, or the general hypothesis for the causal relations between productivity and biomass in tropical forests can be found in Quesada et al. 2012 Biogeosciences or Malhi et al 2012 J. of Ecology

=> Thanks for pointing it out. Actually, this is a wrong citation. We have corrected the problem in the revised MS. Your suggested papers have been considered while making a new conceptual model. Thank you.

Line 60. Does species diversity impact C stocks? The reference provided (Con et al. 2013) does not seem to provide conclusive evidence. I suggest to soften this assertion and to look for additional literature to sustain it. See for example Cardinale et al. 2011. Am. J. Bot.

=> Revised as recommended. Thank you.

Lines 61-63. Although authors use consistently a definition of "stand structural characteristics" throughout the MS which includes both "structural" and "diversity" variables, I consider this concept does not provide to the reader a complete idea of what is being tested here, and could hamper the interest on the work. The role of biodiversity has been the subject of much research in the last two decades and stating it separately may make more appealing the work to a broader audience. Therefore, I would suggest to use different concepts for structure and diversity.

=> This comment is very constructive. We have followed your suggestion by considering stand structural diversity as a latent variable including DBH and height diversity, while species diversity as a separate variable, as shown in the conceptual models (Fig. 1). Thank you.

Line 66. Include the recent work from Poorter et al. 2016 in Nature "Biomass resilience of secondary forests"

=> We have included their work. Thank you.

Line 69. I would say that Age is a variable that summarizes or reflects the action of several processes. Probably the authors need to rethink how age is included in their conceptual model. Particullarly, which would be the direct effect of stand age on carbon stocks? What is the ecological mechanisms behind such effect?

=> Indeed, Age is a variable that is related to processes such as growth, ingrowth and mortality. Our data do not include process-based measurements, and we wish to use age to summarize multiple processes responsible for standing aboveground carbon. We have used a complex conceptual model in the revised MS. In the previous version of the MS, using two different models, such as age model and stand characteristics model, caused much confusion. We have avoided such type of confusion in the revised model. Thank you.

Lines 78-82. Soil C is an important component of the study. However, it is just briefly introduced and the ecological mechanisms linking aboveground biomass or productivity with soil C stocks are not explained here. Therefore, your questions regarding soil C are not fully understandable.

=> After careful consideration, we feel that it may be best to exclude the SOC component since data associated with many drivers such as local site condition, past disturbance history as well as litterfall (leaves and roots) feedback for SOC are not available. Therefore, the SOC component has been excluded in the revised MS.

Lines 83-90. These lines say the same than previous paragraphs, no? Probably better to merge them with previous paragraphs and to try to focus more on the general hypothesis regarding the effects of forest age, stand structure and stand diversity.

=> We have revised and rearranged our introduction by basing on new conceptual models, as you have suggested in earlier comments. We have proposed a new hypothesis based on our new conceptual models. Thank you.

Line 98. What is C synthesis?

=> We apologize for using different terminology here. Actually, we meant C stock or storage.

Lines 110-111. So anything could explain C stocks? Isn0t there a hypothesis on which of this potential explanatory variables could be more important? Also, what is stand density? Isn't it included within stand structure in general?

=> Thanks for your constructive comment. In the revised MS, we have considered stand structural diversity including DBH and height diversity, and species diversity as potential explanatory variables, when assessing the residual effect of stand age on both of them. Stand density is the number of trees per hectare. Yes, it is included within stand structure in general. We have avoided this variable in the revised conceptual models.

Line 112. What is a direct effect of stand age? Isn0t it mediated always by stand charachteristics? Which is its ecological basis?

=> With increasing stand age, biomass accumulation will increase by following stand development, tree growth and increased stand structural diversity. Therefore, stand age can act as a driver for increasing carbon stocks. In the revised MS, we used one complex conceptual model. In the previous version, using two different models, such as age model and stand characteristics model, caused much confusion. We have avoided such type of confusion in the revised model. Thank you.

Lines 114-115. This generalization applies only for wet forest, probably not for dry forests. Please be specific.

=> We have considered the general approach here (Bazzaz, 1979), by considering the original reference in the revised MS. However, this generalization also applies for dry forests but probably based on different aspects of ecological mechanisms (Becknell and Powers, 2014). Thank you.

Lines 117-118. That is not an adequate prediction, that is a "all matters" scenario. Rather, say that you tested the contribution of different predictors.

=> We have revised here according to our new conceptual models. Thank you.

Line 122. Randomly? Within the entire landscape? How were you sure they represented all the successional gradient possible? There were no mature forests, conserved and/or degraded? Did you use a GIS to select them? Please elaborate on site selection.

=> Thanks for pointing it out. 'Randomly' is not an appropriate description of site selection. Actually, we selected sites and plots through both field survey and local forestry inventory that were used for classifying regional vegetation types. We have further elaborated on site selection in the revised MS. Thank you.

Line 122. Stand age in relation to what? What kind of disturbance?

=> We defined stand age as time since last stand replacing disturbance, which includes clearcutting, reclamation from agriculture, and windthrow by typhoon. This has been clarified.

Lines 124-130. Questions should be rephrased, their actual form is not appealing (they seem barely descriptive). Also, questions 1 and 2 are the same but in their discrete and continuous forms, respectively.

=> We have revised the proposed questions according to the new hypothesis and conceptual models. Thank you.

Line 140. The "consequently" is not clear. Authors asserted "there were different intensities of human disturbances (typically logging)" Do they refer to different types of disturbance, different intensities of logging, or both? This is quite important since recent studies on succession have highlighted the relevance of different types of previous land-use or land-use *intensities for the unfold of succession (Mesquita et al. BioSciences 2015, Arroyo-Rodríguez 2015 Biological Reviews). Moreover, it is particullarly relevant the authors provide a detailed description of the disturbance history of the region and of the related criteria for selecting plots in particular.*

=> Yes, different types of disturbances such as logging, land conversion, windthrow by typhoon etc, as well as different intensities of logging at different sites happened in the history. We have clarified those in the revised MS. Thank you.

Line 141. Rather than developmental stages, which may refer to a departure from a clear-cutted forests, authors could use "stands with different levels of degradation" or "stands with different level of perturbation"

=> We have revised it as recommended. Thank you.

Line 142. Does this mean that there was previously a landscape characterization of different landcover types from which it was possible to filter only successional forests and to select randomly the location of the plots?

=> Yes, more exactly saying, there was a landscape characterization of different forest use types, i.e., secondary shrublands, mature forests protected from clearcutting or logging, and logged forest. We have clarified this section "Study site, plots and forest structure" in the revised MS. Actually, the detailed description of the study area was not included in the previous version.

Line 143. Any kind of disturbance? Excluding only recent human disturbance? What do authors mean exactly by "recent"?

=> We have clarified the kind of disturbance in the revision. Recent means for the last 3 decades according to records from the local government. Thank you.

Line 148. What do the authors mean by "typical habitats"? Did the authors include plots in different environmental conditions? Or do they refer to different successional habitats all in under the same environmental conditions?

=> Sorry for the vague wording, we have rephrased this statement. Thank you.

Line 152. It is interesting that until here I assumed the authors constructed a chronosequence of sites derived from a pulse-type disturbance. This was probably because of the use of the terms forest age and secondary forests, which are commonly used in the literature to refer to clear-cutted sites. However, after looking at Table 1, I figured out that sites were assigned to one of three different "development stages", which seems to be different in the intensity of previous logging. Therefore, sites were not clear-cutted but instead affected by a pressure-disturbance like continuous logging. Therefore, I suggest the authors provide their working definition of secondary forest, or, alternatively, use the term "degradation level", "degradation intensity" or simply "logging intensity" to refer to their different levels of logging. Authors can look at several references for the definitions of secondary forest and degraded forest (Chazdon 2014 Second Growth, Chapter 1; Chokkalingam & de Jong 2001 International Forestry Review; Putz & Redford 2010 Biotropica).

=> Thanks for your constructive and helpful comments on site selection. We have clarified those in the revised MS, by following your comments and suggested papers for definitions.

Line 169. Which stages? You have not defined such stages here.

=> Developmental stages such as young, pre-mature and mature forests. Now, we have changed this term to "stands with different levels of degradation", as suggested.

Lines 170-171. Ok, so it is an indirect measure of productivity. Much more is therefore required on the definition of the disturbance regime to which such plots were subjected. Was the initial point (year 0) a clear-cutted forest for all? Or a selectively logged forest as suggested by Table 1?

=> Yes, we have indirectly estimated the site productivity by reviewing the official documents of Ningbo Forestry Bureau, Zhejiang Province, to collect relevant data about the disturbances for each site in the study area. The study plots included both clear-cut forests and selectively logged forests. More specifically, there was a landscape characterization of different forest use types, i.e., secondary shrublands, mature forests protected from clearcutting or logging, and logged forest. Site productivity as a predictor has been excluded from new analyses, as recommended by the reviewer.

Line 176. Which one of these references was used to calculate biomass? Please be specific.

=> We used both references because Brown’s (1989) equation only covers trees with DBH > 5 cm while equations in Ali et al. (2015) were developed for small trees and shrubs. Thank you.

Lines 175-184. Why is this paragraph here? A portion could be used during model framing in the introduction section.

=> Thanks for the constructive suggestion here. We have deleted all description about site productivity, as site productivity is not included as a predictor in the revised MS.

Lines 188-189. This is not an argument to exclude height from biomass calculation. See for example Chave et al. 2014 GCB for a detailed discussion on height inclusion in allometric equations.

=> We have used recent general allometric equations using DBH, H and species’ wood density as predictors for the calculation of AGB (Chave et al., 2014) in the revised MS. Thank you.

Line 192. First sentence is not clear: what kind of uncertainty is avoided and why?
Line 193. second sentence should be re-written

=> Actually, most of the generalized allometric equations are for tropical forests instead of subtropical forests. Therefore, we compared different models to avoid uncertainty. We have used the Chave et al. (2014) equation, which includes subtropical regions. Thank you.

Line 196-197. what are D-H models?

=> Model using DBH and height as predictors for estimation of AGB. We have clarified this in the revised MS.

Lines 210-211. Why you did not use the Chave et al. 2014 equation, which seems to improve Chave0s et al 2005 equations?

=> We have used the Chave et al. (2014) equation in the revised MS. Thank you.

Line 2015. Therefore, which equation you used? I suggest all this discussion could go in an Annex or supplementary material, leaving here in the methods only the description of the equation finnally used

=> Brown’s equation was used for the estimation of AGB of big trees. Now, we have used the Chave et al. (2014) equation in the revised MS. Thank you.

Line 216. Why you did not used the Alí et al. 2015 equation for all the tree community?

=> Ali et al. (2015) equations were only developed for small trees and shrubs.

Line 239. Does this values refers to the number of categories, the range of the categories or the limits of the categories?

=> These values refers to the limits of the categories. For example, for DBH < 2 cm, 2.1 – 4 cm, 4.1 – 6 cm, etc.

Lines 244-245. Why to use correlated DBH-height classes if you then want to assess their explanatory ability in a unique multiple regression model? Should not the categories be selected based on their correlation to the variables you want to explain, i.e. biomass? You could simply try to test correlation between diversity and biomass and select those categorizations given the maximum correlation.

=> Thanks for your constructive comment. By following this comment, we cannot get any good fit for the SEM model when we tried. Therefore, it is better to test different SEM models instead of just focusing on correlations. In the revision, we have tested a number of SEM models through combinations of different DBH and height diversities based on different discrete classes, and then select the best model based AIC (see Table S3). In order to make things clearer, we have provide statistics of all SEM models in Table S3 and more details for selected best models (Fig. 3; Table 1).

=> Interestingly, when we used correlation between DBH and height diversity as a latent variable ‘stand structural diversity’ in SEMs, we also cannot get a good model fit, indicating that these two diversities are independent in our study. Thank you.

Line 251. Mathematical notation is wrong. x should denote only one thing: or the number of different attributes evaluated (3) or the number of classes within a attribute.

Furthermore, sub-index for p should be i (pi), because the proportion is evaluated for each i class within 1 and x (if x is the total number of classes).

=> We have corrected the equation form in the revised MS. Thank you for pointing it out.

Line 270. Please say explicitely at the beggining of the secition 2.3 which C pools are considered in this study: "two carbon pools were assessed in this study: aboveground living biomass of the tree community (excluding lianas and herbs, no'), and soil organic C in the top 20 cm of soil").

=> We have clarified it in the revision.

Lines 270-276. Probably better to summarize lines 270-276 by saying that for each series, al the possible variable combinations and interactions were tested (a fully ...model) and the best model was selected using AIC.

Line 291. If you have previously settled a hypothesis of a hierarchy of effects acting onC stocks, why to use simple and multiple linear models and not going directly to the SEM? What is the original hypothesis? Doesn0t SEM allows you to test the same that multiple regression model allows, that is, which are the structural determinants of the C stocks?

=> By considering all of your comments on the conceptual model, we have only employed SEMs in the revised MS. In addition, the bivariate relationships are included in Fig. 2 and correlation coefficients in Table S2. Thank you.

Line 304. Age is not expected to be linearly related to AGC. Also, from Figure 2 it seems that some of the relations could be better explained using a non-linear (but probabliy linearizable) model.

=> We have considered your suggestion in the revised MS, by assessing both linear and several linearizable forms (log, 2nd and 3rd order polynomial). Finally, we used the simple linear regression analysis to test for bivariate relationships because, 1) there were no big differences between linear and non-linear relationships that may cause any big difference in our results; and 2) in order to avoid complexity of the composite variables in the SEMs. Thank you.

Lines 307-310. So, really the logic behind fitting such models was to select the best to use in SEM? Why not allowing SEM to test the whole model? Why testing two different models if you can test only one?

=> We have used one SEM model and accessed the whole model as well as the best model based on AIC. Thanks for the helpful suggestion.

Lines 314-320. This paragraph is very difficult to grasp. Does the second sentence mean that rather the structural diversity, the proportion of big trees could alternatively explain biomass?

=> Yes, you are right. We have deleted this method in the revised MS because of not too much helpful.

Lines 315-318. If I understood well, this is the same problem with analyzing Shannon index results for species diversity: we do not actually know if an increased diversity is caused by increased number of categories (which in this case means increased number of big trees) or by a more even distribution among categories (that is, basal area is more equitatively distributed among dbh categories). If you want to dissect such effects, then wouldn0t be easier to have from the beginning to different predictors indicating directly such different possible explanations? Moreover, previous findings would allow authors to hypothesize that the amount of big trees is an important predictor of forest biomass (Slik et al. 2013 Global Ecol. Biogeo.), so authors could use some indicator of the size of the biggest trees as a predictor of biomass.

=> Thanks for your constructive comments here. We have used SEMs to test different combination of DBH and height diversities based on different discrete classes, to know whether increased diversity caused by increased number of categories has any different effect on aboveground C storage.

Line 322. I0m not completely sure that a higher correlation with CV means that dominance of big trees is not important. Higher CV values means that deviation from the mean DBH or H increases, which can happen if bigger trees are present but there is an uneven size distribution.

=> We have used the alternative approach, as you have suggested above. Thank you.

Line 332. Most of the significant relations seems to violate linear regression assumptions, particularlly that the straight line is an adequate representation of the relationchip or that variance is homogeneous. Authors do not clarify through the text or in the supplementary tables if other relationships were tested or if variables were transformed to meet assumptions

=> We have provided details in the revised MS, please see the third paragraph in the statistical analyses in the revised MS. Thank you.

Line 334. Species density? Stand density?

=> Actually, it was species diversity and stand density (trees per hectare). We have clarified this.

Line 341. What is the positive variation?

=> Means positive linear relationship. We have revised this.

Lines 360-363. Probably, the synthetic models are not necesary. Authors can check that the relative importance of variables in the synthetic model correlates negatively but perfectly to the p values associated to each of the variables in the best-fit model. So probably that part could be taken to the supplementary material.

=> Thanks for the constructive comment here.

Lines 368-369. As expected, there is no direct functional relation between stand characteristics and C stocks. This only reflects the poor literature review on the mechanisms that drive C accumulation in tropical forests soils.

=> We have included more potential and recent literature about aboveground C storage, while we have dropped the SOC component in the revised MS. Thank you.

Lines 377-379. There is no sense in having these two alternative models, at least if there are no competing hypothesis grounded on strong ecological knowledge.

=> We have focused on our new conceptual model. Therefore, this part has been updated.

Lines 380-381. I really have a doubt on the meaning of the variable "productivity" here. As defined, productivity is calculated on the basis of stand volume divided by forest age. Stand volume is another measure of biomass (the volume of a forest is filled with biomass, so as it is bigger, biomass is bigger), rather than an "independent" structural measurement. I really think that it is an spurious relation and that the authors should consider to exclude it from the model.

=> We agreed with your suggestion to exclude productivity from our conceptual model. Thank you.

Lines 382-383. What is the difference between this model and the multiple regression model?

=> Sorry for providing double proof of the results. We have only considered SEMs in the revised MS.

Lines 410-411. This last sentence evidence the poor literature review made by the authors on the ecological and physical processes controlling C stocks in soils. I suggest to not include soil C stock estimation in the model, but rather to provide their estimates as supplementary material.

=> We have excluded SOC in the revised MS. Thank you.

Lines 419-420. Such argument would imply that higher species diversity have incidence on higher structural diversity. However, there is no association between species and DBH diversity, so data does not support such possibility.

=> According our new analysis in SEM, it is clarified now. Please see Table 1 and Fig. 3 for positive association between species and stand structural diversity. Thank you.

Line 433. If such argument was true, a significant relation between species diversity and stand age should arise.

=> We have revised it accordingly. Please see lines 1441-1454 in the revised MS.

Line 449. Uncertain? It seems authors are "averaging" results from two different approaches and therefore saying that there is no conclusive evidence, even with the same data! That0s *why it is important to have a clearly stated hypothesis from the beginning and to use the adequate analytical framework to test it.*

=> This section has been updated by focusing on our new conceptual models. Thank you.

Line 451. A similar argument was raised by Grace et al. 2016 Nature

=> Thanks for your interest in the argument but this section has been updated based on our new analysis.

Lines 467-468. Site productivity does not mediate such relation according to SEM. Please rephrase.

=> This section has been updated based on our new analysis. Thank you.

Line 481. Dupuy et al. 2012 do not test age as a predictor of biomass. Please see Hernández-Stefanoni et al. 2010 Landscape Ecology for the adequate reference. There are a lot more of references on the recovery of biomass or AGC stock during succession in both wet and dry tropical forests. See also Poorter et al. 2016 Nature for a recent compendium.

=> We have updated it by citing most recent studies (Poorter et al., 2016). Thank you.

Lines 485-487. this argument is not right. Although it is true that at tree level bigger trees acumulate more carbon, at the stand level it is not true if we have a gradient of forest age, for which maximum accumulation commonly occurs early in succession. See Mora et al. 2016 Biotropica, Vargas et al 2008 GCB or Yang et al. 2011 New Phytologist for how expected rates of change should be higher in the first decades of succession.

=> We have deleted this sentence in the revised MS because we are focusing on the stand level analysis instead of tree level. However, we have provided argument to support our result in lines 746-748.

Line 488. Not pretty sure of this since CV test does not seem to be the best indicator.

=> For CV of DBH as a good predictor of AGB, please see (Zhang and Chen, 2015).

However, we have not focused on CV in the revised MS. Thank you.

Line 499. Lohbeck et al. 2015 never tested productivity as a predictor of biomass, but the reverse (biomass as a predictor of productivity).

=> We have revised it. Thank you.

Lines 500-504. In the model site productivity is not affected by forest age, so this argument does not march data.

=> We have excluded productivity from our conceptual model, as you have suggested in an earlier comment. Thank you.

Line 514-516. This argument is not clear at all

=> We have clarified it in the revised MS.

Lines 536-537. Please elaborate more on how stand diversity could be improved based on your results.

=> We have elaborated it in the revised MS. Thank you.

Line 790. Why should soil organic C depend on structural stand variables? There are many ecological process between C accumulation in the aboveground biomass and its accumulation in soil (literfall, biomass decay, microbial growth), plus a set of factors that may have greater potential impact (soil type, bulk density, previous land use, etc).
For the case of soil organic C, this model seems very naive.

=> Thanks for your constructive comment here. Actually, we were interested that whether and how stand characteristic affect SOC stock. We have dropped the SOC component from our analysis, as explained in earlier responses.

Specific comments
Line 123. Replace “in accordance to” by “regarding the” or “about the”
Line 230. Delete “in”
Line 247. Please modify to ".. diversities were calculated for each plot using equation 3".

Line 254. Replace “analysis” by “calculation”

Line 512. Replace by "effect"

=> We have corrected the above mistakes in the revised MS. Thank you.

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~~Relative contribution of stand characteristics on carbon stocks~~Stand structural diversity rather than species diversity enhances aboveground carbon storage in secondary subtropical ~~secondary~~ forests in Eastern China

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Tables: ~~2~~1 Figures: ~~3~~3 References: ~~58~~38

Supplementary information: Tables: ~~14~~3 ~~Figures: 5~~

Contribution of the co-authors: AA, ~~and~~ ERY and HYHC conceived and designed the study. ERY coordinated the research project. AA, YTZ, XDY and MSX conducted sampling design, field and lab works. AA analyzed the data. AA and ERY wrote the paper. HYHC and SXC reviewed, commented and edited the ~~paper~~ drafts. All the authors read and approved the final manuscript.

Abstract

Stand structural diversity,~~ which is~~ typically characterized by~~ species diversity,~~ variances in tree diameter at breast height (DBH) and height, plays an important role in influencing aboveground C storage~~forest carbon (C) stocks~~. However, few studies have considered the multivariate relationships of aboveground C storage with stand age, stand structural diversity and species diversity in natural forests. ~~However, the relative contribution of stand structural diversity in contrast to other stand characteristics on the variation in C stocks in subtropical forests have not been fully explored.~~ In this study, aboveground C ~~stock~~storage~~, soil organic C stock~~, stand age and tree species, DBH and height diversities~~, stand age~~, ~~and stand density, and site productivity~~ were determined across 80 subtropical forest plots in Eastern China. We used structural equation modeling~~s~~ (SEM~~s~~) to test for direct and indirect effects of 48 combinations of discrete classes ~~for~~of DBH diversity (2, 4, 6 and 8 cm classes) and height diversity (2, 3, 4 and 5 m classes), species diversity and stand age on aboveground C storage. The ~~selected~~ three selected SEMs with any direction for the path between species diversity and stand structural diversity had a similar goodness of~~-~~ fit to the data. The ~~selected~~ three SEMs explained 82% of the variation in aboveground C storage, 55-59% of the variation in stand structural diversity and negligible variation in species diversity. Stand structural diversity had the strongest direct and positive effect on aboveground C storage ($\beta = 0.56$, $P = 0.001$), followed by ~~the~~a positive effect of stand age ($\beta = 0.41$, $P = 0.003$) and ~~the~~a negative effect of species diversity ($\beta = -0.23$, $P < 0.001$). ~~Using simple regression analysis, we found that DBH and height diversities, site productivity, and stand age explained 49%, 13%, 41%, and 50% of the variation in aboveground C stock, respectively, whereas species diversity and stand density did not explained any variation (i.e., < 1%). Multiple regression analysis indicated that variation in aboveground C stock was explained to a higher degree (83%) by the joint effects of DBH diversity, stand age, site productivity, species diversity and height~~

~~diversity than by stand structural diversity (54%), and the other three stand characteristics (79%) alone. The structural equation modelling (SEM) showed that the effect of stand age on aboveground C stock was stronger directly (beta = 0.59) than indirectly (beta = 0.11).~~ Stand age ~~has~~ had also a ~~significant and~~ strong effect on ~~DBH (beta = 0.63) and height~~stand structural diversity ($\beta = 0.74$, $P < 0.001$~~beta = 0.55~~)~~.~~, but a weak effect on species diversity~~diversities~~. Our analyses suggest that stand structural diversity is a major determinant for the variation in aboveground C storage in the secondary subtropical forests in Eastern China. Maintaining tree DBH diversity and height diversity through silvicultural operations could be an effective approach for enhancing aboveground C storage in these forests.~~on aboveground C storage lythe Six stand characteristics did not explain any variation in soil organic C stock (i.e., < 2%), based on both simple and multiple regressions analyses, as well as SEM analysis. Our analyses suggest that, rather than species and height diversities, DBH diversity, stand age and site productivity cumulativelybut not contributed to variation in aboveground C stock during stand development in subtropical secondary forests in Eastern China. in eastern ChinaTherefore, improving tree DBH diversity and stand condition could be an effective approach for enhancing C storage in subtropical forests.~~

Key words: biodiversity; carbon storage; evergreen broadleaved forests; species diversity; stand ~~forest~~ structure; ~~regressions;~~ structural equation model.

1 Introduction

Subtropical forests in the East Asian monsoon region play a critical role in global carbon (C) cycling~~,~~, ~~and store~~ capture~~ing~~ more C than previously thought (Yu et al., 2014)~~(Yu et al., 2014)~~. ~~Currently, most of these forests are naturally regenerated secondary forests (Wang et al., 2007), and their C stocks increase as they recover from disturbances (Yu et al., 2014).~~ Despite their importance (Niu et al., 2012; Wang et al., 2014), we still lack a complete understanding of how aboveground C ~~stocks~~ storage vary with ~~changes in stand characteristics~~stand age, and changes in species diversity and stand structural diversity in these forests (see the conceptual models in Fig. 1). Aboveground C storage in forest ecosystems is directly impacted by tree species diversity ~~It is well known that biomass or C stocks in forest ecosystems are directly impacted by site productivity (Lohbeck et al., 2015), stand density (Vayreda et al., 2012), tree species diversity (Cardinale et al., 2011)(Con et al., 2013), t~~and stand structural diversity ~~ree diameter at breast height (DBH, diameter at 1.5 m above root collar) diversity, and tree height diversity~~ (Dănescu et al., 2016; Wang et al., 2011)~~(Wang et al., 2011) (Fig. 1)~~. ~~The last-three diversity parameters alone or combined are typically defined as the stand structural diversity (e.g., Dănescu et al., 2016; Staudhammer and LeMay, 2001)(Staudhammer and LeMay, 2001).~~ In addition, stand age, as an indicator for stand development following disturbances, has been identified as a primary factor that influences aboveground biomass (AGB) in both even-aged (Böttcher et al., 2008)~~(Böttcher et al., 2008)~~ and ~~naturally~~ uneven-aged (Becknell and Powers, 2014; Poorter et al., 2016) ~~(Becknell and Powers, 2014)~~ forest stands. Moreover, ~~variabilities~~variability in stand structural diversity and species diversity ~~, site productivity, and stand density~~ depends to a large ~~degree~~ extent on stand age (Lei et al., 2009; Wang et al., 2011; Zhang and Chen, 2015)~~(Lei et al., 2009; Wang et al., 2011 ; Lohbeck et al., 2015)~~. Therefore, stand age may directly and indirectly affect ~~C stocks~~aboveground C storage, ~~indirectly through the alteration of~~via changes in ~~other stand characteristics, such as~~ stand structural diversity and species diversity~~, , site productivity, and stand density~~ in forest ecosystems (Fig. 1). Surprisingly few studies have teased apart the direct and indirect effects of stand age, species diversity and stand structural diversity on aboveground C storage in complex natural forests (but see Dănescu et al., 2016; Zhang and Chen, 2015).

There has been a reinvigorated research interest ~~in analyzing~~on how AGB (thus aboveground C ~~stock~~storage) ~~vary~~ varies with stand age, species composition, and abiotic factors, in both managed plantations ~~(Smith et al., 1997)~~ and natural secondary forests (Becknell and Powers, 2014; Clark and Clark, 2000; Poorter et al., 2016; Zhang et al., 2012)~~(Clark and Clark, 2000; Becknell and Powers, 2014)~~; however, discrepancies among studies remain unresolved. ~~–~~For instance, some studies have documented that the relationship between species diversity and AGB was either positive (Dayamba et al., 2016; Wang et al., 2011; Zhang and Chen, 2015)~~(Wang et al., 2011; Con et al., 2013; Zhang and Chen, 2015; Dayamba et al., 2016)~~, negative (Szwagrzyk and Gazda, 2007)~~(Szwagrzyk and Gazda, 2007)~~, or non-significant (Vilà et al., 2003)~~(Vilà et al., 2003)~~. ~~(Dănescu et al., 2016; Poorter et al., 2015; Zhang & Chen, 2015)~~We hypothesize that species diversity has a direct effect on aboveground C storage in subtropical forests (Fig. 1a). Species diversity may also affect aboveground C storage via stand structural diversity (Poorter et al., 2015; Zhang and Chen, 2015). ~~and(e.g., Poorter et al., 2015)~~

The importance of stand structural diversity to aboveground C storage has recently been recognized (e.g., Dănescu et al., 2016; Poorter et al., 2015; Zhang and Chen, 2015). Multi-layered stand structure may be theorized to enhance light capture and increase light use efficiency (Yachi and Loreau, 2007). Stand structural diversity, which varies strongly within communities (due to disturbances) and across communities (due to environmental gradients), may have a large direct effect on aboveground C storage (Poorter et al., 2015). Stand structure attributes such as tree size (DBH and/or height) inequality among and within species are critical toward maintaining species diversity (Clark, 2010), and in turn affect aboveground C storage (Fig. 1a; Zhang and Chen, 2015). The effects of tree species diversity on aboveground C storage may be partly attributable to stand structural diversity because tree size variation helps maintain species diversity (Fig. 1b; Clark, 2010). Alternatively, species diversity and stand structural diversity provide positive feedback to each other (Fig. 1c).

(Clark, 2010; Dănescu et al., 2016; e.g., Poorter et al., 2015; Wang et al., 2011; Zhang and Chen, 2015)~~The relationship between species diversity or richness and soil resident organic C has also been reported to be either positive, in an old-growth forest in Northeast China (Chen, 2006), in a boreal forest in northern Sweden (Jonsson and Wardle, 2009), and under different land use types in tropical West Africa (Dayamba et al., 2016), or non-significant in a subalpine coniferous forest (Zhang et al., 2011).~~

The influence~~s~~ of species and structural diversity on aboveground C storage or productivity remains debated (e.g., Dănescu et al., 2016; Poorter et al., 2015), in part because ~~that~~ a well-documented coupling factor such as stand age, which is a critical driver for individual species dynamics, aboveground C storage and productivity (Zhang and Chen, 2015), has not often been explicitly considered. We hypothesize~~d~~ that stand age has a strong influence~~s~~ on aboveground C storage, species diversity and structural diversity in secondary subtropical forests. The effects of stand age ~~on aboveground C storage~~ may be direct (Becknell and Powers, 2014) or indirect~~;~~, ~~indirectly~~via stand structural diversity and/or species diversity,~~,~~ on aboveground C storage ~~on aboveground C storage~~ (Fig. 1).~~In addition to species diversity, forest productivity and aboveground C stock are also related to many other factors such as tree size inequality, stand age, nutrients regime, and climate anomalies (e.g., Chen and Luo, 2015; Zhang and Chen, 2015). Empirical studies have demonstrated that~~

~~aboveground C was either related to stand structural diversity, site productivity, or stand age in tropical forests (e.g., Wang et al., 2011; Con et al., 2013; Becknell and Powers, 2014; Stephenson et al., 2014; Lohbeck et al., 2015; Poorter et al., 2015). Changes in stand characteristics through forest succession have significant impacts on forest productivity and aboveground C stock (Becknell and Powers, 2014). This is because tree size inequality among and within species are critical toward maintaining species, DBH and height diversities (collectively referred as "stand structural diversity"; Wang et al., 2011), which has been recognized to significantly affect forest C stocks (Lexerød and Eid, 2006; Zhang and Chen, 2015). It is understandable that stand structural diversity is shaped by species composition with different sized (DBH and height) trees in multistory canopies (e.g., Lei et al., 2009; Liang et al., 2007)(Liang et al., 2007; Lei et al., 2009). At the community level, variations among tree diameters and heights, resulting from both differences within and among species (Zhang and Chen, 2015)(Zhang and Chen, 2015), may allow different levels of tree canopy heights, and increase the C synthesis of sub-canopy trees or understory plants by facilitating an increase in the availability of light (Chave et al., 2009)(Chave et al., 2005).~~(Dănescu et al., 2016; e.g., Poorter et al., 2015; e.g., Zhang and Chen, 2015)~~as~~

~~Even though the bulk of evidence suggests that forest C stocks are ecologically linked to stand structural diversity, stand productivity, stand density and age in other forest ecosystems, it remains unclear how stand structural diversity alone, or in combination with stand age, site productivity and density, explain the variation in C stocks in secondary subtropical forests. Recently, Barrufol et al. (2013) found that Chinese subtropical tree diversity is an important driver of forest productivity and re-growth after disturbance that supports the provision of ecological services. However, field tests of which stand characteristic best explain variations in C stocks are rarely done (but see Wang et al., 2011; Con et al., 2013), and remains unclear in secondary subtropical forests. In this context, w~~We

~~anticipated that stand structural diversity, stand age, site productivity or stand density are the main drivers to influence variations in C stocks across secondary subtropical forests. The effects of stand age on C stocks may be direct (Becknell and Powers, 2014)(Becknell and Powers, 2014) or indirect (i.e., mediated through stand characteristics) on forest C. For example, stand age leads to changes in the composition of plant species over the course of succession, by which shade-intolerant species trategyare replaced with shade-tolerantly conservative species(Bazzaz, 1979) (Vayreda et al., 2012). We predicted that C stocks would increase with stand age, but after accounting for stand age, residual variations could be explained by a combination of species diversity, DBH diversity, height diversity, site productivity, and stand density (Fig. 1). Thus, stand age may be the primary driver of C stocks in secondary subtropical forests, as previous works have suggested that stand age is a strong determinant of stand growth (Powers et al., 2009; Becknell and Powers, 2014).~~

In this study, we aim~~ed~~ to investigate the effects of stand structural diversity and species diversity on aboveground C storage, while accounting for the effects of stand age. We used structural equation model~~ing~~s~~s~~ (SEMs; Grace et al., 2016) to analyze data from 80 structurally diverse and mixed subtropical forest plots in Eastern China. Specifically, we tested the following paths: 1) the effects~~s~~ of stand age on aboveground C storage, species diversity, and stand structural diversity, 2) the indirect effect of stand age on aboveground C storage via stand structural diversity and/or species diversity, and 3) the direct and indirect effects of stand structural diversity and species diversity on aboveground C storage (Fig. 1). Because of the complex interactions between species diversity and stand structural diversity (Clark, 2010; Zhang and Chen, 2015), we tested the influence of stand structural diversity and species diversity on each other ~~the on~~(Fig. 1c).~~(SEMs; Grace et al., 2016)To test our hypothesized relationships between stand age, stand characteristics, and C stocks across subtropical forests, we randomly selected 80 forest plots with different stand ages in Eastern~~

~~China. Specifically, we asked the following questions in accordance to relative contribution of stand characteristics for explaining variations in C stocks: 1)~~

~~are stand structural diversity, stand age, stem density, and site productivity associated with aboveground C and soil organic C stocks? 2) what are the relative contributions of stand structural diversity *versus* stand age, stand density, and site productivity to variations in aboveground C and soil organic C stocks in subtropical forests? and, 3) what are the direct and indirect effects of stand age on variations in aboveground C and soil organic C in these subtropical secondary forests?~~

2 Materials and methods

2.1 Study site, plots and forest structure

The study was conducted in the lower eastern extension of the Tiantai and Siming Mountains (29º41-50´N, 121º36-52´E) located near Ningbo City, Zhejiang Province, in Eastern China. This region has a typical subtropical monsoon climate with a hot and humid summer and a dry cold winter. The highest peak in this area reaches 800 m above sea level, while most other reliefs are in the 70-500 m range (Yan et al., 2013)~~(Song and Wang, 1995)~~. The soils in these areas were classified as Ferralsols according to the FAO soil classification system (World Reference Base for Soil Resources, 2006), with the parent materials consisting mostly of Mesozoic sedimentary rocks, some acidic igneous rocks, and granite residual weathered material (Yan et al., 2013).

Five study sites were selected in the study area, including Tiantong National Forest Park, Ruiyan Forest Park, Dongqian Lake Landscape Area, Shuangfeng Mountain, and Nanshan Mountain. The studied region had been subjected to both anthropogenic and natural disturbances such as logging, land-use conversion, windthrow by typhoon~~ etc~~, and~~s well as to the~~ different ~~level of~~ intensities of human disturbances in the history~~(typically logging)~~, but has~~ve~~ been protected from ~~this~~ anthropogenic ~~activity~~ activities for the last more than 25 years. Consequently, forests in the region contained stands ~~at~~ with different levels of degradation ~~different developmental stages~~ (Wang et al., 2007; Yan et al., 2009)~~(Wang et al., 2007; Yan et al., 2009)~~. Although forests in the study areas are thought to be secondary subtropical forests, the mature forests around a Buddhist temple in the center of the Tiantong National Forest Park approximate to climax monsoon evergreen broadleaved forests as they have been protected from complete clearance for centuries.

~~in the historyve(for more description about the study area see; Wang et al., 2007; Yan et al., 2009; Yan et al., 2013)~~

We selected stands that have naturally recovered without human disturbances for more than three decades in the study areas. We established a total of 80 plots including young forests (n = 21), premature forests (n = 39) and mature forests (n = 20) (Yan et al., 2013). The measurement of plots was carried out through forest inventory and ground based survey, which were conducted between 2010 and 2013, based on Forestry Standards for 'Observation Methodology for Long-term Forest Ecosystem Research' of the People's Republic of China (LY/T 1952-2011). Each plot (20 × 20 m) was located at a distance of least 100 m from stand edges in order to minimize edge effects. We acknowledge that our plot sizes were quite small; however, similar to other regions, secondary forest patches often occur in smaller tracts than is the case with primary forests (Becknell and Powers, 2014). ~~We randomly sampled the stands in the area that meet the criteria – naturally recovered stands (no recent disturbances). (Wang et al., 2007; Yan et al., 2009)The soils in these areas were classified as Ferralsols according to the FAO soil classification system (WRB, 2006), which is equivalent to the Yellow or Red Soils in the Chinese soil classification system, with the parent materials consisting mostly of Mesozoic sedimentary rocks, some acidic igneous rocks, and granite residual weathered material (Song and Wang, 1995) (Yan et al., 2013). We established a total~~

~~of 80 plots(Yan et al., 2013), covering all typical habitats in this region. Each plot (20 × 20 m) was located at a distance of least 100 m from stand edges in order to minimize edge effects. We acknowledge that our plot sizes were quite small; however, similar to other regions, secondary forest patches often occur in smaller tracts than is the case with primary forests (Becknell and Powers, 2014)(Becknell and Powers, 2014). A description of the vegetation and soil characteristics is provided in Table 1.~~

In each plot, the basal diameter (diameter at 5 cm above root collar) and DBH were measured for trees taller than 1.50 m, while the basal diameter and diameter at 45 cm above the ground ~~(D_{45})~~ were measured (with a diameter tape) for trees that were shorter than 1.50 m. Total tree height for each tree was measured with a telescopic pole for the height of up to 15 m, and with a clinometer for heights of >15 m. The studied plots had between ~~six~~ 6 and 46 tree species per plot, and among them, deciduous species such as *Liquidambar formosana* and *Quercus fabri*, and evergreen species such as *Lithocarpus glaber* were the dominant species in young forests, with evergreen species such as *Choerospondias axillaris* and *Schima superba* dominating in the premature forests, while *Castanopsis fargesii* and *Castanopsis carlesii* dominated in the mature forests.

~~2.2 Estimations of stand age and site productivity~~

~~Stand age represents the number of years since the stand replacing disturbance (e.g., Wang et al., 2007; Yan et al., 2009). The official documents of Ningbo Forestry Bureau, Zhejiang Province, were reviewed to collect relevant data about the disturbances in the study area.~~

~~Previous work has shown that community vertical structures and plant species compositions were similar within each forest developmental stage in our study area (Yan et al., 2013). Thus, we assessed site productivity for each studied plot through direct volume~~

~~measurements using a dendrometric (phytocentric) method (Skovsgaard and Vanclay, 2008). Site productivity was calculated as the mean annual increment of stand volume per year based on stand volume per hectare (Loetsch and Haller, 1964) divided by stand age, which represents productivity accumulated from stand establishment (e.g., Pretzsch et al., 2014).~~

~~It was to note that tree diameter of each individual was used for calculating individual aboveground biomass (AGB; Brown et al., 1989; Ali et al., 2015), and hence tree AGB scales closely with the volume of the individual tree (R^2 = 0.93; P < 0.001 in this study). This is somewhat different from stand volume per hectare (Loetsch and Haller, 1964; Pretzsch et al., 2014). A high stand volume per hectare can be caused by many small trees (each containing little AGB) and/or a few big trees (each containing a disproportionately large AGB; e.g., Liang et al., 2007; Lei et al., 2009; Wang et al., 2011; Slik etal. 2013; Poorter et al. 2015; see Fig. S1). In addition, stand basal area per hectare (used in the calculation of stand volume) has been proved as a useful proxy of productivity in secondary subtropical forests of China (e.g., Barrufol et al., 2013).~~

2.~~3~~2 ~~Measurements and calculations of carbon stocks~~Estimation of aboveground carbon storage

~~For individual trees with~~The AGB of individual tree (AGB*t*) having DBH ≥ 5 cm~~,~~ ~~aboveground biomass (AGB*t*)~~ was calculated using the ~~Brown's~~ general allometric equation (eqn 1; Chave et al., 2014)~~(eqn 1; Brown et al., 1989)~~based on ~~-~~tree DBH (cm), height (H, m) and species' wood density (ρ, g cm^{-3})~~with DBH only because tree height and DBH of the studied subtropical trees was highly correlated (*r* = 0.86, *P* < 0.001)~~.

$$\mathrm{AGB}t = \cancel{exp}\,0.0673 \times \{(\rho \cancel{- 2.134} \times \cancel{+2.530}\,\mathrm{DBH}^2 \times \cancel{\mathrm{Ln(D)}}\,\mathrm{H})^{0.976}\cancel{\}} \qquad \text{eqn 1}$$

~~where D is diameter at breast height.~~

~~To avoid the uncertainty about using of Brown's equation for our studied forests, we have developed regression relationship between basal area (substitute of AGB) and DBH (≥ 5cm) for the species in our studied system. It is found that the Brown's equation and our developed regression equation, for basal area – DBH, yielded almost similar relationships (Fig. S1). In addition, previous work has shown that basal area was highly related with AGB (Ali et al. 2014), and the D-H models for AGB could be generally used across subtropical large trees, small trees and shrubs (Ali et al. 2015). Further, Brown's equations had commonly used for estimation of AGB in different subtropical forests (e.g., Conti and Díaz, 2013).~~

~~In addition, the individual tree AGB (DBH ⩾ 5 cm) estimated with Brown's (1989) equation was compared with each of simple geometric equation and most recent equations using plant height and wood density (such as Chave et al.'s 2005 equations; see Fig. S3). We found that the Brown's equation tended to over-estimate individual tree aboveground biomass as compared to the estimations obtained using simple geometrical equation, but the results of the two models were highly consistent ($R^2 = 0.91$, $P < 0.001$; see Fig. S3a). Further, the Brown's equation also tended to over-estimate individual tree aboveground biomass as compared to the estimations obtained using Chave et al.'s (2005) $\rho D^2 H$ model while almost similar estimations to Chave's ρD model for moist forests, but the results of the models were highly consistent ($R^2 = 0.91$ and 0.96 with $P < 0.001$ for two equations of Chave's with Brown's equation; see Fig. S3b and c). These results were therefore consistent with recent continental scale study (Paul et al., 2016) showing that when comparing the estimated AGB through model using stem diameter as a single predictor there was little improvement in accuracy of estimation when the model included other plant variables (e.g. height, wood density).~~

We estimated AGB of individual shrubs and small trees having DBH < 5 cm (AGB*s*) using a ~~diameter-height (DBH < 5 cm) based~~ multi-species allometric equation (eqn 2) developed locally, based on DBH, height and species' wood density (Ali et al., 2015)~~($n = 96$, $R^2 = 0.71$, $P < 0.001$; Ali et al., 2015)~~. is

$$\mathrm{AGBs} = 1.460 \times \exp\{-3.23 + 2.17 \times \mathrm{Ln}(\mathrm{D})\} \qquad \text{eqn 2}$$

~~where D is DBH < 5 cm, and H is tree height (m).~~

Total AGB per plot was the sum of the AGB*t* and AGB*s*. Subsequently, we converted AGB to aboveground C storage (Mg ha^{-1}) by multiplying AGB with a conversion factor of 0.5, assuming that 50% of the total tree biomass is C ~~The sum of the aboveground biomass for trees and shrubs was is considered as total AGB per plot. Subsequently, we converted AGB to aboveground C stock (Mg ha^{-1}) by multiplying AGB with a factor of 0.5, as 50% of the total tree biomass being C~~ (Dixon et al., 1994)~~(Dixon et al., 1994)~~.

~~Soil samples were collected from 0–20 cm depth from 65 sample plots. Soil samples in each plot were collected from five randomly selected points, resulting in 325 samples, which were taken to the laboratory and air-dried over 30 days. Each soil sample was then sifted through a 0.25 mm sieve and thoroughly mixed to determine organic soil C concentrations using the oil bath-K_2CrO_7 titration method (Nelson and Sommers, 1974). In each plot, soil bulk density was determined using a steel corer of a known volume, and five soil cores were collected per plot. The soil cores were dried in at 105 °C in an oven for > 48 hours, after coarse fragment such as stone was removed. Bulk density (g cm^{-3}) was calculated by dividing the oven dry weight of the soil (g) by the volume of the soil core. The amount of soil organic C (Mg ha^{-1}) was calculated by multiplying the organic C content by the soil depth and soil bulk density (Brown, 2004).~~

2.~~4~~3 ~~Calculation of stand structural diversity~~Explanatory variables

Our conceptual models include~~d~~ four explanatory variables for predicting aboveground C storage (Fig. 1): stand age, species diversity, DBH diversity and height diversity. In this study, stand age represents the number of years since the stand replacing disturbance (e.g., Wang et al., 2007; Yan et al., 2009). The official ~~documents~~records of Ningbo Forestry Bureau, Zhejiang Province, were reviewed to collect relevant data about the disturbances in the study area.

We used the Shannon-Wiener biodiversity index to quantify tree species, DBH and height diversities (Magurran, 2004). We quantified tree-size variation (i.e., tree DBHs and heights) within each plot as structural diversity at the stand level. ~~We selected the Shannon-Wiener biodiversity index to quantify tree size variation (Magurran, 2004)(Magurran, 2004).~~ With the Shannon–Wiener index, DBH and height were grouped into different discrete classes in order to evaluate ~~that~~ which combination of discrete classes for DBH and height diversities best predict aboveground C storage in secondary subtropical forests. For DBH, 2, 4, 6, and 8 cm classes were tested, while for height, 2, 3, 4, and 5 m classes were tested in order to ~~calculate~~ assess the different variations in DBH and height diversities~~indices~~. Similar to species diversity, DBH diversity and height diversity were calculated by replacing the number of species with the number of DBH or height classes of tree individuals. ~~We assessed the correlation between DBH diversity and height diversity with different classes of DBH and height, respectively, for the purpose of stand structural management (e.g., Lei et al., 2009). Hence, the highest correlation coefficient (r = 0.54, P < 0.001) between DBH diversity and height diversity was achieved with DBH and height classes of 8 cm and 3 m increments, respectively. Therefore, 8 cm and 3 m increments were utilized for the DBH and height classes in calculating DBH and height diversity, respectively.~~ Based on basal area proportions, tree species, DBH and height diversities were calculated for each plot using equations 3, 4 and 5, respectively ~~for each plot~~ (Buongiorno et al., 1994; Magurran, 2004; Staudhammer and LeMay, 2001)~~(Buongiorno et al., 1994; Staudhammer and LeMay, 2001; Magurran, 2004)~~.

$$\mathrm{H_s} = -\sum_{i=1}^{s} \mathrm{p}_i \times \ln(\mathrm{p}_i) \qquad \text{eqn 3}$$

$$\mathrm{H_d} = -\sum_{j=1}^{d} \mathrm{p}_j \times \ln(\mathrm{p}_j) \qquad \text{eqn 4}$$

$$\mathrm{H_h} = -\sum_{k=1}^{h} \mathrm{p}_k \times (\ln \mathrm{p}_k) \qquad \text{eqn 5}$$

where p_i, p_j, and p_k ~~were~~are the proportion of basal areas of *i*th species, *j*th DBH classes and *k*th height classes, respectively, while *s*, *d*, and *h* ~~were~~are the number of tree species, DBH and height classes, respectively. ~~$\mathrm{H}_x = -\sum_{i=1}^{x} \mathrm{p}_x \times Log\, \mathrm{p}_x$ eqn 3~~

~~where H_x was either species diversity, DBH diversity or height diversity; p_{xx} was either the proportion of basal areas of *x*th species, *x*th diameter classes or *x*th height classes, respectively, while *x* was either the number of tree species, diameter or height classes, respectively.~~

The ~~analysis~~ calculations on the Shannon-Weiner indices ~~was~~ were performed using the *vegan* package for the R 3.2.2 (Oksanen et al., 2015; R Development Core Team, 2015)~~(Oksanen et al., 2015; R Development Core Team, 2015)~~.

2.~~5~~4 Statistical ~~analysis~~analyses

As recommended (Grace et al., 2016), we ~~specified~~constructed three SEMs based on known theoretical multivariate causes of forest diversity and aboveground C storage in natural forests (Fig. 1). We used stand structural diversity as a latent variable by incorporating two observable variables, tree DBH diversity and height diversity, which are highly correlated based on different discrete classes (r = 0.34 to 0.60, P = 0.002 to < 0.001). To assess how DBH and height classes affect the prediction of~~ng~~ aboveground C storage, we tested 48 SEMs using different combinations of discrete classes ~~for~~of tree DBH diversity (2, 4, 6 and 8 cm classes) and height diversity (2, 3, 4 and 5 m classes)~~,~~ based on ~~our~~the three conceptual models (Fig. 1).

For the ~~support of SEMs and~~ interpretation of results (Grace et al., 2016), we conducted bivariate relationships between each hypothesized causal paths according to our hypothesis in Fig. 1, using Pearson's correlation and regression analysis. Specifically, we fit each pair of variables using simple linear regression and multiple linear regressions by adding quadratic and cubic polynomial terms to test for bivariate relationships of aboveground C storage with each of stand age, species diversity, and DBH and height diversities based on their various discrete classes. We also tested the bivariate relationships between stand age and species diversity, and DBH and height diversities based on their various discrete classes. Our analyses indicated that simple linear regression analysis was the best in describing ~~for~~ bivariate relationships based on the Akaike information criterion (AIC). A summary of variables used in the statistical analyses is listed in Table S1. Bivariate relationships for all hypothesized causal paths in the final ~~selected~~ SEMs are shown in Fig. 2~~,~~ and Pearson's correlations coefficients between all tested variables are listed in ~~supplementary~~ Table S2.

Shapiro-Wilk goodness-of-fit test was used to assess the normality for all variables. As recommended (Grace et al., 2016), all numerical variables including aboveground C storage, species diversity, stand age, and DBH and height diversities were natural-logarithm transformed and standardized in order to meet the assumptions of normality and linearity, and to allow comparisons among multiple predictors and models (Zuur et al., 2009).

~~5~~(Grace et al., 2016; Zuur et al., 2009)~~We conducted three sets of data analysis. Firstly, we used a simple linear regression analysis to test for pair-wise associations of C stocks (aboveground and/or soil organic) with each of species diversity, DBH diversity, height diversity, stand age, stand density, and site productivity. We also tested the pair-wise~~

~~association between stand age and species diversity, DBH diversity, height diversity, stand density, and site productivity.~~

~~Secondly, three series of ordinary least squares (OLS) multiple regressions analyses were conducted to test whether C stocks (aboveground and/or soil organic) were primarily driven by stand structural diversity (species, DBH, and height diversity; first series), other characteristics of the stand (stand age, stand density, and site productivity; second series), and a combination of stand structural diversity and other stand characteristics (third series). The OLS multiple regression analyses were conducted using the Spatial Analysis in Macroecology software package (SAM version 4.0; Rangel et al., 2010). Regressions were developed for each C stock response variable by starting from three potential predictor variables (species diversity, DBH diversity, and height diversity; or stand age, stand density and site productivity) without interactions, resulting in a total of seven possible models for each of the first and second series (Fig. 1). With respect to the third series for each response variable, a total of 63 possible models were tested by beginning from six potential predictor variables (species diversity, DBH diversity, height diversity, stand age, stand density, and site productivity; Fig. 1). For the significance test, the model with the lowest Akaike Information Criterion (AICc; Akaike, 1973) was selected as being the best for each series. In addition, a model averaging approach (synthetic model) was developed in SAM to evaluate which predictor variable contributed consistently across all the models of each series. For this, regression coefficients of each predictor were averaged across all models of each series, and weighted by their Akaike Information Criterion weight (AICc-wi), which represented the likelihood of a given model relative to all other models (Wagenmakers and Farrell, 2004). An importance value was calculated by adding the AICc-wi values of the models in which the variables were present (Slik et al., 2013). Importance values ranged between zero (low importance) and one (high importance). For each response variable, the final best model~~

~~among the three competing series was selected on the basis of the lowest AICc. It is worth mentioning here that aboveground C stock, DBH diversity and site productivity were calculated using tree diameters, thus, we ran the multicollinearity statistics. Multicollinearity diagnosis was performed in multiple regressions using the variance inflation factor (VIF) as multicollinearity larger than 10 could cause inaccurate model parameterization and decreased statistical power, and exclude significant predictor variables (Graham, 2003).~~

~~Lastly, we employed a structural equation model (SEM) to assess the direct effects of species diversity, DBH diversity, height diversity, stand age, stand density, and site productivity on C stocks (aboveground and/or soil organic), and the indirect effects of stand age, on each of the C stocks through the mediation of other stand characteristics.~~ ~~However, even if VIF value is lower than 10, it may still cause inaccurate model parameterization, decrease statistical power and exclude significant predictor variables. Hence, it potentially impairs the identification of significant effects and invalidates approaches that assume no collinearity among predictor variables (Graham, 2003). Thus~~For the selection of the best SEM, several tests ~~in SEM~~ were used to assess the model fit of all SEMs (Malaeb et al., 2000), i.e., the Chi-square (χ^2) test, goodness-~~-~~of-~~-~~fit index (GFI), comparative fit index (CFI)~~, minimum discrepancy (CMIN/df)~~, standardized root mean square residual ~~Root mean square error of approximation~~ (~~RMSEA~~SRMR) and ~~Akaike Information Criterion (~~AIC)~~.~~ . The indirect effect of a predictor was calculated by multiplying the standardized effects of all paths on one route from one predictor to mediator and then to aboveground C storage, while total effect was calculated by adding standardized direct and indirect effects (Grace et al., 2016). ~~The SEM is an advanced and robust multivariate statistical method that allows for hypotheses testing of complex path-relation networks (Malaeb et al., 2000); assuming linear relationships and correlations between variables in the model. Here, we tested two different models, a stand characteristics model and a stand age model (Fig. 1). The stand~~

~~characteristics model was the best finally selected model among the three competing OLS series (see second step of the statistical analysis). Thus, we tested the direct effects of the stand characteristics, and retained predictor variables in the final best model on C stocks. With respect to the stand age model, stand age was employed as the primary explanatory variable by testing the direct and indirect effects (mediated by stand characteristics) on C stocks.~~ The SEM was implemented using the *lavaan* package (Rosseel, 2012) in R 3.2.2 (R Development Core Team, 2015). ~~The SEM analyses were conducted using IBM SPSS Amos (version 21), and a summary of variables and their categories are described in Table S1.~~

~~It is to note that the largest (dominant) trees could also determine the total number of diameter classes (e.g. "size richness" based on Eqn. 3). Therefore, it is necessary to justify whether significant effects of stand structural diversity on C stocks in the regressions and/SEM are caused by the "diversity" of tree structure frequency distribution, rather than by the dominant characteristics of trees. As such, we conducted a Pearson correlation analysis on the relationships between stand structural diversity (i.e., tree DBH and height) and each of 90-percentile diameter/height (i.e., P90 of D/H) and coefficient of variation in diameter/height (i.e., CV of D/H). If the proposed stand structural diversity indices were more related to the CV of D/H, the significant results in the regressions and/or SEM on a response variable would be caused by the "diversity" of tree structure frequency distribution, rather than by the characteristics of dominant trees in forests. We found that tree DBH and height diversity indices had significantly stronger relationships with tree structure frequency distribution (e.g., CV of D and H) than with the dominant characteristics of trees in forests (e.g., P90 of D/H, Table S8).~~

3 Results

~~**3.1 Relationships between stand characteristics and carbon stocks**~~

~~Aboveground C stock was positively related to tree DBH diversity (Fig. 2a), tree height diversity (Fig. 2b), and site productivity (Fig. 2c), which explained 49, 13, and 41 % of the variation, respectively. There was no significant relationship between aboveground C stock and species diversity and density (Table S2). Soil organic C stock was not significantly related to stand age or other stand characteristics (Table S2).~~

~~Stand age was positively related to aboveground C stock, and explained 50 % of the variation in aboveground C stock (Fig. 2d). Mature stands exhibited a greater range in tree DBH and height distribution in that they had a greater number of large trees overall (Fig. S4a and b). Aboveground C stock was observed to ranged widely across forests, from 3.15 to 238.91 Mg ha-1, and forests with similar ages had different levels of aboveground C stock (Fig. 2d). Stand age also explained 39 and 30% of the positive variation in each of tree DBH (Fig. 2e) and height diversities (Fig. 2f). However, stand age did not explain any of the variation (≤ 2%) in species diversity, site productivity, and stand density (Table S2).~~

~~**3.2 Relative contribution of stand** characteristics **to carbon stocks**~~

~~When testing the effects of species, DBH, and height diversities on aboveground C stock (first series) by using the best regression model (R2 = 0.54, P < 0.001), we found that aboveground C stock was negatively related to species diversity, but positively related to DBH diversity (Table 2). Further, in the synthetic model, the significant predictors with the highest importance values were DBH diversity (1.0) and species diversity (0.97; Table S3). In contrast, tree height diversity was not significant in both the synthetic and the best models.~~

~~For the testing of the second series, aboveground C stock was positively correlated to stand age and site productivity, but negatively related to stand density in the best regression model (R2 = 0.79, P = 0.001; Table 2). In the synthetic model, all three predictors were significant;~~

~~however, stand age and site productivity had the similar highest importance value (1.0) as compared to stand density (0.70) (Table S3). When species diversity, DBH diversity, height diversity, stand age, stand density, and site productivity were jointly tested (third series), the best regression model (R2 = 0.83, P < 0.001) revealed that aboveground C stock was positively correlated to stand age, site productivity and DBH diversity, but negatively related to species and height diversity (Table 2). In the synthetic model, the significant predictors with high importance value were stand age (1.0), site productivity (1.0), species diversity (0.96), DBH diversity (0.90) and height diversity (0.77; Table S3); however, stand density was not significant in both the synthetic and the best models. It is worthy of mention that the best model of the third series was the best-fit model among the competing best models of all three series, in that it had the lowest AICc as well as the highest R2 (Table 2).~~

~~With respect to organic soil C stock, the best models of all series revealed that none of the species diversity, DBH diversity, height diversity, stand age, stand density, and site productivity had significant effects (Table S4). Although some of the predictors were retained in the best models of each series, they were not significant and explained very low variations in soil organic C stock (R2 values ranged between 0.00 and 0.03; Table S4). Also, in the synthetic model of each series, the importance values of the predictor variables were very low within the range of 0.29-0.50 (Table S5). It was noted that all VIF values were lower than the critical heuristic value of 10, which suggested that collinearity among predictor variables did not strongly affect our results (Table S6).~~

~~3.3 Direct and indirect effects of stand age on carbon stocks~~

Tree DBH diversity based on 8 cm and height diversity based on 2 m class were selected as the stand structural diversity (a latent variable) because this combination resulted in the best-fit SEM ~~based on~~that had the lowest AIC, with a *P*-value of χ^2 test for the overall model fit

~~larger~~greater than 0.05 (Table S3; Fig. 3). The SEMs based on combinations of 4 cm or 6 cm discrete class for DBH diversity and 2 m class for height diversity were also accepted ($P > 0.05$), whereas the SEMs based on all other combinations of discrete classes for DBH and height diversities were rejected ($P < 0.05$; Table S3).

The selected SEMs with the three directions for the path between species diversity and stand structural diversity had a similar good-fit to the data (Fig. 3; Table S3). The three final SEMs all accounted for 82% of the variation in aboveground C storage, 55% to 59% of the variation in stand structural diversity and negligible variation in species diversity (Fig. 3). Stand structural diversity had the strongest positive direct effect on aboveground C storage ($\beta = 0.56$, $P = 0.001$), followed by ~~the~~ positive effect of stand age ($\beta = 0.41$, $P = 0.003$) and ~~the~~ negative effect of species diversity ($\beta = -0.23$, $P < 0.001$) in these ~~three three~~ SEMs (Table 1; Fig. 3). There was a significantly positive direct effect of stand age on stand structural diversity, but an insignificant effect on species diversity in these SEMs (Fig. 3). Species diversity and stand structural diversity had a significant positive direct effect on each other (Fig. 3)

Stand age had a strong indirect effect via stand structural diversity ($\beta = 0.41$, $P = 0.002$; Table 1) and insignificant indirect effects via species diversity ($\beta = -0.10$, $P = 0.357$) on aboveground C storage in all three SEMs (Fig. 3, Table 1). The indirect effects of stand structural diversity via species diversity were insignificant regardless of SEMs, while species diversity had a marginally significant positive indirect effect via stand structural diversity ($\beta = 0.11$, $P = 0.059$, Table 1). The total (direct + indirect) effects of stand age, stand structural diversity, and species diversity were 0.82, 0.56 and -0.12, respectively, on aboveground C storage (Fig. 3a; Table 1). In the alternative SEMs (Figs. 3b and 3c), the total effect of stand age, stand structural diversity and species diversity on aboveground C storage were almost similar to SEM in Fig. 3a (Table 1).~~had a relatively weak indirect effect which waslythe~~

s~~Stand characteristics models and stand age models yielded almost identical fit measures (Chi-square = 4.48 and 2.24, *df* = 5 and 3, P-value = 0.483 and 0.486, CFI = 1.00 and 1.00, GFI = 0.98 and 0.99, CMIN/df = 0.90 and 0.81, RMSEA < 0.001 and < 0.001, respectively (Fig. 3). The stand characteristics model explained 81% of the variation in aboveground C stock (Fig. 3a), while the stand age model explained 83% (Fig. 3b).~~

~~In the stand characteristics model, aboveground C stock was directly linked with stand age, species diversity, DBH diversity, height diversity, and site productivity (Fig. 4a). According to the final best model in OLS series (Table 2), and in order to achieve the best-fit model in SEM, the non-significant relationship between aboveground C stock and stand density was removed (Fig. 3a). Thus, the size (standardized regression weight: beta) of the direct effects of stand age, species diversity, DBH diversity, height diversity, and site productivity on aboveground C stock was 0.61 ($P < 0.001$), -0.19 ($P < 0.001$), 0.24 ($P = 0.001$), -0.14 ($P < 0.028$), and 0.46 ($P < 0.001$), respectively (Fig. 4a; Table S7). In the stand age model, 39% and 30% of the variations in DBH diversity and height diversity were explained by stand age (Fig. 3b). In contrast, stand age did not explain the variations (< 2%) in species diversity, site productivity, and stand density (Fig. 3b). Considering the total effects of stand age (sum of direct and indirect effects), aboveground C stock was positively affected by the sum of the direct (positive) and indirect (positive) effects of stand age through species diversity (negative), DBH diversity (positive), height diversity (negative), and site productivity (positive) (Fig. 3b). Aboveground C stock was not indirectly affected via stand density by stand age (Fig. 3b). Although the effect of stand age on aboveground C stock was stronger directly (beta = 0.59) than indirectly (beta = 0.11), the total effect of stand age was significant and stronger, with an effect size of 0.70 ($P < 0.001$; Table S7).~~

~~For soil organic C stock, the stand characteristics model revealed that the direct relationships between each of the stand characteristics and soil organic C stock was not~~

~~significant (Fig. S5a). Also, in the stand age model, the direct and indirect effects of stand age on soil organic C stock were not significant (Fig. S5b).~~

4 Discussion

To the best of our knowledge, this is the first study to analyz~~s~~e the multivariate relationships between aboveground C storage and its drivers (stand age, stand structural diversity and species diversity) in secondary subtropical forests in China. We found a positive relationship between stand structural diversity and aboveground C storage, but a negative relationship between species diversity and aboveground C storage, while accounting for the strong positive influence of stand age in our ~~analysis~~study. Our results indicate that the positive relationships reported in previous studies between stand structural~~e~~ diversity and aboveground C storage in boreal and temperate forest ecosystems (e.g., Dănescu et al., 2016; Zhang and Chen, 2015) can be extended to subtropical forests. (Cavanaugh et al., 2014; Chisholm et al., 2013; Poorter et al., 2015)ed~~(e.g., Dănescu et al., 2016; Zhang and Chen, 2015)~~wre(i.e., rarefied species richness; Barrufol et al., 2013; Poorter et al., 2015)

~~The significant relationships of stand characteristics with aboveground C stock, but not with soil organic C stock, in the studied forests suggest that, relative to soil organic C stock, aboveground C stock is more predictable with respect to aboveground stand attributes. It is understandable that stand characteristics were derived from the aboveground forest structure. It may be the case that soil organic C stock is related to belowground stand characteristics, which were not studied in this research.~~

~~4.1 Relationship between stand structural diversity and aboveground C stock~~

Our results ~~indicated~~ showed that tree DBH ~~diversity~~ and height diversities~~y~~ were strongly positively ~~correlated~~ related with aboveground C ~~stock~~ storage across plots; those relationships~~.~~ ~~, indicating that stand structural diversity is one of the key factors that affect aboveground C stock in subtropical forests (Fig. 2). The strong positive relationships between aboveground C stock storage and stand structural diversity might have~~likely resulted from increased light capture and light use efficiencies ~~initiated by~~in association with complex tree size structures (Dănescu et al., 2016; Zhang and Chen, 2015). ~~might result from high resource use efficiencies initiated by complex tree size structures (Dănescu et al., 2016; Zhang and Chen, 2015)(Vayreda et al., 2012). Tree species~~Forest communities possessing different diameters and heights may also have their own set of habitat requirements for water and soil nutrients ~~possessing different diameters and heights be more effective in using~~(Wang et al., 2011). ~~may have their own set of habitat requirements for nutrients and coverage (Wang et al., 2011)(Wang et al., 2011).~~ The maintenance of high stand structural diversity supports species ~~to meet their specific requirements, whereas low or homogenous structural arrangements~~ may ~~reduce~~ increase complementarity effects (Lei et al., 2009)~~(Lei et al., 2009)~~. Our results and those from previous studies collectively suggest that a multilayered forest structure allows~~ing~~ for more efficient utilization of light, water and soil nutrients at the stand level (Poorter et al., 2015), and as a result increases the accumulation of aboveground C storage (Buongiorno et al., 1994; Wang et al., 2011; Zhang and Chen, 2015).

~~Therefore, significant variations in tree DBH and heights may result in a multilayered forest structure with enhanced structural complexity, allowing for more efficient light capture at the stand level(Poorter et al., 2015), leading to a larger accumulation of aboveground C stock (Buongiorno et al., 1994; Wang et al., 2011; Zhang and Chen, 2015)(Buongiorno et al., 1994; Staudhammer and LeMay 2001; Zhang and Chen 2015).~~

~~It is worth noting that tree species diversity had a non-significant and negative pair-wise association with aboveground C stock (Table S2), which likely resulted from increased species richness, while species evenness decreased through stand development in the forests~~

~~under study (Table 1). Although biomass should increase with species richness and evenness (e.g., Zhang et al., 2012), the explanation for why we did not observe a positive effect of species diversity on aboveground C stock might be that less diverse stands were dominated by more productive species, such as those that are early successional. Furthermore, tree species diversity decreased slightly from young to premature stands, which leveled to constant, from premature to mature stages (Table 1). This might result in a weak relationship between species diversity and aboveground C stock during forest stand development. In the SEM analysis, however, we found negative relationships between aboveground C stock with species and height diversities (Fig. 3), likely stemming from the complex shift patterns of species diversity through forest succession, as discussed above, which was also observed in a semi-deciduous tropical forests (Larpkern et al., 2011). In addition, we also included the effects of other stand characteristics in the SEM analysis, but did not consider the effects of other factors on aboveground C stock in the simple linear regression. In this situation, the relationship of species diversity with aboveground C stock includes the combined effects of other stand characteristics on aboveground C stock in the SEM analysis.~~

~~Similarly, the negative relationship between aboveground C stock and tree height diversity was observed in the SEM analysis. However, we found that the relationship between tree height diversity and aboveground C stock was positive in the simple linear regression. These contrasting results suggest that the association between height diversity and aboveground C stock is uncertain, and largely contingent on whether additional effects of other stand characteristics on aboveground C stock are considered. When the effects of other stand characteristics were considered in the SEM analysis, there was a negative effect of tree height diversity on aboveground C stock. The negative relationship of aboveground C stock with tree height diversity in the SEM model demonstrated that forest stands with high tree height diversity may reduce aboveground C stock through the alternation of other stand~~

~~characteristics, such as shifting species composition during forest succession. Forest stands with high tree height diversity, but without high tree DBH diversity and increasing stand age, may have low aboveground C stock. Generally, aboveground C stock might be more loosely correlated to tree height alone, but is likely correlated with the combination of the tree height and the growth rates of tree species. For instance, some of the most extensive aboveground C stock observed in the old growth conifer forests, were associated with the slow growth of tree species(e.g., Gahagan et al., 2015) (e.g., Gahagan et al., 2015). Conversely, shrublands and young forests dominated by deciduous species with very high growth rates were associated with low aboveground C stock in the study area (Yan et al., 2013)(Yan et al., 2013). Therefore, it was clear that, rather than great height diversity, tree species with low height diversity and great DBH diversity maintained high aboveground C stock in the forests under study~~We found that species diversity had an insignificant negative relationship with aboveground C storage in our studied forests. Although AGB is expected to increase with species richness and evenness (e.g., Zhang et al., 2012), the lack of positive effect of species diversity on aboveground C storage might be attributable to species redundancy in the studied forests. Since forests in the study area are already diverse, an increase in species richness may lead to niche overlap, instead of niche differentiation, causing negative interspecific interactions through competition (Walker, 1992). Moreover, in contrast with previous studies that have showed strong indirect effects of species diversity via stand structural diversity, or indirect effect of stand structural diversity via species diversity, on aboveground C storage or productivity (Vilà et al., 2013; Zhang and Chen, 2015), our study showed weak associations between species diversity and stand structural diversity, indicating that intraspecific size variation is the primary cause for stand structural diversity (Clark, 2010) and its positive effects on aboveground C storage in our study forests.~~alstand non-wa~~(e.g., Vilà et al., 2013; Walker, 1992; Zhang and Chen, 2015; Zhang et al., 2012)

~~.~~

~~4.2 Stand structural diversity and site productivity mediate the relationship between stand age and aboveground C stock~~

~~In this investigation, stand structural diversity, site productivity, and stand age, in conjunction, explained more variation in aboveground C stock than did singular components, such as stand structural diversity or other stand characteristics. More importantly, stand characteristic models and stand age models provided strong support for our prediction that stand age, site productivity, and stand structural diversity could jointly explain large variations (i.e., 81%) in aboveground C stock. Therefore, our hypothesis was partially confirmed, i.e., stand structural diversity, stand age, or site productivity alone, or jointly, comprised the drivers of variations in C stocks across the forests under study.~~

The strong positive contribution of stand age to aboveground C storage is attributable to the accumulation of tree growth and increased structural complexity over time. Stand age can also indirectly impact aboveground C storage through the directional changes in stand structurale and/or species diversity during forest succession (Becknell and Powers, 2014; Zhang and Chen, 2015). As hypothesized, we found that stand age was significantly positively related to stand structural diversity, which had a strong direct effect on aboveground C storage. Our findings are consistent with the idea that the complementarity effects increase through time via increasing stand structural diversity ~~al~~(Zhang and Chen, 2015). ~~The clearly positive contribution of stand age and site productivity to aboveground C stock might relate to successional patterns of tree growth and other stand characteristics. This study revealed that, relative to other stand characteristics, stand age was the most significant factor in predicting aboveground C stock (Table 2; Fig. 2d; Fig. 3a), which were also found in tropical dry and seasonal forests (Dupuy et al., 2012; Becknell and Powers 2014).~~

~~(Becknell and Powers, 2014; Zhang and Chen, 2015) It is true that stand age may affect aboveground C stock directly, as tree DBH increases when forest stands become mature (Lohbeck et al., 2015). In general, mature stands typically contain old large trees. The AGB growth rates (C stock accumulation rates), for tree species increases with tree DBH (Slik et al., 2013; Stephenson et al., 2014). A set of large trees in mature stands may add the same level of C to the forest within a year as do all of the mid-sized trees contained in the same forest (e.g., Stephenson et al., 2014)(Stephenson et al., 2014).~~ (Becknell and Powers, 2014; Giardina et al., 2003; Yan et al., 2009)~~In this study, we found that variation in aboveground C stock was mainly affected by tree structure frequency distribution (e.g., CV of D and H), compared to the dominant characteristics of trees in forests (Table S8; Zhang and Chen, 2015). Consequently, a positive relationship must exist between aboveground C stock and stand age. In this case, stand age acts as a primary determinant of stand growth (Powers et al., 2009; Becknell and Powers, 2014), to drive variation in aboveground C stocks (e.g., Poorter et al., 2016)(e.g., Chen and Luo, 2015).~~

We found little direct effect of stand age on tree species diversity and indirect effect of stand age via species diversity on aboveground C storage in our study forests. It is highly debated how stand age as a measure of disturbance frequency affects tree species diversity across forest landscapes with diverse local site conditions (Yeboah et al., 2016). For instance, disturbances of intermediate intensity may selectively remove specific species, and hence decrease species diversity (Yeboah and Chen, 2016). Our findings of the weak direct effect of stand age on species diversity and indirect effect of stand age via species diversity on aboveground C storage as well as the negative direct effect of species diversity on aboveground C storage might have resulted from historical human disturbances, which might have selectively harvested certain species in the study region. Future research is needed to improve our conceptual model by including the effects of disturbance history on tree species diversity and its influence on aboveground C storage.~~(Yeboah et al., 2016)(Yeboah & Chen, 2016)Stand age might also indirectly impact aboveground C stock through the directional changes in other stand characteristics during forest succession (Campetella et al., 2011; Lohbeck et al., 2015). As expected, we found that stand age was significantly related to tree DBH and height diversity (Figs 2 and 3b), which had a significant influence on aboveground C stock (Fig. 3b). The positive contribution of site productivity to aboveground C stock during stand development was also found in secondary tropical forests (Lohbeck et al., 2015). It is well known that increases in forest productivity and biomass play a critical role in shaping C accumulation through high nutrient supply (Giardina et al., 2003). In this study, most of the stands were still recovering from disturbances, thus site productivity and nitrogen availability increased with stand development (Yan et al., 2009). As a result, aboveground C accumulation increased through forest succession.~~

~~Distinguishing the direct and indirect effects of stand age through mediations of stand characteristics on aboveground C stock may determine the role that stand age plays in driving variation in C stock during forest succession. By employing a structural equation model, we observed that stand age could explain a small additional variation (~ 2%) in aboveground C stock when it was considered as a primary driver of aboveground C stock through the mediation of stand characteristics (Fig. 3b). However, the results showed that stand age had substantial direct and total effects (sum of direct and indirect effects) on aboveground C stock (Fig. 3b). Clearly, these contrasting results indicated that the direct effects of stand age on aboveground C stock was much stronger than the indirect effects of stand age through the mediation of stand characteristics in the forests under study. The possible reasons for the low indirect effects of stand age on aboveground C stock in this investigation might be attributed to the contributions of the other factors such as environmental properties and species~~

~~competition, which were not included in our model. It should be noted that this study did not focus on the association of C stock with environmental properties, or tree mortality rates, recruitment, and survival. However, these biotic and abiotic factors also have linkages with stand age toward the influence of C stock in forest ecosystems (Lei et al., 2009; Liang et al., 2007; Poorter et al., 2015; Zhang and Chen, 2015)(Giardina et al., 2003; Lutz and Halpern, 2006; Liang et al., 2007; Lei et al., 2009; Vayreda et al., 2012; Chen and Luo, 2015). Therefore, we suggested that further research should be conducted to improve our model by including the direct and indirect effects of environmental properties, as well as the demographic traits of tree species on the relationship between stand age and iesC stock.~~

5 Conclusions

This study has presented and articulated the inherent complexities of variation, as relates to aboveground C ~~stock~~storage, by utilizing ~~six stand characteristics~~stand age, stand structural diversity and species diversity of secondary subtropical forests across e~~E~~astern China. We found that ~~81~~ 82% of variations in aboveground C storage ~~stock~~ could be explained by stand characteristics in these heterogeneously aged forests ~~(Fig. 3a)~~. ~~However, it is noteworthy here that s~~Stand age had strong direct effect on~~is the main driver, directly and indirectly, via~~ stand structural diversity ~~and~~ but weak effect on ~~site productivity~~species diversity, and therefore strongly indirectly affect, via stand structural diversity, ~~affecting variation in~~ aboveground C storage~~stock in subtropical secondary forests (Fig. 3b)~~. Stand structural diversity is a major determinant for the variation in aboveground C storage in the secondary subtropical forests in Eastern China. Maintaining tree DBH diversity and height diversity through silvicultural operations could be an effective approach for enhancing aboveground C storage in these forests.~~Rather than species and height diversities, DBH diversity, stand age and site productivity cumulatively contributed to variations in aboveground C stock during stand~~

~~development in subtropical forests in Eastern China. Therefore, improving tree DBH diversity and stand condition could be an effective approach for continue C storage in subtropical forests.~~

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~~**Table 1** Characteristics of three forest development stages considered for the study on the linkage between stand characteristics and carbon stock (vegetation and soil) in subtropical evergreen broadleaved forests in Eastern China. Values are mean ± *SD* for each degradation level of the forest. Values with different lowercase letters in a given row are significantly different at $P < 0.05$ (*LSD* Fisher). The number of plots used (n) for young forests, premature forests and mature forests was 21, 39, and 20, respectively, for the vegetation data, and 21, 25, and 19, respectively, for the soils data.~~

~~-~~	~~Young forest~~	~~Pre-mature forest~~	~~Mature forest~~
~~***Vegetation structure***~~			
~~Maximum tree height (m)~~	~~14.2±7.5a~~	~~21.8±5.1b~~	~~24.1±5.1b~~
~~Maximum tree DBH (cm)~~	~~19.2±7.3a~~	~~38.6±11.5b~~	~~47.7±11.2c~~
~~Species richness~~	~~21±9a~~	~~26±10ab~~	~~29±8b~~
~~Species evenness~~	~~0.6±0.1a~~	~~0.6±0.2a~~	~~0.5±0.2a~~
~~Tree biomass (Mg ha^{-1})~~	~~48.2±31.3a~~	~~172.7±76.5b~~	~~256.81±105.8c~~
~~aboveground C stock (Mg ha^{-1})~~	~~24.1±15.7a~~	~~86.4±38.2b~~	~~128.4±52.9c~~
~~Tree species diversity index~~	~~2±0.6a~~	~~2±0.5a~~	~~2±0.5a~~
~~Tree DBH diversity index~~	~~1±0.3a~~	~~1±0.3b~~	~~2±0.3b~~
~~Tree height diversity index~~	~~1±0.5a~~	~~2±0.2b~~	~~2±0.2b~~
~~Age (year)~~	~~22±4.7a~~	~~79±6.1b~~	~~125±6.9c~~
~~Site productivity (m^{3} ha^{-1} year^{-1})~~	~~3.3±2.1a~~	~~4.4±2.2a~~	~~3.7±1.7a~~
~~Stand density (stems ha^{-1})~~	~~6068±3371a~~	~~4970±2457a~~	~~4512±1857a~~
~~***Soil property (0-20 cm)***~~			
~~Bulk density (g cm^{-3})~~	~~1.2±0.2a~~	~~1.1±0.2ab~~	~~1±0.2b~~
~~Soil organic C stock (Mg ha^{-1})~~	~~80.8±26.7a~~	~~85.3±28.8a~~	~~87.3±20.6a~~
~~***Forest management history and land-use regime***~~ (Wang et al., 2007; Yan et al., 2009)	~~Naturally regenerated stands after harvesting. In recent decades, forest harvesting has declined due to the availability of natural gas for cooking and heating.~~	~~Snags and downed deadwood harvesting. Nature disturbance regimes including typhoon and landslide.~~	~~Protected from clear-cutting. The stands were in the canopy gap-phase. Typhoon is the major disturbance regime (that returns 1-3 years) at the regional scale.~~

~~DBH: Diameter at breast height~~

~~**Table 2** The best model obtained from a series of regression analyses of a response variable (aboveground C stock) on stand structural diversity (species, DBH, and height diversities; first series), other stand characteristics (stand sage, stand density, and site productivity; second series), and a combination of stand structural diversity and other stand characteristics (third series). For each predictor variable, the regression coefficient (Coeff.), standardized regression coefficient (Beta), *t*-test and *P*-value are given. The coefficient of determination (R^2), *F*-test, *P*-value and Akaike Information Criterion (AICc) of the model are also given. For each effect of the first and second series, all seven possible models were tested, while all 63 possible models were tested for the third series. See Table S3 for the contribution to the models of all variables tested. Detailed statistics of all models for the first, second, and third series are provided in Tables S9, S10, and S11, respectively. *P* values < 0.05 are given in bold.~~

~~Model and predictor variable~~	~~Coeff.~~	~~Beta~~	~~*t*~~	~~*P*~~	~~R^2~~	~~AICc~~
~~**Effects of stand structural diversity**~~						
~~*Model*~~[1]			~~45.68~~	~~**<0.001**~~	~~0.54~~	~~809.22~~
~~Constant~~	~~-15.38~~	~~0.00~~	~~-0.82~~	~~0.414~~		
~~Species diversity~~	~~-23.36~~	~~-0.24~~	~~-3.02~~	~~**0.003**~~		
~~DBH diversity~~	~~105.17~~	~~0.74~~	~~9.47~~	~~**<0.001**~~		
~~**Effects of other stand characteristics**~~						
~~*Model*~~			~~97.69~~	~~**<0.001**~~	~~0.79~~	~~747.66~~
~~Constant~~	~~-26.85~~	~~0.00~~	~~-3.02~~	~~**0.003**~~		
~~Stand age~~	~~0.81~~	~~0.61~~	~~11.40~~	~~**<0.001**~~		
~~Site productivity~~	~~14.72~~	~~0.57~~	~~10.44~~	~~**<0.001**~~		
~~Stand density~~	~~-<0.01~~	~~-0.11~~	~~-1.98~~	~~**0.05**~~		
~~**Joint effect of stand structural diversity and other characteristics**~~						
~~*Model*~~			~~70.06~~	~~**<0.001**~~	~~0.83~~	~~739.12~~

~~Constant~~	~~-5.16~~	~~0.00~~	~~-0.34~~	~~0.736~~
~~Species diversity~~	~~-17.42~~	~~-0.18~~	~~-3.46~~	~~**0.001**~~
~~Height diversity~~	~~-19.93~~	~~-0.13~~	~~-2.12~~	~~**0.037**~~
~~DBH diversity~~	~~33.70~~	~~0.24~~	~~3.08~~	~~**0.003**~~
~~Site productivity~~	~~11.33~~	~~0.44~~	~~7.66~~	~~<**0.001**~~
~~Stand age~~	~~0.77~~	~~0.58~~	~~8.74~~	~~<**0.001**~~

~~[1] The value under *t* column represents *F*-test of the model~~

~~Figure Legends~~

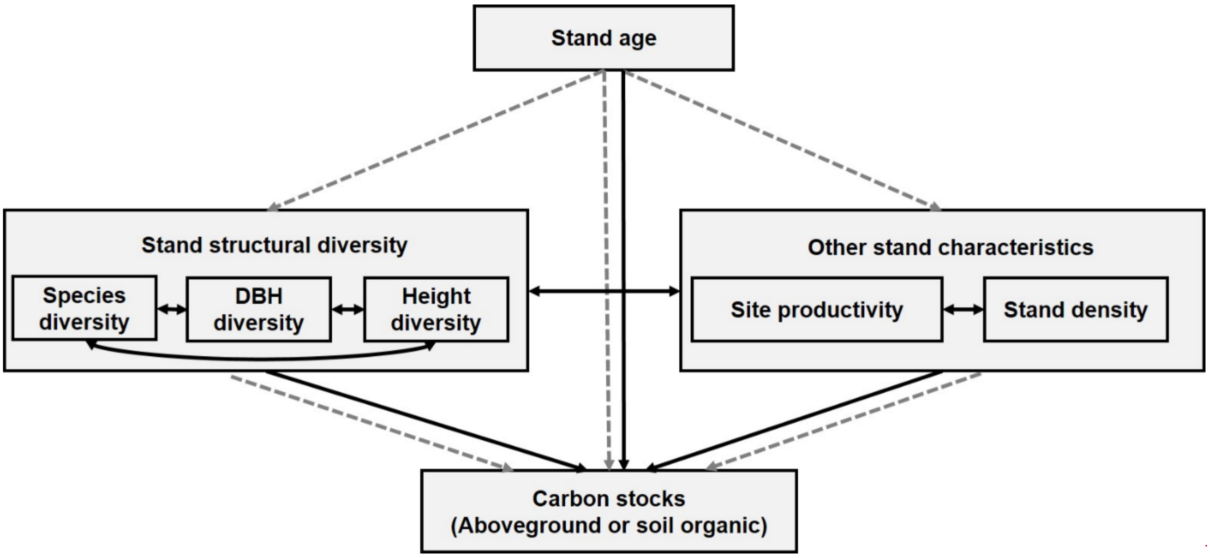
~~**Fig. 1** Conceptual model for explaining C stocks in secondary subtropical forests in Eastern China. The general model represented two basic models. 1) Model of the direct effects of stand structural diversity (i.e., species diversity, DBH diversity, height diversity) and other stand characteristics (i.e., stand age, stand density, and site productivity) on C stocks (stand characteristics model; indicated by black solid arrows). 2) Model of the direct and indirect effects of stand age through mediations of the stand structural diversity and other stand characteristics (stand age model; indicated by gray dashed arrows). Note that the one-sided solid or dashed arrow with black or gray color represents regression path, and the two-sided arrow with black color represents correlation between variables.~~

~~**Fig. 2** Relationships between stand characteristics and C stocks and between stand age and stand structural diversity in subtropical evergreen broadleaved forests. Only significant associations (see Table S2) are shown here **(a-d)** Aboveground C stock (ACS) as a function of tree DBH diversity, tree height diversity, site productivity, stand age; **(e)** DBH diversity as a function of stand age; and **(f)** height diversity as a function of stand age.~~

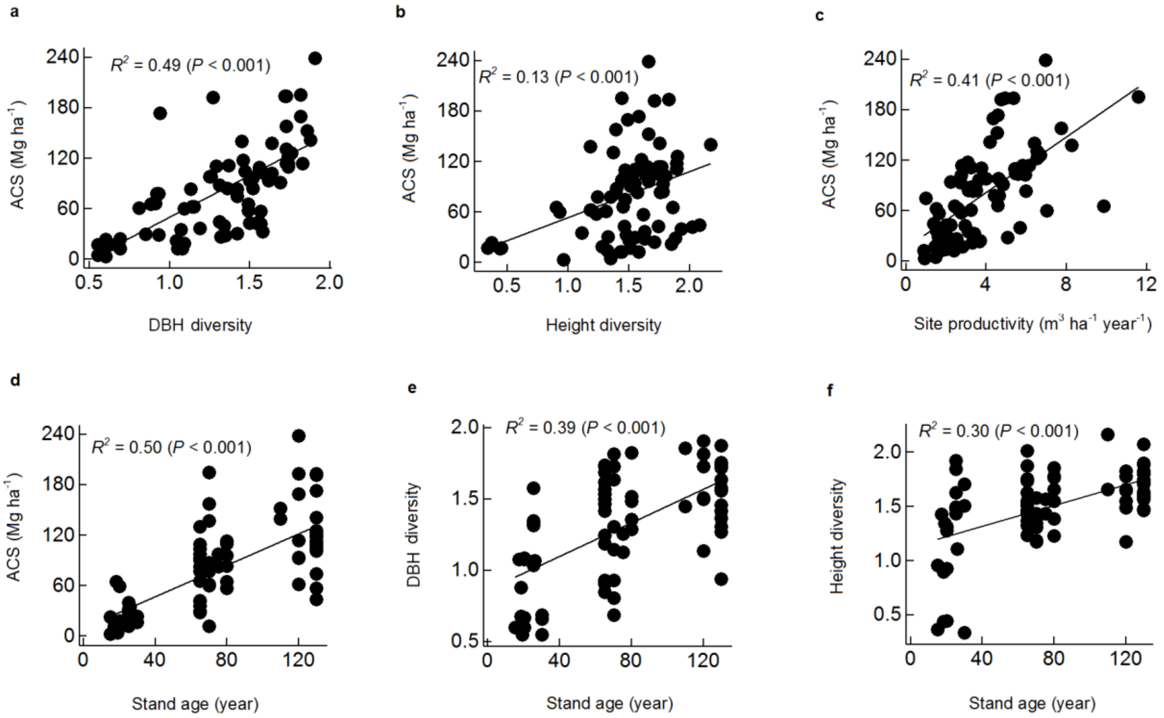
~~**Fig. 3** Best-fit structural equation models for aboveground C stock; a) combining species diversity, DBH diversity, height diversity, stand age, stand density, and site productivity~~

~~(stand characteristics model), b) stand age as a primary explanatory variable by testing direct and indirect effects through mediation of stand characteristics (stand age model) across all 80 subtropical forest plots. Stand characteristics model includes correlations among species diversity, DBH diversity, height diversity, stand age, stand density, and site productivity. However, the selected best model of the third series excludes these correlations (see Table 2). Values give the standardized coefficients for the correlation between variables; all coefficients are significant at *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; ns, non-significant; and coefficient of determination (R^2) for response variables are indicated. Epsilons (ε) within small circles represent the error term for downstream variables, ellipses represent response variable (aboveground C stock), and squares or rectangles represent predictor variables. But in the case of model (b), the squares or rectangles with white fill represent mediators, while those with gray fill represent primary variables.~~

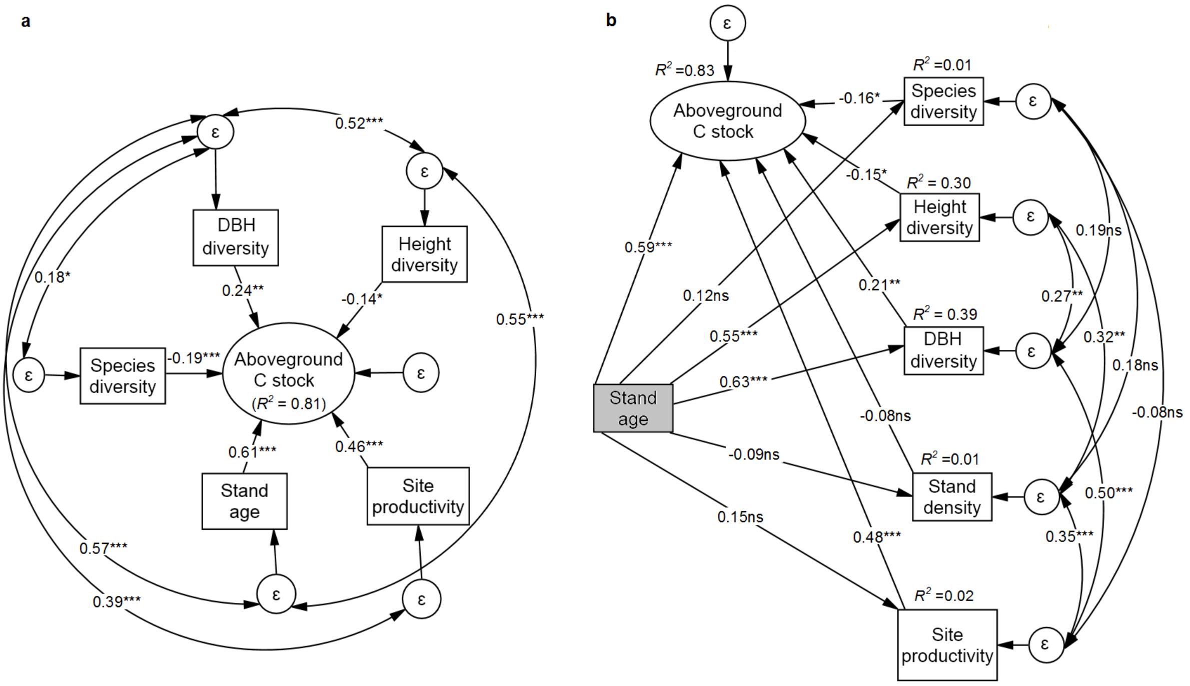
~~Fig. 1~~


Stand age
Stand structural diversity
Species diversity
DBH diversity
Height diversity
Other stand characteristics
Site productivity
Stand density
Carbon stocks
(Aboveground or soil organic)

~~Fig. 2~~


a
ACS (Mg ha^{-1})
240
180
120
60
0
R^2 = 0.49 (P < 0.001)
0.5
1.0
1.5
2.0
DBH diversity
b
ACS (Mg ha^{-1})
240
180
120
60
0
R^2 = 0.13 (P < 0.001)
0.5
1.0
1.5
2.0
Height diversity
c
ACS (Mg ha^{-1})
240
180
120
60
0
R^2 = 0.41 (P < 0.001)
0
4
8
12
Site productivity (m^3 ha^{-1} year^{-1})
d
ACS (Mg ha^{-1})
240
180
120
60
0
R^2 = 0.50 (P < 0.001)
0
40
80
120
Stand age (year)
e
DBH diversity
2.0
1.5
1.0
0.5
R^2 = 0.39 (P < 0.001)
0
40
80
120
Stand age (year)
f
Height diversity
2.0
1.5
1.0
0.5
R^2 = 0.30 (P < 0.001)
0
40
80
120
Stand age (year)

~~Fig. 3~~



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Poorter, L., van der Sande, M., Thompson, J., Arets, E., Alarcon, A., Alvarez-Sanchez, J., Ascarrunz, N., Balvanera, P., Barajas-Guzman, G., Boit, A., Bongers, F., Carvalho, F., Casanoves, F., Cornejo-Tenorio, G., Costa, F., de Castilho, C., Duivenvoorden, J., Dutrieux, L., Enquist, B., Fernandez-Mendez, F., Finegan, B., Gormley, L., Healey, J., Hoosbeek, M., Ibarra-Manriquez, G., Junqueira, A., Levis, C., Licona, J., Lisboa, L., Magnusson, W., Martinez-Ramos, M., Martinez-Yrizar, A., Martorano, L., Maskell, L., Mazzei, L., Meave, J., Mora, F., Munoz, R., Nytch, C., Pansonato, M., Parr, T., Paz, H., Perez-Garcia, E., Renteria, L., Rodriguez-Velazquez, J., Rozendaal, D., Ruschel, A., Sakschewski, B., Salgado-Negret, B., Schietti, J., Simoes, M., Sinclair, F., Souza, P., Souza, F., Stropp, J., ter Steege, H., Swenson, N., Thonicke, K., Toledo, M., Uriarte, M., van der Hout, P., Walker, P., Zamora, N., and Pena-Claros, M.: Diversity enhances carbon storage in tropical forests, Global Ecology and Biogeography, 24, 1314-1328, 2015.

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Table 1. The direct, indirect, and total standardized effects on aboveground C storage based on structural equation models (SEMs). The indirect effect was calculated by multiplying the standardized effects of all paths on one route from one predictor to mediator and then to aboveground C storage, while the total effect was calculated by adding standardized direct and indirect effects, presented in Fig. 3.

Predictor	Pathway to aboveground C storage	Model 3a		Model 3b		Model 3c	
		Effect	*P*-value	Effect	*P*-value	Effect	*P*-value
Stand age	Direct effect	0.41	0.003	0.41	0.003	0.41	0.003
	Indirect effect ~~through~~via species diversity	-0.005	0.827	0.07	0.199	-0.005	0.827
	Indirect effect ~~through~~via stand structural diversity	0.41	0.002	0.41	0.002	0.41	0.002
	Total effect	0.82	<0.001	0.89	<0.001	0.82	<0.001
Species diversity	Direct effect	-0.23	<0.001	-0.23	<0.001	-0.23	<0.001
	Indirect effect ~~throughiva~~via stand structural diversity	0.11	0.059	----	----	----	----
	Total effect	-0.12	0.056	-0.23	<0.001	-0.23	<0.001
Stand structural diversity	Direct effect	0.56	0.001	0.56	0.001	0.56	0.001
	Indirect effect ~~through~~via species diversity	----	----	-0.10	0.357	----	----
	Total effect	0.56	0.001	0.46	0.011	0.56	0.001

Figure Legends

Fig. 1 Conceptual models for predicting aboveground C storage in secondary subtropical forests in Eastern China,~~.~~ ~~Conceptual models~~ showing hypothesized relationships ~~that~~of how does stand age affect forest diversity, and how do stand age and forest diversity together affect aboveground C storage. Forest diversity ~~are~~is characterized by their magnitude (e.g., species diversity) and variation in stand structure (e.g., DBH and height diversity; a latent variable). Three conceptual models are proposed based on different direct effects of forest diversity components on each other; a) stand structural diversity → species diversity; b) species diversity → stand structural diversity; and c) species diversity ↔ stand structural diversity. ~~the~~

Fig. 2 Bivariate relationships between endogenous (dependent) and exogenous (independent) variables ($n = 80$), for all hypothesized causal paths in the final selected structural equation models (SEMs). All numerical variables were natural log-transformed and standardized. (a)-(d) Aboveground carbon (AGC) storage (Mg ha^{-1}) vs. height diversity (Hh, 2 m class), DBH diversity (Hd, 8 cm class), stand age (SA) and species diversity (Hs), respectively; (e-g) Diversity (Hh, Hd, and Hs) vs. stand age (SA); (h)-(i) DBH diversity (Hd, 8 cm class) and height (Hh, 2 m class) diversity vs. species diversity (Hs); and (j)-(k) species diversity (Hs) vs. DBH diversity (Hd, 8 cm class) and height (Hh, 2 m class) diversity. All other fitted regressions are significant at $P < 0.001$ with exception of fitted regressions in panels' (d), (g), (h)-(k) ($P > 0.05$).

Fig. 3 The final best-fit structural equation models (SEMs) relating aboveground C storage to stand age and forest diversity (stand structural diversity and species diversity). Solid arrows represent significant ($P < 0.05$) paths and dashed arrows represent ~~for~~ non-significant paths ($P > 0.05$). For each path the standardized regression coefficient is shown. R^2 indicates the total variation in a dependent variable that is explained by the combined independent variables. Final SEMs (a, b and c) are consistent with conceptual models in Figure 1. The summary of model selection of best-fit SEM for aboveground C storage is provided in Table S3.

Fig. 1

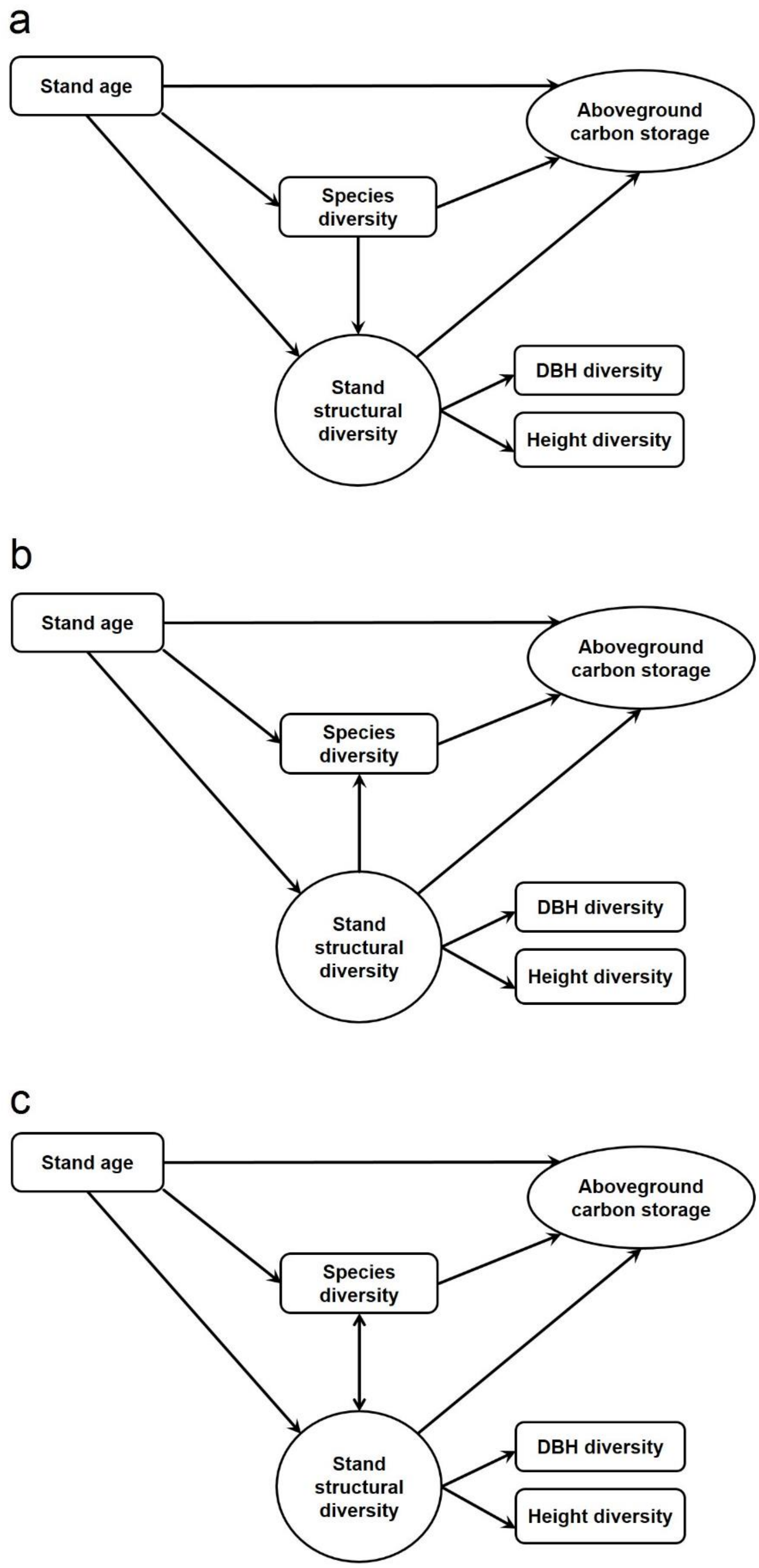

a
Stand age
Aboveground carbon storage
Species diversity
Stand structural diversity
DBH diversity
Height diversity
b
Stand age
Aboveground carbon storage
Species diversity
Stand structural diversity
DBH diversity
Height diversity
c
Stand age
Aboveground carbon storage
Species diversity
Stand structural diversity
DBH diversity
Height diversity

Fig. 2

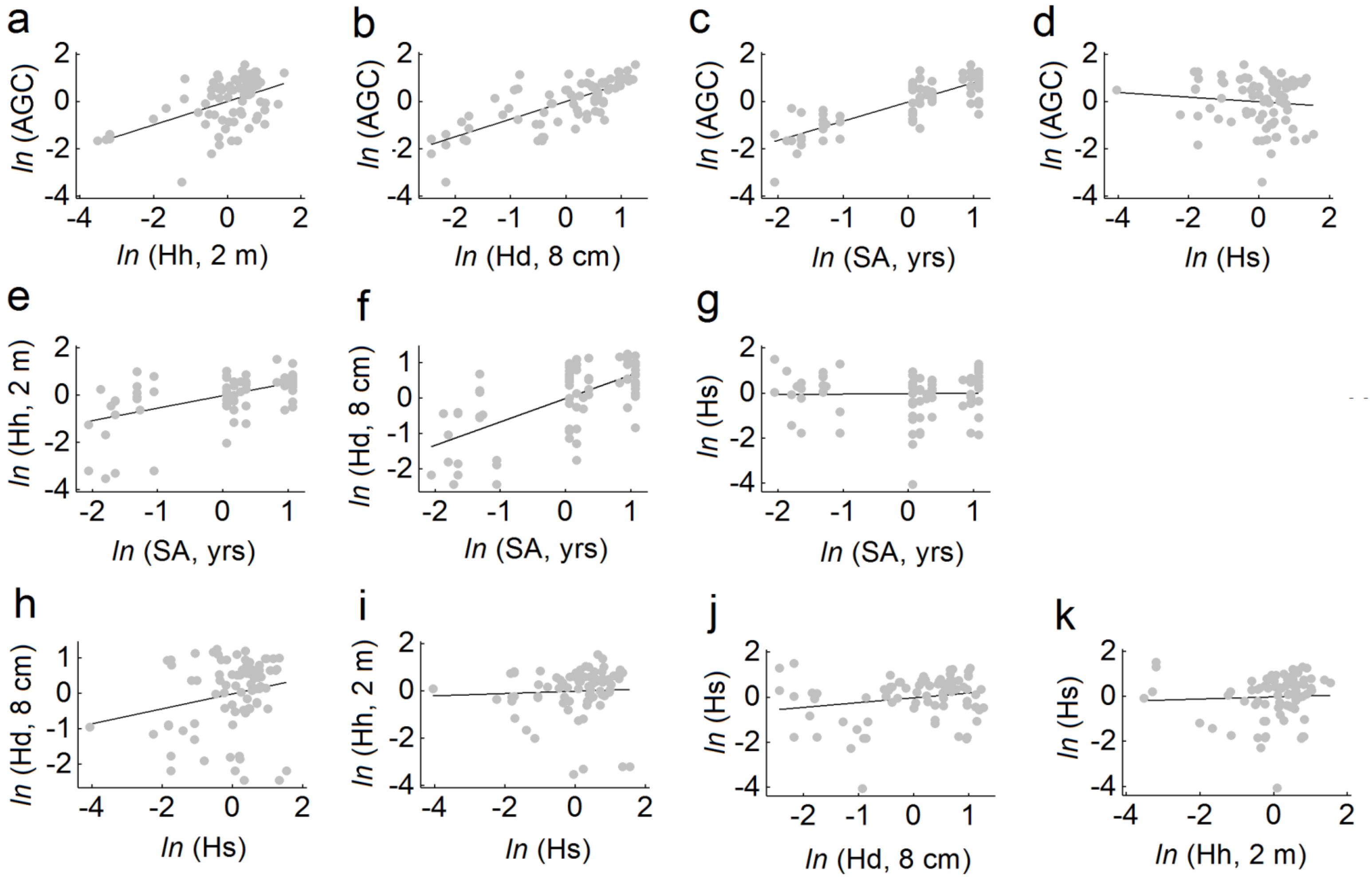
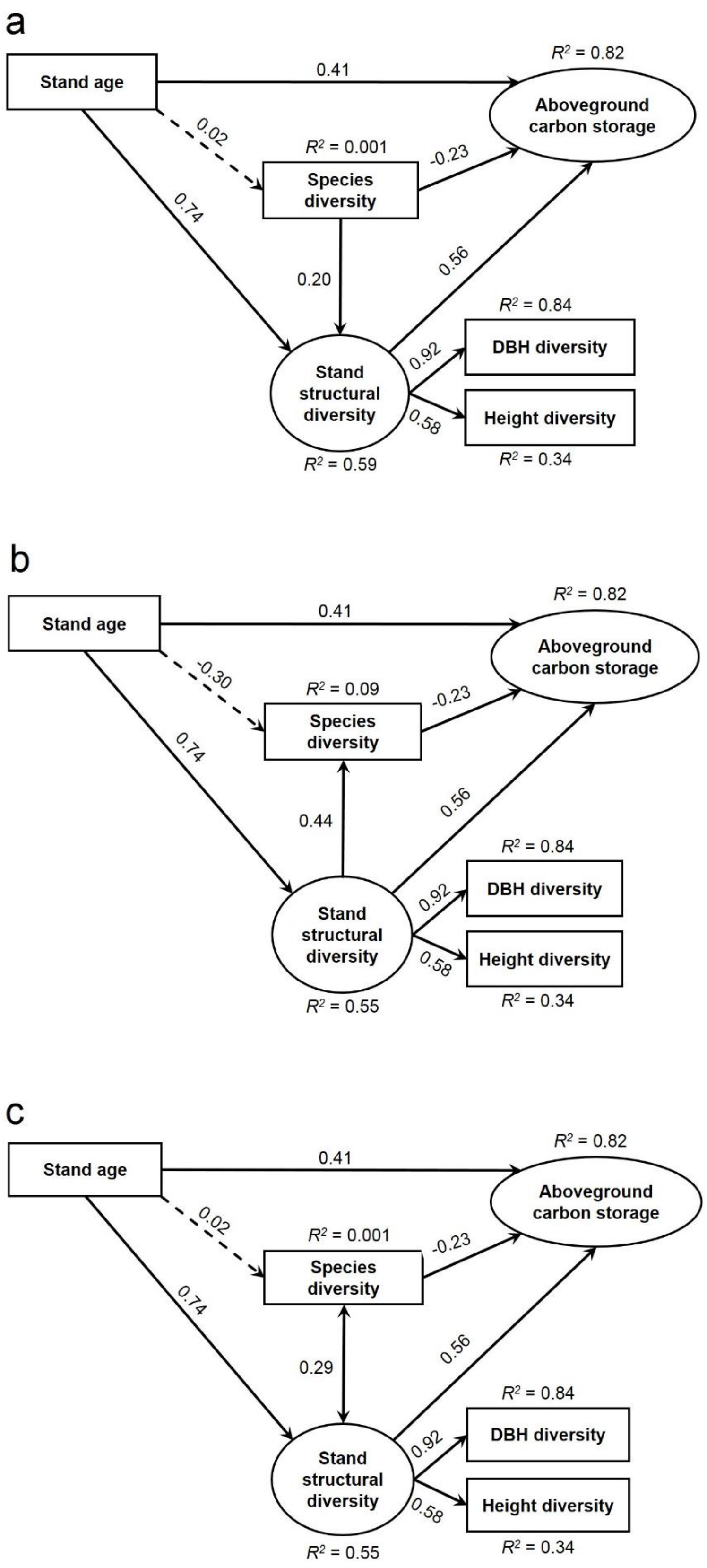


Fig. 3


a
Stand age
0.41
R^2 = 0.82
Aboveground carbon storage
0.02
R^2 = 0.001
Species diversity
-0.23
0.74
0.20
0.56
R^2 = 0.84
DBH diversity
0.92
Stand structural diversity
0.58
Height diversity
R^2 = 0.59
R^2 = 0.34
b
Stand age
0.41
R^2 = 0.82
Aboveground carbon storage
-0.30
R^2 = 0.09
Species diversity
-0.23
0.74
0.44
0.56
R^2 = 0.84
DBH diversity
0.92
Stand structural diversity
0.58
Height diversity
R^2 = 0.55
R^2 = 0.34
c
Stand age
0.41
R^2 = 0.82
Aboveground carbon storage
0.02
R^2 = 0.001
Species diversity
-0.23
0.74
0.29
0.56
R^2 = 0.84
DBH diversity
0.92
Stand structural diversity
0.58
Height diversity
R^2 = 0.55
R^2 = 0.34

Supplementary information

Stand structural diversity rather than species diversity enhances aboveground carbon storage ~~Relative contribution of stand characteristics on carbon stocks~~ in secondary subtropical ~~secondary~~ forests in Eastern China

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Table S1. Summary of plot variables used in the bivariate relationships and structural equation models (SEMs) for the quantification of ~~stand characteristics and carbon stock (aboveground and soil)~~forest diversity and aboveground C storage in secondary subtropical evergreen broadleaved forests in ~~eastern~~ Eastern China. $n = 80$; ~~*SD* = standard deviation~~ln = natural log. ~~Number of sample plots used for aboveground carbon stock were 80 while for soil organic carbon stock were 65.~~

~~Variable~~		~~Vegetation part~~		~~Soil part (0-20 cm)~~	
	~~Unit~~	~~Mean~~	~~*SD*~~	~~Mean~~	~~*SD*~~
~~***Dependent variable***~~					
~~Carbon stock~~	~~Mg ha^{-1}~~	~~80.53~~	~~53.67~~	~~84.44~~	~~25.69~~
~~***Stand structural diversity***~~					
~~Tree species diversity index~~	~~unitless~~	~~1.80~~	~~0.54~~	~~1.72~~	~~0.52~~
~~Tree DBH diversity index~~	~~unitless~~	~~1.31~~	~~0.38~~	~~1.23~~	~~0.37~~
~~Tree height diversity index~~	~~unitless~~	~~1.49~~	~~0.36~~	~~1.48~~	~~0.38~~
~~***Other stand characteristics***~~					
~~Stand age~~	~~year~~	~~72.60~~	~~40.38~~	~~70.82~~	~~40.68~~
~~Site productivity~~	~~m^3 ha^{-1} year^{-1}~~	~~3.92~~	~~2.08~~	~~3.34~~	~~1.70~~
~~Stand density~~	~~stems ha^{-1}~~	~~5144.03~~	~~2636.61~~	~~4791.80~~	~~2678.07~~

Variable	Unit	Transformation	Minimum	Maximum
Dependent variable				
Aboveground C (AGC) storage	Mg ha^{-1}	ln and standardized	-3.42	1.58
Explanatory variables				
Stand age (SA)	years	ln and standardized	-2.06	1.07
Tree species diversity (Hs)	unitless	ln and standardized	-4.06	1.54
Tree DBH diversity (Hd, 2 cm)	unitless	ln and standardized	-3.27	1.30
Tree DBH diversity (Hd, 4 cm)	unitless	ln and standardized	-3.02	1.14
Tree DBH diversity (Hd, 6 cm)	unitless	ln and standardized	-4.07	1.17
Tree DBH diversity (Hd, 8 cm)	unitless	ln and standardized	-2.44	1.26
Tree height diversity (Hh, 2 m)	unitless	ln and standardized	-3.53	1.55
Tree height diversity (Hh, 3 m)	unitless	ln and standardized	-4.20	1.22
Tree height diversity (Hh, 4 m)	unitless	ln and standardized	-2.87	1.70
Tree height diversity (Hh, 5 m)	unitless	ln and standardized	-4.16	1.45

DBH, tree diameter at breast height

Table S2. Pearson's correlation coefficients between variables used in this study for testing structural equation models (SEMs) of aboveground C storage. The highlighted gray portion in the table indicating variables used in the selected SEMs (see Fig. 2).

	Hs	Hh (2 m)	Hd (8 cm)	SA	AGC	Hh (3 m)	Hh (4 m)	Hh (5 m)	Hd (2 cm)	Hd (4 cm)	Hd (6 cm)
Hs											
Hh (2 m)	0.05										
Hd (8 cm)	0.21	0.53***									
SA	0.02	0.52***	0.66***								
AGC	-0.10	0.49***	0.74***	0.82***							
Hh (3 m)	-0.06	0.94***	0.59***	0.56***	0.50***						
Hh (4 m)	0.02	0.89***	0.58***	0.60***	0.53***	0.90***					
Hh (5 m)	-0.02	0.80***	0.60***	0.59***	0.51***	0.84***	0.87***				
Hd (2 cm)	0.28*	0.40***	0.80***	0.51***	0.62***	0.38***	0.34***	0.38***			
Hd (4 cm)	0.27*	0.50***	0.94***	0.63***	0.71***	0.52***	0.52***	0.56***	0.93***		
Hd (6 cm)	0.24*	0.42***	0.89***	0.61***	0.69***	0.45***	0.47***	0.50***	0.87***	0.95***	

All variables were natural log transformed and standardized. Coefficients are significant at $P < 0.05$ (*), < 0.01 (**), and < 0.001 (***). See Table S1 for abbreviations and units of variables.

Table ~~S2~~S3. Model selection of good-fit structural equation model (SEM) for aboveground carbon storage. Model fit summary particularly AIC was used to determine the best-fit SEM model from all SEM models. Selected models, based on three conceptual models in the study, are highlighted in bold. All possible combinations of discrete classes for DBH and height diversity along with stand age and species diversity were tested, see Figure 1 for conceptual models.

df: degrees of freedom; CFI: comparative fit index; GFI: goodness of fit index; SRMR: standardized root mean square residual; AIC: Akaike information criterion; R^2 indicates the total variation in aboveground C storage that is explained by the combined independent variables. Note: df is based on the number of ‘knowns’ minus the number of free parameters in the model, not on the sample size.

~~Simple linear regression relationship between stand age, stand characteristics, and C stocks in the subtropical evergreen broadleaved forests in eastern China. Values indicate the coefficient of determination (R^2) from simple linear regression analysis. All coefficients are significant at *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; ns, not significant. Relationships showing a negative slope are indicated with negative signs.~~

~~Stand variables~~	~~ACS (Mg ha^{-1})~~	~~SOCS (Mg ha^{-1})~~	~~Stand age (year)~~
~~Tree species diversity~~	~~-0.01ns~~	~~<0.01ns~~	~~0.01ns~~
~~Tree DBH diversity~~	~~**0.49*****~~	~~<0.01ns~~	~~**0.39*****~~
~~Tree height diversity~~	~~**0.13*****~~	~~<0.01ns~~	~~**0.30*****~~
~~Stand age (year)~~	~~**0.50*****~~	~~<0.01ns~~	
~~Site productivity (m^3 ha^{-1} year^{-1})~~	~~**0.41*****~~	~~0.02ns~~	~~0.02ns~~
~~Stand density (stems ha^{-1})~~	~~<0.01ns~~	~~0.01ns~~	~~0.01ns~~

Conceptual model	Discrete classes used for stand structure indices		df	Model fit summary						Model remarks based on chi-square test, selection based on lowest AIC and other parameters
	Height (class in m)	DBH (class in cm)		CFI	GFI	SRMR	AIC	R^2	Chi-square (*P*-value)	
1a	2	2	2	0.97	0.97	0.05	33.25	0.88	7.25 (0.027)	Rejected
1b	2	2	2	0.97	0.97	0.05	33.25	0.88	7.25 (0.027)	Rejected
1c	2	2	2	0.97	0.97	0.05	33.25	0.88	7.25 (0.027)	Rejected
1a	2	4	2	0.98	0.98	0.04	31.27	0.83	5.27 (0.072)	Accepted
1b	2	4	2	0.98	0.98	0.04	31.27	0.83	5.27 (0.072)	Accepted
1c	2	4	2	0.98	0.98	0.04	31.27	0.83	5.27 (0.072)	Accepted
1a	2	6	2	0.99	0.98	0.04	30.20	0.90	4.20 (0.123)	Accepted
1b	2	6	2	0.99	0.98	0.04	30.20	0.90	4.20 (0.123)	Accepted

1c	2	6	2	0.99	0.98	0.04	30.20	0.90	4.20 (0.123)	Accepted
1a	**2**	**8**	**2**	0.99	0.98	0.03	**30.18**	**0.82**	**4.18 (0.124)**	**Accepted & selected**
1b	**2**	**8**	**2**	0.99	0.98	0.03	**30.18**	**0.82**	**4.18 (0.124)**	**Accepted & selected**
1c	**2**	**8**	**2**	0.99	0.98	0.03	**30.18**	**0.82**	**4.18 (0.124)**	**Accepted & selected**
1a	3	2	2	0.92	0.94	0.07	40.87	0.88	14.87 (0.001)	Rejected
1b	3	2	2	0.92	0.94	0.07	40.87	0.88	14.87 (0.001)	Rejected
1c	3	2	2	0.92	0.94	0.07	40.87	0.88	14.87 (0.001)	Rejected
1a	3	4	2	0.94	0.94	0.07	39.78	0.80	13.78 (0.001)	Rejected
1b	3	4	2	0.94	0.94	0.07	39.78	0.80	13.78 (0.001)	Rejected
1c	3	4	2	0.94	0.94	0.07	39.78	0.80	13.78 (0.001)	Rejected
1a	3	6	2	0.95	0.95	0.06	37.45	0.83	11.45 (0.003)	Rejected
1b	3	6	2	0.95	0.95	0.06	37.45	0.83	11.45 (0.003)	Rejected
1c	3	6	2	0.95	0.95	0.06	37.45	0.83	11.45 (0.003)	Rejected
1a	3	8	2	0.95	0.94	0.07	38.75	0.78	12.75 (0.002)	Rejected
1b	3	8	2	0.95	0.94	0.07	38.75	0.78	12.75 (0.002)	Rejected
1c	3	8	2	0.95	0.94	0.07	38.75	0.78	12.75 (0.002)	Rejected
1a	4	2	2	----	----	----	----	----	----	Bad-fit
1b	4	2	2	----	----	----	----	----	----	Bad-fit
1c	4	2	2	----	----	----	----	----	----	Bad-fit
1a	4	4	2	0.96	0.95	0.05	36.45	0.83	10.45 (0.005)	Rejected
1b	4	4	2	0.96	0.95	0.05	36.45	0.83	10.45 (0.005)	Rejected
1c	4	4	2	0.96	0.95	0.05	36.45	0.83	10.45 (0.005)	Rejected
1a	4	6	2	0.96	0.96	0.05	34.75	0.87	8.75 (0.013)	Rejected
1b	4	6	2	0.96	0.96	0.05	34.75	0.87	8.75 (0.013)	Rejected
1c	4	6	2	0.96	0.96	0.05	34.75	0.87	8.75 (0.013)	Rejected
1a	4	8	2	0.96	0.96	0.04	35.44	0.81	9.44 (0.009)	Rejected
1b	4	8	2	0.96	0.96	0.04	35.44	0.81	9.44 (0.009)	Rejected
1c	4	8	2	0.96	0.96	0.04	35.44	0.81	9.44 (0.009)	Rejected
1a	5	2	2	0.93	0.94	0.07	41.01	0.91	15.01 (0.001)	Rejected
1b	5	2	2	0.93	0.94	0.07	41.01	0.91	15.01 (0.001)	Rejected
1c	5	2	2	0.93	0.94	0.07	41.01	0.91	15.01 (0.001)	Rejected
1a	5	4	2	0.94	0.94	0.07	40.81	0.79	14.81 (0.001)	Rejected
1b	5	4	2	0.94	0.94	0.07	40.81	0.79	14.81 (0.001)	Rejected
1c	5	4	2	0.94	0.94	0.07	40.81	0.79	14.81 (0.001)	Rejected
1a	5	6	2	0.95	0.95	0.06	38.27	0.81	12.27 (0.002)	Rejected
1b	5	6	2	0.95	0.95	0.06	38.27	0.81	12.27 (0.002)	Rejected
1c	5	6	2	0.95	0.95	0.06	38.27	0.81	12.27 (0.002)	Rejected
1a	5	8	2	0.95	0.94	0.06	39.71	0.79	13.07 (0.001)	Rejected
1b	5	8	2	0.95	0.94	0.06	39.71	0.79	13.07 (0.001)	Rejected
1c	5	8	2	0.95	0.94	0.06	39.71	0.79	13.07 (0.001)	Rejected

~~ACS: aboveground C stock, and SOCS: soil organic C stock~~

~~**Table S3.** Synthetic model obtained from a series of regression analyses of a response variable (aboveground C stock) on each of stand structural diversity (species, DBH and height diversity; first series), other stand characteristics (stand sage, stand density and site productivity; second series), and a combination of stand structural diversity and other stand characteristics (third series). For each predictor variable, their importance (Imp.), regression coefficient (Coeff.) and standardized regression coefficient (Beta) are given. The results are averaged over all seven possible models using AICc-wi (the Akaike information criterion weight) as a weighting criterion for first and second series, but averaged over all 63 possible models using AICc-wi for third series. Significant coefficients (*P* < 0.05) are given in bold.~~

	~~Synthetic model of first series~~			~~Synthetic model of second series~~			~~Synthetic model of third series~~		
~~Predictor variable~~	~~Imp.~~	~~Coeff.~~	~~Beta~~	~~Imp.~~	~~Coeff.~~	~~Beta~~	~~Imp.~~	~~Coeff.~~	~~Beta~~
~~Constant~~	~~---~~	~~-14.26~~	~~0.00~~	~~---~~	~~-29.71~~	~~0.00~~	~~---~~	~~-5.70~~	~~0.00~~
~~Species diversity~~	~~0.97~~	~~-23.54~~	~~**-0.24**~~				~~0.96~~	~~-15.98~~	~~**-0.16**~~
~~Height diversity~~	~~0.28~~	~~-8.50~~	~~-0.06~~				~~0.77~~	~~-21.03~~	~~**-0.14**~~
~~DBH diversity~~	~~1.00~~	~~106.23~~	~~**0.75**~~				~~0.90~~	~~30.13~~	~~**0.21**~~
~~Stand age~~				~~1.00~~	~~0.81~~	~~**0.61**~~	~~1~~	~~0.78~~	~~**0.59**~~
~~Site productivity~~				~~1.00~~	~~14.50~~	~~**0.56**~~	~~1~~	~~12.05~~	~~**0.47**~~
~~Stand density~~				~~0.70~~	~~-0.002~~	~~**-0.11**~~	~~0.42~~	~~-0.002~~	~~-0.08~~

~~**Table S4.** The best model obtained from a series of regression analyses of a response variable (soil organic C stock) on each of stand structural diversity (species, DBH and height diversity; first series), other stand characteristics (stand sage, stand density and site productivity; second series), and a combination of stand structural diversity and other stand characteristics (third series). For each predictor variable, the regression coefficient (Coeff.), standardized regression coefficient (Beta), *t*-test and *P*-value are given. The coefficient of determination (R^2), *F*-test, *P*-value and Akaike Information Criterion (AICc) of the model are also given. For each effect of first and second series, all 7 possible models were tested, while all 63 possible models were tested for third series. See Table S5 for the contribution to the models of all variables tested. Detailed statistics of all models for first, second and third series are provided in Tables S12, S13 and S14, respectively. *P* values < 0.05 are given in bold.~~

~~Model and predictor variable~~	~~Coeff.~~	~~Beta~~	~~*t*~~	~~*P*~~	~~R^2~~	~~AICc~~
~~**Effects of stand structural diversity**~~						
~~*Model*[1]~~			~~0.10~~	~~0.751~~	~~0.002~~	~~611.75~~
~~Constant~~	~~80.46~~	~~0.00~~	~~6.25~~	~~**<0.001**~~		
~~Height diversity~~	~~2.69~~	~~0.04~~	~~0.32~~	~~0.751~~		
~~**Effects of other stand characteristics**~~						
~~*Model*~~			~~0.99~~	~~0.324~~	~~0.02~~	~~610.84~~
~~Constant~~	~~90.70~~	~~0.00~~	~~12.83~~	~~**<0.001**~~		
~~Site productivity~~	~~-1.88~~	~~-0.12~~	~~-0.99~~	~~0.324~~		
~~**Joint effect of stand structural diversity and other characteristics**~~						
~~*Model*~~			~~0.99~~	~~0.324~~	~~0.02~~	~~610.84~~

~~Constant~~	~~90.70~~	~~0.00~~	~~12.83~~	~~<**0.001**~~
~~Site productivity~~	~~-1.88~~	~~-0.12~~	~~-0.99~~	~~0.324~~

[1] ~~The value under *t* column represents *F*-test of the model~~

~~**Table S5.** Synthetic model obtained from a series of regression analyses of a response variable (soil organic C stock) on each of stand structural diversity (species, DBH and height diversity; first series), other stand characteristics (stand sage, stand density and site productivity; second series), and a combination of stand structural diversity and other stand characteristics (third series). For each predictor variable, their importance (Imp.), regression coefficient (Coeff.) and standardized regression coefficient (Beta) are given. The results are averaged over all seven possible models using AICc-wi (the Akaike information criterion weight) as a weighting criterion for first and second series, but averaged over all 63 possible models using AICc-wi for third series. Significant coefficients (*P* < 0.05) are given in bold.~~

	~~Synthetic model of first series~~			~~Synthetic model of second series~~			~~Synthetic model of third series~~		
~~Predictor variable~~	~~Imp.~~	~~Coeff.~~	~~Beta~~	~~Imp.~~	~~Coeff.~~	~~Beta~~	~~Imp.~~	~~Coeff.~~	~~Beta~~
~~Constant~~	~~---~~	~~83.10~~	~~0.00~~	~~---~~	~~88.70~~	~~0.00~~	~~---~~	~~88.34~~	~~0.00~~
~~Species diversity~~	~~0.43~~	~~-0.69~~	~~-0.01~~				~~0.29~~	~~-1.58~~	~~-0.03~~
~~Height diversity~~	~~0.44~~	~~2.92~~	~~0.04~~				~~0.29~~	~~1.59~~	~~0.02~~
~~DBH diversity~~	~~0.43~~	~~-0.13~~	~~-0.002~~				~~0.29~~	~~-0.93~~	~~-0.01~~
~~Stand age~~				~~0.39~~	~~0.04~~	~~0.06~~	~~0.30~~	~~0.04~~	~~0.06~~
~~Site productivity~~				~~0.50~~	~~-1.80~~	~~-0.12~~	~~0.40~~	~~-1.93~~	~~-0.13~~
~~Stand density~~				~~0.47~~	~~-0.001~~	~~-0.11~~	~~0.36~~	~~-0.001~~	~~-0.11~~

~~**Table S6.** Collinearity statistics for each characteristics of the stand within multiple regressions model of each of aboveground C and soil organic C stock.~~

~~Predictor variables~~	~~Collinearity Statistics~~	
	~~Tolerance~~	~~VIF~~
~~***Aboveground C stock as a response variable***~~		
~~Species diversity~~	~~0.83~~	~~1.20~~
~~Height diversity~~	~~0.56~~	~~1.79~~
~~DBH diversity~~	~~0.36~~	~~2.78~~
~~Site productivity~~	~~0.58~~	~~1.71~~
~~Stand age~~	~~0.51~~	~~1.95~~
~~Stand density~~	~~0.68~~	~~1.47~~
~~***Soil C stock as a response variable***~~		
~~Species diversity~~	~~0.79~~	~~1.27~~
~~Height diversity~~	~~0.52~~	~~1.94~~
~~DBH diversity~~	~~0.39~~	~~2.56~~
~~Site productivity~~	~~0.65~~	~~1.54~~
~~Stand age~~	~~0.51~~	~~1.96~~

~~Stand density~~	~~0.65~~	~~1.55~~

~~**Table S7.** Direct, indirect, and total standardized effects of predictors on aboveground C stock based on structural equation models (SEMs). The upper section of table (model A) showing the direct standardized effect of stand characteristics on aboveground C stock (see Fig. 4a). The lower section of table (model B) showing the direct, indirect, and total effects of stand age on aboveground C stock; and also direct effect on other stand characteristics (see Fig. 4b). Significant effects are at *, P < 0.05; **, P < 0.01; ***, P < 0.001; and ns, not significant.~~

~~SEM model and response variable~~	~~Predictors within each model~~																	
	~~Stand age~~			~~Species diversity~~			~~DBH diversity~~			~~Height diversity~~			~~Site productivity~~			~~Stand density~~		
	~~Direct~~	~~Indirect~~	~~Total~~	~~Direct~~	~~Indirect~~	~~Total~~	~~Direct~~	~~Indirect~~	~~Total~~	~~Direct~~	~~Indirect~~	~~Total~~	~~Direct~~	~~Indirect~~	~~Total~~	~~Direct~~	~~Indirect~~	~~Total~~
~~**A, stand characteristics model in Fig. 4a**~~																		
~~ACS~~	~~0.61 ***~~	~~——~~	~~0.61 ***~~	~~-0.19 ***~~	~~——~~	~~-0.19 ***~~	~~0.24 ***~~	~~——~~	~~0.24 ***~~	~~-0.14 *~~	~~——~~	~~-0.14 *~~	~~0.46 ***~~	~~——~~	~~0.46 ***~~	~~——~~	~~——~~	~~——~~
~~**B, stand age model in Fig. 4b**~~																		
~~ACS~~	~~0.59 ***~~	~~0.11 ns~~	~~0.70 ***~~	~~-0.16 *~~	~~——~~	~~-0.16 *~~	~~0.21 ***~~	~~——~~	~~0.21 ***~~	~~-0.15 *~~	~~——~~	~~-0.15 *~~	~~0.48 ***~~	~~——~~	~~0.48 ***~~	~~-0.08 ns~~	~~——~~	~~-0.08 ns~~
~~Species diversity~~	~~0.16 ns~~	~~——~~	~~0.16 ns~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~
~~DBH diversity~~	~~0.63 ***~~	~~——~~	~~0.63 ***~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~
~~Height diversity~~	~~0.55 ***~~	~~——~~	~~0.55 ***~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~
~~Site productivity~~	~~0.15~~	~~——~~	~~0.15~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~

	~~ns~~		~~ns~~															
~~Stand density~~	~~-0.09~~	~~——~~	~~-0.09~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~	~~——~~
	~~ns~~		~~ns~~															

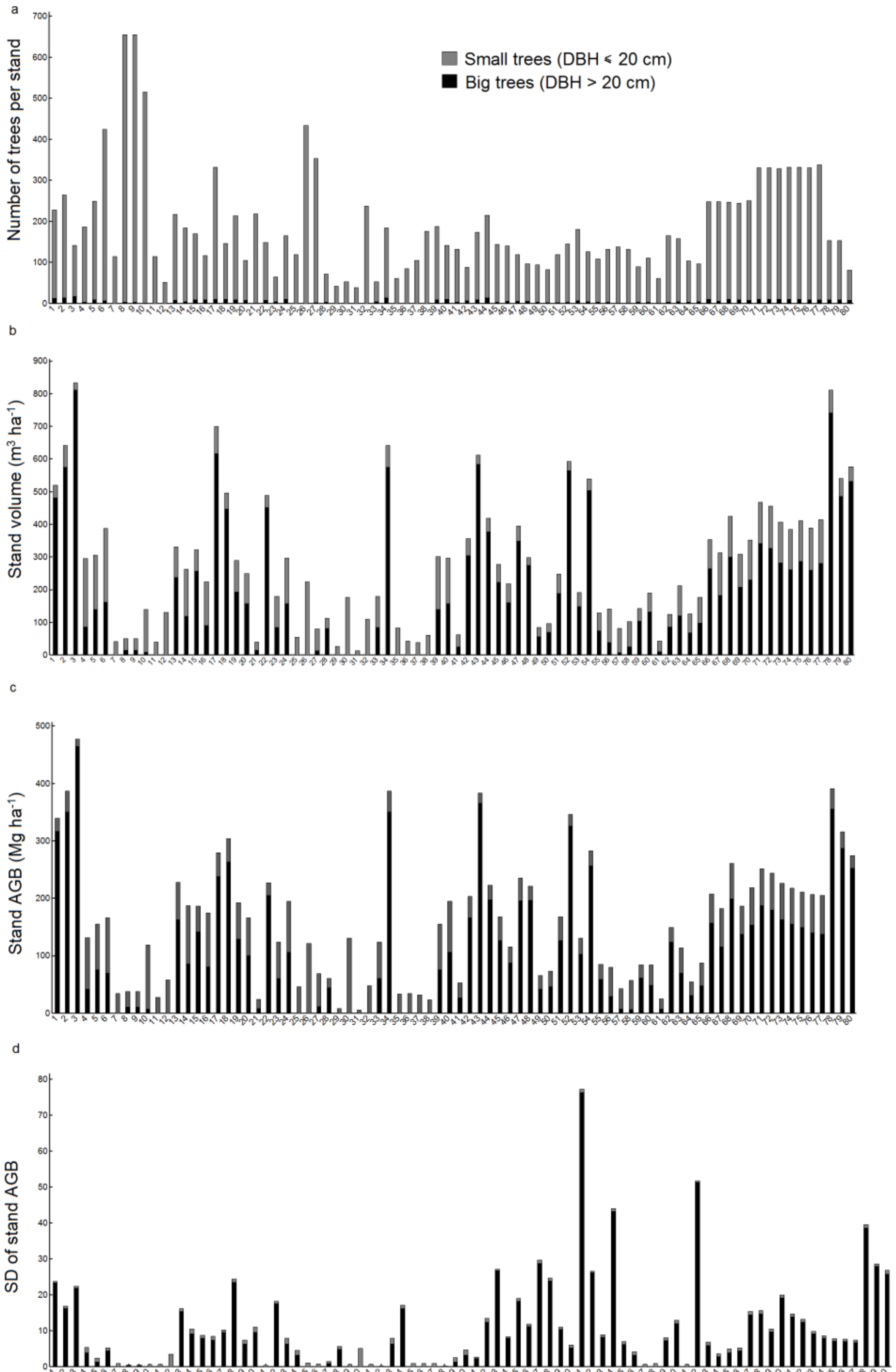
~~**Table S8** Correlation coefficients between stand structural (tree DBH and height) diversity and each of 90-percentile diameter/height and coefficient of variation in diameter/height of trees.~~

~~Stand variables~~	~~CV of D~~	~~P90 of D~~	~~CV of H~~	~~P90 of H~~
~~Tree DBH diversity~~	~~0.681**~~	~~0.243*~~	~~0.322**~~	~~0.073ns~~
~~Tree height diversity~~	~~0.433**~~	~~0.127ns~~	~~0.576**~~	~~0.114ns~~

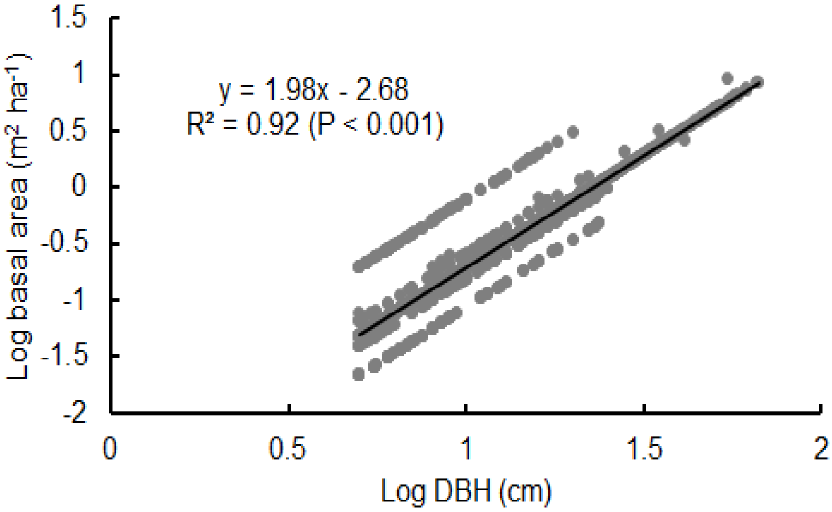
~~CV: coefficient of variance; D: tree diameter; H: tree height; and P90: 90 percentile; indicated with asterisks if statistically significant (*: $P <$ 0.05; **: $P < 0.01$; ***: $P < 0.001$; ns: not significant)~~

~~**Figure Legends**~~

~~**Fig. S1** a) Number of trees per stand (trees 0.04ha^{-1}); b) stand volume (m^{3} ha^{-1}); c) stand aboveground biomass (Mg ha^{-1}); and d) standard deviation of stand aboveground biomass of 80 subtropical forest plots.~~


a
Number of trees per stand
0
100
200
300
400
500
600
700
Small trees (DBH ≤ 20 cm)
Big trees (DBH > 20 cm)
b
Stand volume (m^3 ha^{-1})
0
100
200
300
400
500
600
700
800
900
c
Stand AGB (Mg ha^{-1})
0
100
200
300
400
500
d
SD of stand AGB
0
10
20
30
40
50
60
70
80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

~~**Fig. S2** Relationship between the log of basal area (m^2 ha^{-1}) and log of diameter at breast height (DBH, cm) for all tree species (DBH > 5cm) across 80 subtropical forest plots.~~



~~**Fig. S3.** Comparison of the individual tree aboveground biomass (DBH ≥ 5 cm) estimated with Brown’s (1989) equation and a) simple geometric equation, and b, c) Chave et al.’s (2005) moist forest equations. The dashed line represents a 1:1 theoretical relationship; the solid line represents the observed relationship. It should be noted here that the individuals having specific wood density were used for the comparison purpose only.~~

~~For panel (a) of the graph; a simple geometrical equation suggests that the total aboveground biomass (AGB, in kg) of a tree with diameter D should be proportional to the product of wood density (ρ, oven-dry wood over green volume), times trunk basal area (BA= π D^2/4), times total tree height (H). Hence, the following relationship should hold across forests:~~

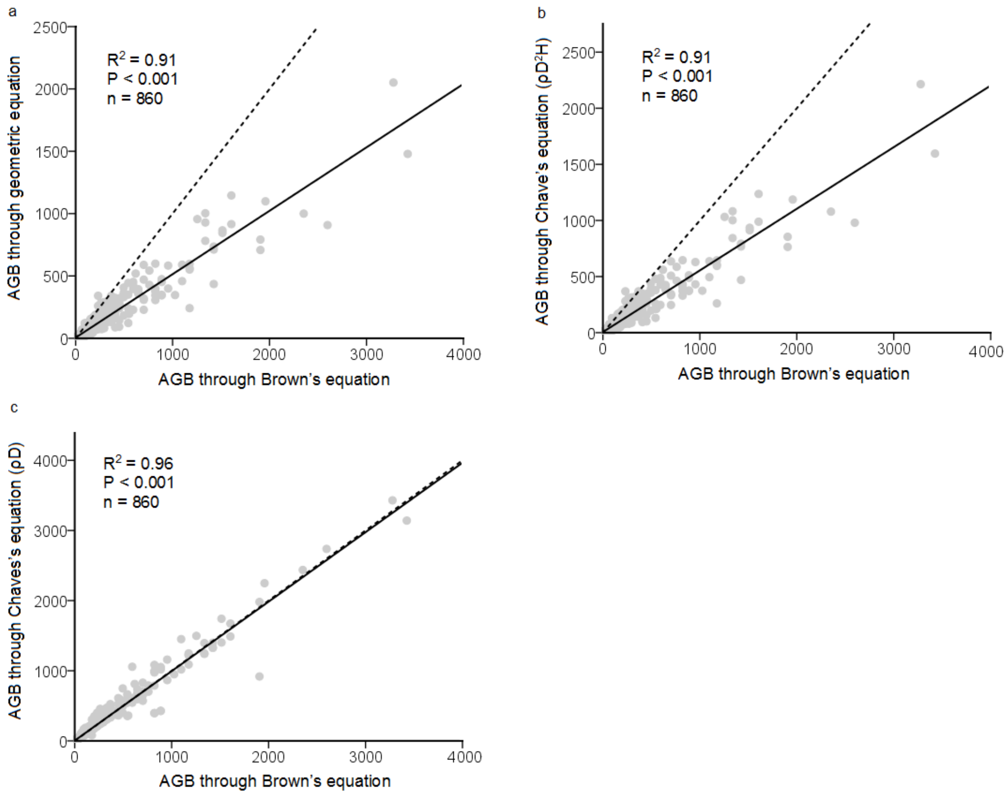
~~$AGB = F \times \rho \times (\frac{\pi \times D^2}{4}) \times H$ (a)~~

~~Dawkins (1961) and Gray (1966) predicted a constant form factor (F) across broadleaf species, with F = 0.06 (Cannell, 1984).~~

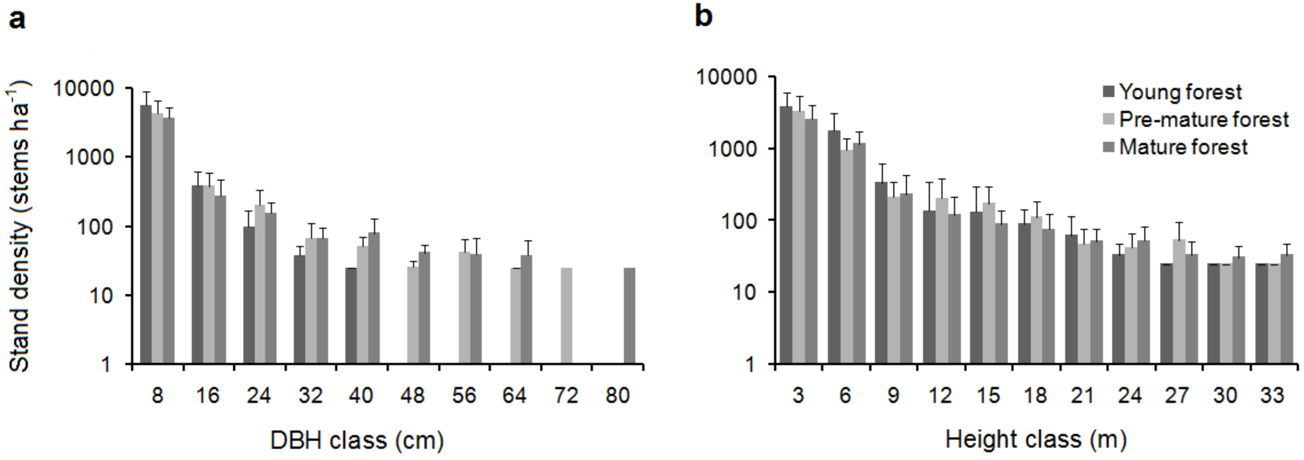
~~For panels (b. c) of the graph, the best predictive models proposed by Chave et al. (2005) for moist forests were used to estimate the AGB (kg) of each individual tree.~~

~~$AGB = \exp\,(-2.977 + \ln(\rho D^2 H)$ (b)~~

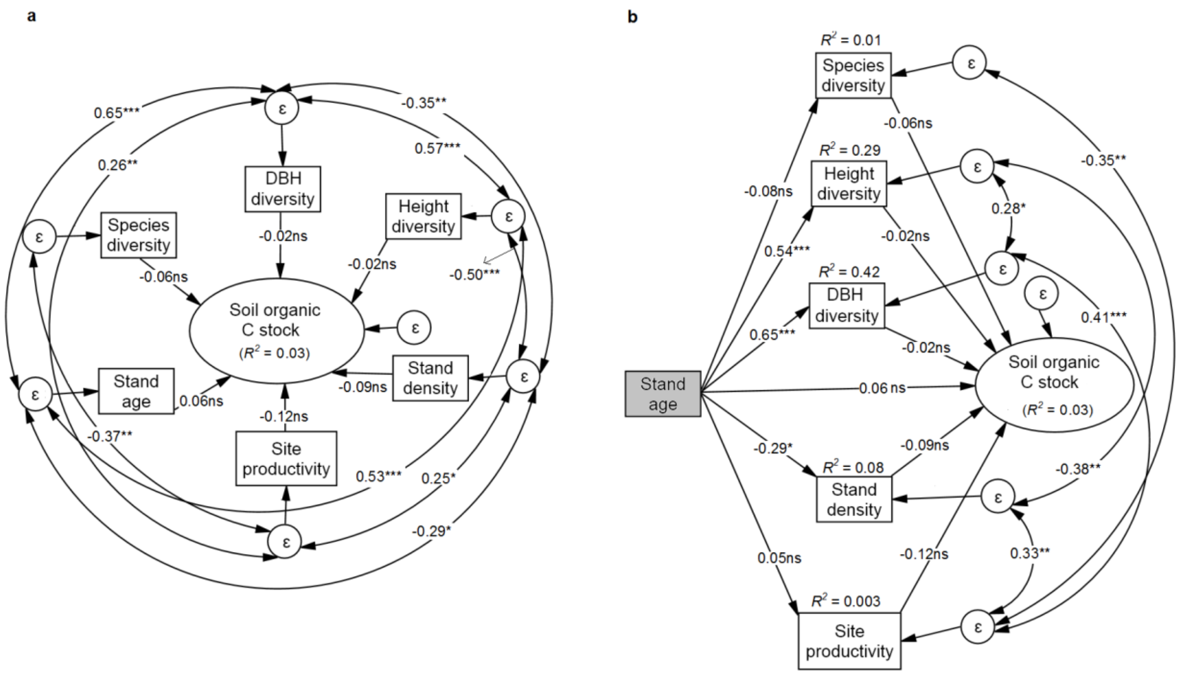
~~$AGB = \rho \times \exp\,(-1.499 + 2.148 \times \ln(D) + 0.207 \times (\ln(D))^2 - 0.0281 \times (\ln(D))^3)$ (c)~~


a
R^2 = 0.91
P < 0.001
n = 860
AGB through geometric equation
2500
2000
1500
1000
500
0
0
1000
2000
3000
4000
AGB through Brown's equation
b
R^2 = 0.91
P < 0.001
n = 860
AGB through Chave's equation (ρD^{2}H)
2500
2000
1500
1000
500
0
0
1000
2000
3000
4000
AGB through Brown's equation
c
R^2 = 0.96
P < 0.001
n = 860
AGB through Chave's equation (ρD)
4000
3000
2000
1000
0
0
1000
2000
3000
4000
AGB through Brown's equation

~~**Fig. S4** The distribution of (a) diameter and (b) height in subtropical evergreen broadleaved forests in different forest development stages. The diameter class interval used in the graph is 8 cm while height class interval is 3 m. The vertical bars are mean + *SD*. A log$_{10}$ scale is used for the Y-axis in each graph.~~



~~**Fig. S5** Best-fit structural equation models for soil organic C stock; a) combining species diversity, DBH diversity, height diversity, stand age, stand density and site productivity (stand characteristics model), b) stand age as a primary predictor variable by testing the direct and indirect effects through mediation of stand characteristics (stand age model), across all 65 subtropical forest plots. Values give the standardized coefficients for the relationship and correlation between variables; all coefficients are significant at *, $P < 0.05$; **, $P <0.01$; ***, $P < 0.001$; ns, non-significant; and coefficient of determination (R^2) for response variable are indicated. Epsilons (ε) within small circle represent the error term for downstream variables, ellipse represents response variable (soil organic C stock), and squares or rectangles represent predictor variables. But in case of model (b), the squares or rectangles with white fill color represent mediators while with gray fill represent primary variable. Model fit statistics for each of the stand characteristics and stand age models are Chi-square = 4.62 and 7.50, *df* = 6 and 5, *P*-value = 0.593 and 0.186, CFI = 1.00 and 0.97, GFI = 0.98 and 0.97, CMIN/*df* = 0.77 and 1.50, RMSEA < 0.001 and = 0.09.~~


a
ε
0.65***
-0.35**
0.26**
0.57***
DBH diversity
-0.02ns
Height diversity
-0.02ns
-0.50***
Species diversity
-0.06ns
Soil organic C stock
(R^2 = 0.03)
Stand age
0.06ns
Stand density
-0.09ns
-0.12ns
Site productivity
-0.37**
0.53***
0.25*
-0.29*
b
R^2 = 0.01
Species diversity
-0.06ns
-0.35**
R^2 = 0.29
Height diversity
-0.08ns
-0.02ns
0.28*
0.54***
R^2 = 0.42
DBH diversity
0.65***
-0.02ns
0.41***
Stand age
0.06 ns
Soil organic C stock
(R^2 = 0.03)
-0.29*
-0.09ns
R^2 = 0.08
Stand density
-0.38**
0.33**
0.05ns
-0.12ns
R^2 = 0.003
Site productivity

~~References~~

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