AC3 – Reply on RC3 (Anonymous Referee #3)

We thank reviewer 3 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 in **green**.

This manuscript describes the size-class-dependent characteristics of fine woody debris according to their detailed field experiment, and the new allometric relationship by using literature data, for the Cajander larch forest in Northeast Siberia. Since such data in this region (central Yakutia) is limited, this manuscript will contribute a lot to future modeling and remote sensing studies in this region. I've already seen the comments from the two reviewers and the author's replies, so I'd like to add some minor comments about what I'm still unsure about.

About fine woody debris: The authors show the MSD and specific gravity of Cajander larch for each diameter size class.

On the other hand, they compared their single factor *M* with other species in different regions in Table A1, but it is shown in the percentage difference by size class, not the actual values of *M*. I think the single factor M and the fuel load W can be the important outcomes of this study, so I suggest the authors show these results.

3A. Thank you for this suggestion. We will include Table A1 in the main text and modify it to show the actual values of M (see below). We will also include a new figure, as described in RC2, that shows the percentage difference in FWD fuel loads in 47 larch forest stands using M factors derived for other species and regions. Differences were calculated from the estimates based on the M values developed in this study (i.e., *Larix cajanderi* in Northeast Siberia). Finally, we will add a new table in appendix with fuel load means and ranges per diameter size class for each location and species.

Table. Values of the multiplication factor M from this study and those from other boreal tree species in the Canadian Northwest Territories and Saskatchewan by diameter size class. M values for *Larix laricina* (tamarack), *Picea glauca* (white spruce), and *Picea mariana* (black spruce) were derived from Equation (5) using specific gravity (G) and mean squared diameter (MSD) values from Nalder et al. (1999). To facilitate comparisons with M values from our study, we used a tilt correction factor (sec h) of 1.13 as suggested by Brown (1974).

Location	Species	Value of M per diameter size class (II-V)			
		II	III	IV	V
Northeast Siberia	*Larix cajanderi*	0.628	2.89	12.1	32.3
Northwest Territories	*Picea glauca*	0.389	2.45	10.6	22.9
	Picea mariana	0.424	2.94	11.5	25.2
Saskatchewan	*Larix laricina*	0.338	1.85	9.63	31.1
	Picea glauca	0.397	2.47	10.1	19.5
	Picea mariana	0.380	2.48	10.7	23.1

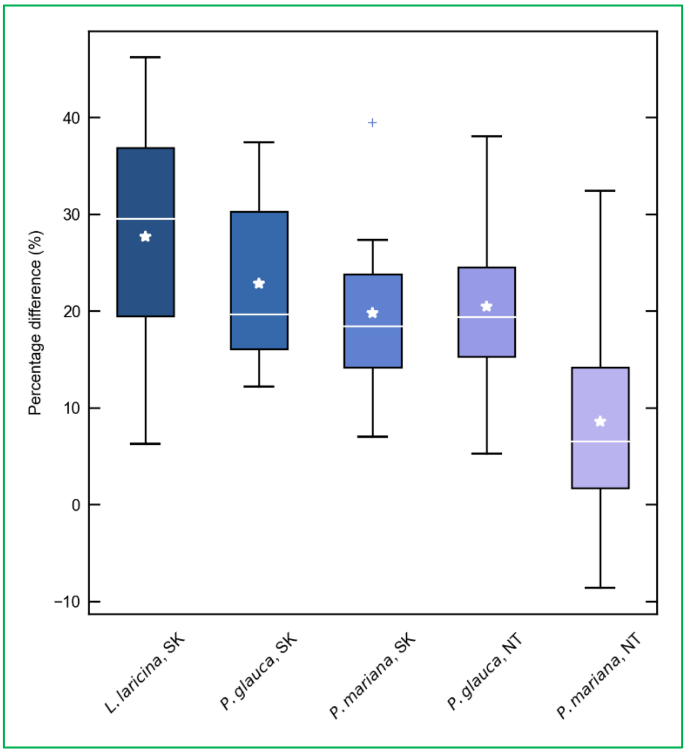

Figure. Percentage difference in fine woody debris (FWD) biomass estimates in 47 larch forest stands (*Larix cajanderi*) near Yakutsk using *M* factors derived for other species and regions. Differences were calculated from the estimates based on the *M* values developed in this study, such that a positive 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.

Equation (1):

- Even though the final answer is correct, I strongly suggest you adopt the consistent units in the equation. Specifically, the unit of QMD should be [m], not [cm], and the equation should be multiplied by 10^4 to convert the unit from [Mg m^{-2}] to [Mg ha^{-1}]. This will avoid confusion by the readers and avoid careless mistakes in calculation.

  3B. Thank you for your comment. We will express the specific gravity (G) in [g cm^{-3}] to be consistent throughout our manuscript. However, we think that QMD still need to be expressed in [cm] in the revision. Using both [m] and [cm] in Equation (1) might be confusing for the readers, yet this equation has originally been developed with the diameter of the woody piece (d) and the length of the transect line (L) expressed in [cm] and [m] (Van Wagner, 1968; 1982). Particularly, the quantity $\frac{\pi^2}{8}$ is a constant, usually referred to as k (Van Wagner, 1982), that allows to retrieve fuel load [t ha^{-1}] from d [cm] and L [m]. This equation is consistently applied and reported within and across studies (e.g., Delisle and Woodard, 1988; Nalder et al., 1999; Alexander et al., 2004; Santín et al., 2015).

$$\frac{[\mathrm{g\ cm^{-3}}]\times[\mathrm{cm}]^2}{[\mathrm{m}]} \Leftrightarrow \frac{[\mathrm{g}]\times[\mathrm{cm}]^{-1}}{100\times[\mathrm{cm}]} \Leftrightarrow \frac{[\mathrm{g\ cm^{-2}}]}{100} \Leftrightarrow \frac{100\times[\mathrm{t\ ha^{-1}}]}{100} \Leftrightarrow [\mathrm{t\ ha^{-1}}]$$

Alexander, M. E., Stefner, C. N., Mason, J. A., Stocks, B. J., Hartley, G. R., Maffey, M. E., Wotton, B. M.; Taylor, S. W., Lavoie, N., Dalrymple, G. N.: Characterizing the jack pine – black spruce fuel complex of the International Crown Fire Modelling Experiment (ICFME), Canadian Forestry Service, Northern Forestry Centre, Edmonton, Alberta, Inf. Rep. NOR-X-393, 2004.

Delisle G. P. and Woodard P. M.: Constants for calculating fuel loads in Alberta, Canadian Forestry Service, Northern Forestry Centre, Edmonton, Alberta, Forest Management Note No. 45, 1988.

Nalder, I. A., Wein, R. W., Alexander, M. E., and de Groot, W. J.: Physical properties of dead and downed round-wood fuels in the Boreal forests of western and Northern Canada, Int. J. Wildl. Fire, 9, 85–99, doi:10.1071/WF00008, 1999.

Santín, C., Doerr, S. H., Preston, C. M., and González-Rodríguez, G.: Pyrogenic organic matter production from wildfires: a missing sink in the global carbon cycle, Glob. Change Biol., 21, 1621-1633, doi:10.1111/gcb.12800, 2015.

Van Wagner, C. E.: The Line Intersect Method in Forest Fuel Sampling, For. Sci., 14, 20–26, 605 doi:10.1093/forestscience/14.1.20, 1968.

Van Wagner, C. E.: Practical aspects of the line intersect method, Canadian Forestry Service, Maritimes Forest Research Centre, Fredericton, New Brunswick, Information Report PI-X-12E, 11 pp., 1982.

- Secant (sec) should be in non-italic.

  3C. We will change this in the revision.

- Is G_i the arithmetic mean of *G* (specific gravity) within the diameter size class *i*?

  3D. G_i is the specific gravity of the diameter size class i for a given species and location. Our values are shown in Table 3. They were indeed derived by calculating the arithmetic mean of specific gravity within each size class. We will explicit this in the revision.

- Is h_i the arithmetic mean of *h* (piece tilt angle) within the diameter size class *i*? If yes, is it mathematically correct to calculate the secant using the arithmetic mean value of h for obtaining the fuel load?
  - For example, If *h* takes 0 degrees and 180 degrees, the arithmetic mean of them can be 90 degrees.
  - Besides, according to Fig. 2, *h* is always related to the diameter of each sampled piece, so I think the product of the diameter and sec *h* should be used for the statistical calculation.

  3E. Thank you for your comment. The basic equation developed by Van Wagner (1968) to retrieve fuel load using the line-intersect approach assumed that sampled pieces lie horizontally on the ground. If pieces are tilted, due to ground slope or because the piece is partially hanging, they are less likely to be intercepted by the transect line. h is the angle between the piece and the horizontal plane and is therefore not related to the diameter of the piece ($\mathrm{h} < 90°$). To minimize the bias related to non-horizontal pieces, W can be multiplied by a correction factor equal to the secant of the angle of tilt from horizontal (h) (Brown, 1974). Brown and Roussopoulos (1974) showed that the average correction factor for naturally fallen branches in American conifer forests ranged between 1.09 ($\mathrm{h} \approx 23°$) and 1.21 ($\mathrm{h} \approx 34°$). Tilted bias can be larger in fresh logging slash (correction factor as high as 1.38) where smaller pieces are attached to larger ones. h_i is the specific tilt angle for the diameter size class i. It can be derived from the arithmetic mean of h within the size class i (e.g., Nalder et al., 1999).

Brown, J. K.: Handbook for inventorying downed woody material, U.S. Dept. of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah, Gen. Tech. Rep. INT-16, 24 pp., 1974.

Brown, J. K. and Roussopoulos, P. J.: Eliminating biases in the planar intersect method for estimating volumes of small fuels, For. Sci., 20, 350–356, 1974.

Van Wagner, C. E.: The Line Intersect Method in Forest Fuel Sampling, For. Sci., 14, 20–26, 605 doi:10.1093/forestscience/14.1.20, 1968.

Nalder, I. A., Wein, R. W., Alexander, M. E., and de Groot, W. J.: Physical properties of dead and downed round-wood fuels in the Boreal forests of western and Northern Canada, Int. J. Wildl. Fire, 9, 85–99, doi:10.1071/WF00008, 1999.

- If N represents the (total) number of intercepts over the length of the transect line, what does N_i mean?

  3F. N_i represents the number of intercepts per diameter size class i over the length of the sample line. We will explicit this definition in the revision.

Equation (2):

- I suggest using a single character (e.g., α) instead of "*slope*" to represent the ground slope.

  3G. Thank you for this suggestion. We will change this in the revision.

- $(\tan \alpha)^2$ is generally written as $\tan^2\alpha$.

  3H. We will rewrite Equation (2) as suggested.

Equation (3) and L140:

- The authors use two characters to represent the specific gravity. One is G in equation (1) and L104 (kg m^{-3}), and another is S here (g cm^{-3}).

  3I. Thank you for this comment. We will use a single character to represent the specific gravity (i.e., G in g cm^{-3}).

L158-159, equation (5):

- Does a single factor M represent the fuel loads per intercept (sample) on the transect line? Please explain this concept concisely since the reference (Nalder et al., 1999) was not accessible from my environment.

3J. M is a multiplication factor introduced by Nalder et al. (1999) to simplify fuel loads calculations. It combines the values of specific gravity, tilt angle, and MSD, as shown in Equation (5). For each diameter size class i, fuel loads are then obtained as follows:

$$W_i = \frac{N_i \times M_i}{L},$$

where W_i is the fuel load (t ha^{-1}) for the diameter size class i, N_i is the number of intercepts within the size class i, M_i is the appropriate multiplication factor (g cm^{-1}) derived from G_i (g cm^{-3}), h_i (degrees), MSD_i (cm^2), and L is the length of the transect line (m). It represents the fuel load per intercept per meter of transect.

Nalder, I. A., Wein, R. W., Alexander, M. E., and de Groot, W. J.: Physical properties of dead and downed round-wood fuels in the Boreal forests of western and Northern Canada, Int. J. Wildl. Fire, 9, 85–99, doi:10.1071/WF00008, 1999.

- If you share the same units with equation (1), G_i has the unit of [Mg m^{-3}], and MSD_i might have the unit of [cm^2]. However, the author specified that M has the unit of [g cm^{-1}]. In this case, the units of the left and right sides of equation (5) are inconsistent. I suppose the unit of G_i in equation (5) would be [g cm^{-3}], or it should be S_i according to equation (3).

  3K. Thank you for your comment. Mg m^{-3} is equivalent to g cm^{-3}, but we will change the unit of G_i as g cm^{-3} in the revision so that both sides of Equation (5) have similar units.

- As pointed out in equation (1), I still wonder whether the use of "sec h_i" is mathematically correct if h_i represents the arithmetic mean of h in class i.

  3L. Please see our response 3E. The tilt correction factor (sec h) has consistently been applied and reported within and across studies (e.g., Brown and Roussopoulos, 1974; Nalder et al., 1999).

Brown, J. K. and Roussopoulos, P. J.: Eliminating biases in the planar intersect method for estimating volumes of small fuels, For. Sci., 20, 350–356, 1974.
Nalder, I. A., Wein, R. W., Alexander, M. E., and de Groot, W. J.: Physical properties of dead and downed round-wood fuels in the Boreal forests of western and Northern Canada, Int. J. Wildl. Fire, 9, 85–99, doi:10.1071/WF00008, 1999.

3M. Based on the comments of reviewer 1 and you, we will articulate the section *2.1 Fine woody debris sampling* as follows:

L100: The line-intersect method is a widely used approach to quantify fine woody debris lying on the ground in a forest stand (Warren and Olsen, 1964; Van Wagner, 1968; Brown, 1971). It requires measuring the diameter of each piece of wood at its intersection with a sample line which can be considered as a strip of infinitesimal width containing a series of cross-sectional areas (Van Wagner, 1982). The sum of cross-sectional areas divided by the length of the sample line can then be converted to volume by multiplying both numerator and denominator by width. Fuel load is then obtained from Equation (1) by multiplying the volume by the specific gravity of wood as follows (Van Wagner, 1982):

$$W = \frac{\pi}{2} \times \sum d^2 \times \frac{\pi}{4} \times \frac{G}{L}, \quad (1)$$

where W is fuel load or weight per unit ground area, $\pi/2$ is a probability factor that allows to sum the cross-sectional areas as circles, d is piece diameter, $\pi/4$ is the factor required to convert d^2 into a circular area, L is length of sample line, and G is specific gravity in units of weight per unit volume. Equation (1) assumes that woody pieces are horizontal and does not account for ground slope. To minimize the bias related to tilted pieces that are less likely to be intercepted by the sample line, W can be multiplied by a correction factor equal to the secant of the angle between the piece and the horizontal plane (Brown and Roussopoulos, 1974). Similarly, a correction factor can be calculated from the ground slope angle as follows (Brown, 1974):

$$s = \sqrt{1 + \tan^2\alpha}, \quad (2)$$

where s is slope correction factor, α is ground slope (degrees). Consequently,

$$W = \frac{\pi^2 \times G \times \sec h \times \sum d^2 \times s}{8 \times L}, \quad (3)$$

where h is piece tilt angle (degrees). Measuring diameter on each intersected piece along a sample line can be tedious and time-consuming, especially if small pieces are abundant. In practice, FWD are tallied by diameter size class using a go/no-go sizing gauge, and the number of intercepts over the sample line is reported for each class (Brown, 1974; McRae et al., 1979). Therefore, the term $\sum d^2$ in Equation (3) is replaced by $\sum_i n_i \times D_i^2$, where n_i is the number of intercepts over the sample line in the diameter size class i, and D_i is the representative class diameter (Van Wagner, 1982). The quadratic mean diameter (QMD) is generally used as the appropriate class diameter so that fuel load for any species and diameter size class i can be calculated as follows (Van Wagner, 1982; Nalder et al., 1999):

$$W_i = \frac{\pi^2 \times G_i \times \sec h_i \times n_i \times \mathrm{QMD}_i^2 \times s}{8 \times L}, \quad (4)$$

where W_i is the fuel load (t ha^{-1}) for the diameter size class i, G_i is the specific gravity (g cm^{-3}) of the size class i, h_i is the piece tilt angle (degrees) of the size class i, n_i is the number of intercepts over the sample line within the size class i, s is the slope correction factor, L is the length of the sample line (m), and QMD_i is the quadratic mean diameter (cm) of the size class i given by

$$\mathrm{QMD}_i = \sqrt{\frac{\sum_i d_i^2}{n_i}}, \quad (5)$$