AC2 – Reply on RC2 (Anonymous Referee #2)

We thank the reviewer for the constructive and valuable assessment of our paper. We respond below with original reviewer text in **black**, author comments in **blue**, and manuscript amendments given in **green**.

The authors of Allometric equations and wood density parameters for estimating aboveground and woody debris biomass in Cajander larch (Larix cajanderi) forests of Northeast Siberia observed mean squared diameter and specific gravity. They developed allometric equations at 25 sites in the Republic of Sakha in Russia. They then make comparisons to allometric equations developed in other studies. Overall the methods appear rigorous. This study provides valuable information from an important yet remote region of the world from which little in-situ data is available and makes the case that further data collection efforts are needed. My major concern is that the claim that the allometric equations presented in the text are more generally applicable needs to be better supported or more nuanced. The equations and the comparison of them to other previously developed equations are not validated against in situ data or across a larger region of space. It seems that the equations from earlier work would be more applicable than those developed by the authors in some more northeastern regions or specific stand types, especially near where they were developed. This is very problematic given the manuscripts focus on providing generalized equations to improve our ability to estimate above-ground biomass in this region.

2A. We agree with the reviewer that pooling data from sites with different forest structure and stand age may not be desirable. We will therefore remove the site-common allometric equation from our revised paper. By doing so, a main contribution of our paper is significantly increasing (from 3 to 5) the number of allometric equations available for Cajander larch forests. We agree with the reviewer that near the sampling sites of these five locations (two previous studies, two newly developed equations), the recommendation is to use the corresponding site-specific equation. A practical challenge arises when scientists would want to measure tree biomass in areas that are further away from those four sampling locations. In this case, we recommend that researchers could use site-specific equations when site parameters (e.g., stand age, DBH distribution, etc.) closely match with one of the sampling sites. When this is not the case, we recommend that researchers calculate tree biomass from the five different equations which will result in uncertainty range (e.g., mean biomass and standard deviation). These planned changes in the revision alter some of the main conclusions of the paper, for example those focused on generalized applicability, and we will rewrite these sections in order to reflect these changes.

L95 introduction: I suggest highlighting some of the other roles that this data could play (previously mentioned around L35) to strengthen the introduction.

2B. Thank you for your comment. We will do this in the revision.

L140: Is there a citation for the two equations above. Also, some brief explanation of why the samples were dipped in paraffin could be useful.

2C. Thank you for the comment. We will add the appropriate reference and specified why the samples were dipped in paraffin in the revision as follows:

L131: "After drying, the water displacement method requires to seal the surface of woody pieces to prevent bias in volume determination resulting from water absorption during immersion. Each oven-dried sample was then covered with a thin impermeable layer by immersion in hot liquid paraffin (solidification point 57–60 °C, 0.90 g cm^{-3} at 20 °C), and the mass of the coated piece was measured again before volume determination."

L136: "Finally, specific gravity of each sample was determined as follows (ASTM International, 2014):

$$G = \frac{K \times m_0}{V_0}, \tag{3}$$

where G is the specific gravity (g cm^{-3}), K is a constant equal to 1 when the mass is in grams and the volume is in cubic centimeters, m_0 is the oven-dry mass (g) and V_0 is the oven-dry volume (cm^3), given by:

$$V_0 = m_{w,disp} - \frac{m_{coated} - m_0}{\rho_{paraffin}}, \tag{4}$$

where $m_{w,disp}$ is the mass of water displaced (g), m_{coated} is the mass of the oven-dried sample after immersion in the paraffin (g), and ρ_{paraffin} is the density of the paraffin wax (g cm^{-3})."

L205-210: I suggest including a bit more information about this fitting method and selecting the exponent c, including references to other work that uses this method. It could also be useful to include these residual plots in the appendix.

2D. Thank you for your comment. We will include new references to other studies that use weighted nonlinear regression as a fitting method (e.g., Whraton and Cunia, 1987; Brown et al., 1989; Parresol, 1999; Moore, 2010) in the revision. We will explain in more detail how we selected the exponent *c* by (1) trial and error after visualization of the plots of the weighted residuals against the fitted values, and (2) approximation of the conditional variance of biomass following the steps described below (Picard et al., 2012):

1. We divided DBH range into K classes centered on DBH_k (k = 1,…, K). We took K = 5 in this study and visually checked that the power model was appropriate for modeling the residual variance.
2. We calculated the empirical variance of biomass, σ_k^2, for the observations in class k (k = 1,…, K)
3. We fitted the linear regression between $\ln(\sigma_k)$ and $\ln(DBH_k)$. The slope of this regression is an approximation of the exponent c.

We will specify that we used both approaches to estimate the exponent c for each site (Yakutia and Magadan) and biomass component. We will include residual plots as supplementary materials in the revision of our paper.

Brown, S., Gillespie, A. J. R., and Lugo, A. E.: Biomass estimation methods for tropical forests with applications to forest inventory data, Forest Sci., 35, 881–902, doi:10.1093/forestscience/35.4.881, 1989.

Moore, J. R.: Allometric equations to predict the total above-ground biomass of radiata pine trees, Ann. For. Sci., 67, 806, doi:10.1051/forest/2010042, 2010.

Parresol, B. R.: Assessing tree and stand biomass: a review with examples and critical comparisons, Forest Sci., 45, 573–593, doi:10.1093/forestscience/45.4.573, 1999.

Picard, N., Saint-André, L., and Henry, M.: Manual for building tree volume and biomass allometric equations: from field measurements to prediction, Food and Agricultural Organization of the United Nations, Rome, Italy, and Centre de Coopération Internationale en Recherche Agronomique pour le Développement, Montpellier, France, 215 pp., 2012.

Whraton, E. H. and Cunia, T.: Estimating tree biomass regressions and their error, in: Proceedings of the workshop on tree biomass regression functions and their contribution to the error of forest inventory estimates, Syracuse, NY, USA, 26–30 May 1986, U.S. Dept. of Agriculture, Forest Service, Northeastern Forest Experiment Station, Broomall, Pennsylvania, USA, Gen. Tech. Rep. NE-117, 1987.

Figure 3: It would be good to include the data points on this plot where possible and the standard error envelopes for the fits. These lines are also somewhat difficult to distinguish when printed in black and white.

2E. Thank you for this comment. We will modify Figure 3 as suggested and will change the colors to improve its readability in gray scale in our revision.

L206: I think table A1 is important and merits inclusion in the text. It could be interesting to see this comparison done differently. For example, calculating fuel loads at one of the study sites using these different parameters and then plotting the values could better illustrate their importance in percentage terms.

2F. Thank you for this suggestion. We calculated fuel loads at 47 of 53 studied sites where *Larix cajanderi* fine woody debris were observed using *M* factors from this study. For each site, we derived the percentage difference between these estimates and fuel loads computed using *M* factors from other species and boreal regions provided in Nalder et al. (1999), and plotted this in a new figure as follows:

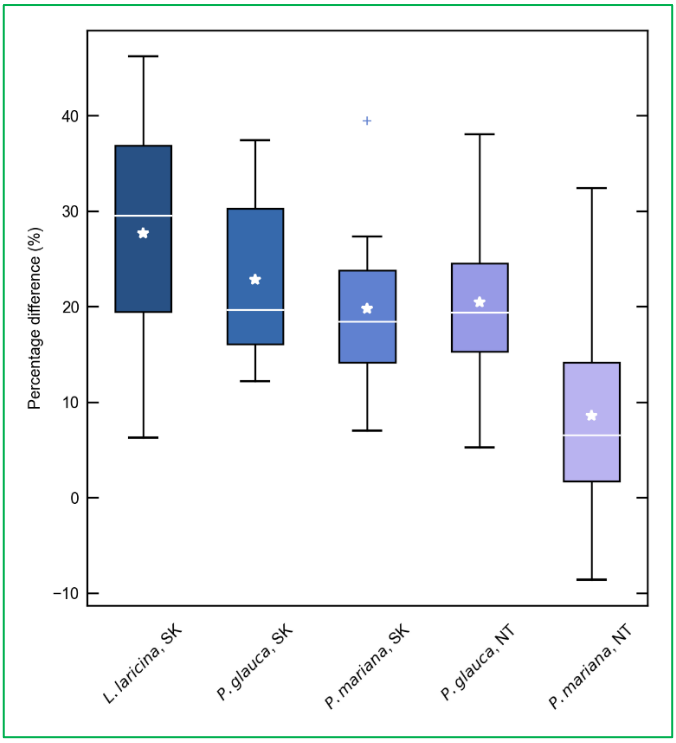

Figure. Percentage difference in fine woody debris (FWD) biomass estimates in 47 larch forest stands (*Larix cajanderi*) near Yakutsk using *M* factors derived for other species and regions. Differences were calculated from the estimates based on the *M* values developed in this study, such that a positive percentage difference reflects a lower biomass estimate. Each box ranges from the first quartile (Q1) to the third quartile (Q3), with the median and mean indicated by a white horizontal line and a star respectively. The whiskers extend from Q1 and Q3 to the minimum and maximum defined as Q1−1.5×IQR and Q3+1.5×IQR respectively, where IQR is the interquartile range (Q3−Q1). Outliers above the maximum or below the minimum are indicated by crosses.

L310: The Magadan site has many more samples than the Yakutian site, although the size range of the available samples varies. Given the conclusion that allometry is somewhat region-specific, it could be interesting to see the result of a fit where this imbalance of samples is corrected using weighting.

2G. That is a good suggestion. Based on the comments of reviewer 1 and you, we have decided to remove the site-common allometry from the revision, and now focus on providing two newly developed allometric equations and their potential use.

Figure 4: For this box plot of the site observations, it would be good to explain the quantiles, etc. shown in the figure caption

2H. Thank you for this suggestion. We will explain the statistics displayed in the boxplots in the figure caption in our revision as in the following: 'Each box ranges from the first quartile (Q1) to the third quartile (Q3), with the median and mean indicated by a white horizontal line and a star respectively. The whiskers extend from Q1 and Q3 to the minimum and maximum defined as Q1−1.5×IQR and Q3+1.5×IQR respectively, where IQR is the interquartile range (Q3−Q1). Outliers above the maximum or below the minimum are indicated by crosses.'

L315: Some additional summary information for these 53 sites could be useful (i.e., the mean, sd, and range of dbh)

2I. We agree that this information could be useful. It will be included in a new table that will summarize main characteristics of the 53 forest stands where we estimated FWD and tree biomass using the parameters and equations developed in this study.

Table 5. Stand characteristics of 53 study sites located near Yakutsk (Republic of Sakha, Russia). G: wood specific gravity; MSD: mean squared diameter; DBH: diameter at breast height.

Forest stands characteristics	**Site location**	
	Batamay	**Yert**
Latitude	63°31'N	62°01'N
Longitude	129°23'E	125°47'E
Number of stands	30	23
Number of sites with measurements/estimates for		
Fine woody debris, *G* and MSD	4	21
Fine woody debris biomass	25	22
DBH, tree biomass	30	23
Larch trees		
Mean density ± std (range) (thousand trees ha^{-1})	10.55 ± 9.93 (1.00–45.33)	13.50 ± 13.69 (0.17–46.33)
Mean tree age ± std (range) (years)	83.2 ± 40.9 (9–214)	97.1 ± 39.1 (40–162)
Mean DBH ± std (range) (cm)	5.48 ± 3.56 (1.20–15.08)	5.09 ± 5.14 (0.22–18.56)

L315-320, 350-365: I suggest heavily revising these sections of the paper. The claim that the other allometric equations underestimate aboveground biomass or are more generally applicable seems too strong. The actual aboveground biomass of the 53 comparison sites is not truly known. From the text or maps, it's unclear where exactly these test sites are located and how close they are to the sites from Siewert 2015. The comparison to Siewet 2015 is not emphasized in the text. This point would be much stronger if some additional non-allometry-derived data sources, more information from the literature, etc., were included as validation. It could also be interesting to see this comparison done across multiple sites. I imagine these other two equations will perform better in certain areas or stand types. Such a comparison would add more depth to the point about how generalizable each set of equations is.

2J. Thank you for this comment. We agree with you. As explained in our response 2A, we decided to remove the site-common allometry, and focus on our two newly developed allometric equations and their potential use. This changes some of the main conclusions of our work and we will rewrite these sections accordingly.

The aim of comparing the different available equations (3 existing, 2 newly developed) was to show the differences in biomass estimates that result from using the currently available allometric relationships for Eastern Siberian larch forests. We are aware that the estimates at our sampling plots do not represent ground truth. Yet, we believe that this comparison is of interest as it demonstrates that using the available site-specific allometric equations for Cajander larch forests may lead to significantly different biomass estimates. We already stated that further field efforts to advance our understanding of forest structure and biomass in Cajander larch is necessary and will further reinforce this point in the revision, yet we believe that our paper provides advances in this direction by providing new measurements (for fine woody debris) and increasing the number of available allometric equations.

Following your suggestion, we will include additional comparisons with studies that reported aboveground biomass estimates for larch-dominated forest stands in nearby areas. We will include a new map figure to show the locations of these study sites in reference to our 53 sampling locations.

L313-320: Figure 3d shows differences between our newly developed allometric models and existing aboveground biomass equations developed for *Larix cajanderi* trees in northeast Siberia (Kajimoto et al., 2006; Alexander et al., 2012). To illustrate these differences, we calculated aboveground biomass at 53 study sites near Yakutsk using each allometric model (Figure 1, new table from our response 2I). Total aboveground biomass estimated by applying site-specific allometry from the Ust-Yansky district (Yakutia) averaged at 7.21 ± 3.42 kg m^{-2} (range: 0–15.1 kg m^{-2}), and at 6.58 ± 3.94 kg m^{-2} (range: 0–

17.9 kg m^{-2}) when using the equation developed for the Magadan oblast (Fig. 4). Estimates from allometric relationships developed for the Chersky and Oymyakon areas resulted in significant lower biomass estimates (Wilcoxon, $p < 0.05$), ranging from 3.64 kg m^{-2} to 4.40 kg m^{-2} (Fig. 4). A similar trend was found when predicting stem biomass (Fig. 3; Fig. B2). Aboveground biomass is assumed to vary along a latitudinal gradient within larch forests of Northeast Siberia (Usoltsev et al., 2002), ranging from 0.1 kg m^{-2} in northern regions to 18 kg m^{-2} in more productive southern stands (Usoltsev, 2001; Kajimoto et al., 2010). Using the allometric equations developed in this study, mean aboveground biomass estimates across our larch forest stands were 33–48% higher than predictions from existing biomass equations. Our estimates were in good agreement with allometry-derived values reported for similar larch forest ecosystems located in the same area (new map figure). Indeed, Siewert et al. (2015) reported a mean aboveground tree biomass of 7.2 kg m^{-2} in 12 *L. cajanderi* dominated forest stands in the Spasskaya Pad/Neleger study area (62°14'N, 129°37'E). Our study area was in the contact zone between *Larix cajanderi* and another closely related Siberian larch species, *Larix gmelinii* (Rupr.) Rupr. (Abaimov, 2010). Schulze et al. (1995) and Sawamoto et al. (2003) used allometric relationships to compute aboveground biomass in *L. gmelinii* forest stands. Their estimates ranged from 4.4 kg m^{-2} (49 years old) to 12.0 kg m^{-2} (125 years-old), and 2.0 kg m^{-2} (25 years old) to 10.5 kg m^{-2} (170 years-old). The biomass estimates at our study sites are of the same order as those of previous studies in nearby areas. Further efforts are needed to verify and validate the utility of our newly developed allometric equations. Part of this effort could focus on cross-comparing biomass estimates derived from allometric equations with remote sensing measurements from optical and light detection and ranging (LiDAR) sensors.

L339-347: Our study shows that using our newly developed allometric equations may result in higher biomass estimates compared to values derived from existing DBH-based equations. This may have important implications for understanding changes in boreal vegetation dynamics, carbon, and energy budgets in a warming climate. Our results suggest that site-specific allometric equations should be applied near the sampling sites from which they were developed. Given the vastness of the area covered by Cajander larch and the comparatively limited number of available allometric equations, a practical challenge arises when one would want to measure tree biomass in areas that are further away from the four sampling locations described in this study (i.e., the Ust-Yansky district, Chersky and Oymyakon areas in the Republic of Sakha, and the Magadan Oblast). In this case, we recommend using site-specific equations when site parameters (e.g., stand age, DBH, tree height, etc.) closely match with one of the sampling sites. When this is not the case, we recommend that one calculates tree biomass from the five different equations (Fig. 4). This will result in a mean estimate and an uncertainty range.

L330-340: Interpreting the fitted allometric parameters (i.e., as in Niklas 1994) here and further discussing the differences in climate and other properties between the sites could strengthen the conclusions in this section.

2K. This is a good point, and we will include this interpretation and discussion in the revision. We will emphasize differences in climate, stand structure (e.g., tree density, stand age, DBH), permafrost characteristics, natural disturbances, that can explain differences between site-specific allometric relationships. We will include a summary of the tree samples in the Chersky and Oymyakon areas in Table 1 to facilitate the interpretation of differences in forest structure.