Modeling the additive stand biomass of *Larix* spp. for Eurasia

Vladimir Andreevich Usoltsev[1, 2], Seyed Omid Reza Shobairi[2*], Viktor Petrovich Chasovskikh[2]

[1]Botanical Garden, Russian Academy of Sciences, Ural Branch, 8 Marta 202a St, Yekaterinburg,
620144 Russian Federation
[2]Ural State Forest Engineering University, Sibirskii Trakt 37 St, Yekaterinburg,
620100 Russian Federation,
*e-mail: Omidshobeyri214@gmail.com

Abstract. When using the unique in terms of the volumes of database on the level of a stand of the genus *Larix* Mill., the trans-Eurasian additive allometric models of biomass for Eurasian larch forests are developed for the first time, and thereby the combined problem of model additivity and generality is solved. The additive model of forest biomass of *Larix* is harmonized in two levels, one of which provides the principle of additivity of biomass components, and the second one is associated with the introduction of dummy independent variables localizing model for eco-regions of Eurasia. Comparative analysis of the biomass structure of larch stands of different ecoregions at the age of 100 years shows, that the greatest values of biomass (210-450 t/ha) correspond to the regions adjacent to the Atlantic and Pacific coasts, as well as to the regions, located at the southern limit of larch growing area and the lowest – to northern taiga regions of Siberia, where larch grows on permafrost. The biomass indices of different ecoregions differed not only in absolute value but also in biomass ratios of different components; for example, the proportion of needles in the aboveground biomass is maximum (5.0-7.3%) in the northern taiga of Central Siberia and the Far East on permafrost and is minimum (1.4-1.9%) in larch forests of upper productivity having biomass values 210-450 t/ha. The proposed model and corresponding tables for estimating stand biomass makes them possible to calculate larch stand biomass on Eurasian forests when using measuring taxation.

Keywords: allometric models, biological productivity, biomass of forests; *Larix* Mill., sample plots.

1. Introduction

Evaluation of biological productivity and carbon-depositing ability of forests is currently one of the priority directions of forest ecology in relation to global climate change. In recent years, scientific direction associated with the evaluation of the biological productivity of trees and stands, is the most intensely developed in at least two aspects: (1) in compiling the world's data bases on actual biological productivity at the levels of forest stands and single-trees with development of their global and transcontinental patterns (Gill & Jackson, 2000; Usoltsev et al., 2002; Schenk & Jackson 2002, 2003; Crowther et al., 2015; Poorter et al., 2015; Liang et al., 2016; Jucker et al., 2017) and (2) in the development of methodological backgrounds of regression modeling with the aim to improve the accuracy of our estimates and the correctness of the empirical models of biological productivity of forests and their constituent trees (Parresol, 2001; Usoltsev et al., 2002; Dong et al., 2015a, b).

Generic allometric models were intensively developed only on aboveground biomass, they seemed promising for estimating forest biomass in total, usually within the single wood species (Tritton & Hornbeck, 1981; Schmitt & Grigal, 1981; Crow, 1983; Pastor et al., 1984; Grigal

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* corresponding author.

& Kernik, 1984; Zianis & Mencuccini, 2003; Case & Hall 2008; De-Miguel et al., 2014), and in tropical forests also within the totality of different species (pantropical models) (Ogawa et al., 1965; Crow, 1978; Chave et al., 2005, 2014; Vieilledent et al., 2012; Rutishauser et al., 2013; Stas et al., 2017).

But because various biomass components are characterized by different rates as growth and mortality, they make a different contribution to the cycling of substances and should be evaluated separately. Therefore, the development of generic allometric models is replaced by a phasing out of them and moving on to the concept of their harmonizing. To the latter at least two directions can be attributed: (1) construction of compatible regional models based on dummy variables (Usoltsev et al., 2002; Dieguez-Aranda et al., 2006; Nord-Larsen, 2006; Li et al., 2006; Wang et al., 2007, 2008; Fehrmann et al., 2008; Lang, 2008; Tang et al., 2008; Li & Zhang, 2010; Zeng et al., 2011; Fu et al., 2012, 2013, 2017; Zeng, 2015) and (2) the development of compatible models based on principles of additivity of biomass component composition (Parresol, 2001; Carvalho & Parresol, 2003; Bi et al., 2004, 2015; Sanquetta et al., 2015; Dong et al., 2015a, b; Dong et al., 2016). Additive allometric models are designed today exclusively at the level of single trees. Similar models developed at the level of forest stands, to which is dedicated this work, are presented today with single researches, that are fulfilled, for example, in *Pinus radiata* (D. Don) plantations (Bi et al., 2010) and in mixed spruce-fir forests of Eurasia (Usoltsev et al., 2017a, b), and models were built using alternative algorithms of harmonization that are defined respectively as «from private-to-general" (Bi et al., 2010) and «from general-to- private (Usoltsev et al., 2017a, b) without attempting any of their regionalization.

Thus, the modern methods of modelling the biological productivity of trees and tree stands have been developed towards additivity of biomass components (Bi et al., 2010; Dong et al., 2015b) and towards transition from «pseudo-generic» allometric models to really genericl, involving regionalization of biomass models by introducing dummy variables (Fu et al., 2012), that usually fulfilled on local sets of actual biomass of trees and tree stands. We generated the database of forest stand biomass for the main forest species in Eurasia (Usoltsev, 2010, 2013), that has enabled these modern methodologies to be implemented on the entirely different, higher level, namely to begin modelling additive biomass on transcontinental level.

So far, the additivity principle is implemented only for local models of forest stand biomass (Bi et al., 2010). Its complexity and structural unwieldness of analytical expression, apparently, are the reason that nowadays it is not implemented at the continental level, for example, by

the dismemberment of a general additive biomass model on a set of compatible regional sub-models, marked by dummy variables or in some other way. Previously (Usoltsev et al., 2017a, b) the transcontinental additive biomass models of forest stands of Norway spruce (*Picea* Dietr.) and fir (*Abies* Mill.) growing on the territory of Eurasia were first proposed, that are generic additive models for these species i.e. without taking into account their regional specificities.

In this article, the first attempt to develop transcontinental harmonized allometric models of larch (genus *Larix* Mill.) forest stand biomass, which combine both mentioned by Jacobs and Cunia (1980) approaches, namely, ensuring the principle of additivity of biomass component composition and localizating (dismemberment) of biomass additive model on regions of Eurasia by introducing dummy variables. In other words, an attempt is made to solve the problems of combining additivity and totality of models. These models will provide the basis for the development of trans-continental regional standards for evaluation biomass of trees and forest stands.

2. Material and methods

Of the database mentioned the material in a number of 384 sample plots with estimations of larch forest stand biomass (t/ha) is extracted. Genus *Larix* Mill. is introduced by eight species (correspondingly *L. decidua* Mill., *L. sukaczewii* N.Dyl., *L. sibirica* L., *L. gmelinii* Rupr., *L. cajanderi* Mayr., *L. olgensis* A.Henry, *L. principis-rupprechtii* Mayr, *L. leptolepis* Gord.; taxonomy according to Sokolov et al., 1977, and Bobrov, 1978), distributed across twelve eco-regions and designated respectively with the twelve dummy variables from X_0 to X_{11} (Table 1). The distribution of sample plots, on which the larch forest biomass is measured in ecoregions of Eurasia, is shown in Figure 1.

According to the structure of disaggregation three-step model (Tang et al., 2000; Dong et al., 2015b), biomass value, estimated by the total biomass equation, exploded into components according to the scheme presented in Figure 2. The coefficients of the regression models for all three steps are evaluated simultaneously, which ensures additivity of biomass of all the components – total, intermediate and initial (Dong et al., 2015b).

Table 1. The encoding scheme of the regional actual biomass data sets of 384 larch forest stands of larch

Re-gion*	Species *Larix* Mill.	Block of dummy variables											stand age, yrs	Ranges of:			Plot quantity
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}		tree number, thousands per ha	mean diameter, cm	mean height, m	
WME	*L. decidua* Mill.	0	0	0	0	0	0	0	0	0	0	0	13÷210	0.19÷2.68	10.2÷72.9	4.2÷34.0	13
ER	*L. sukaczewii* N.Dyl.	1	0	0	0	0	0	0	0	0	0	0	10÷240	0.27÷122.5	1.9÷51.6	3.6÷40.0	58
Tst	*L. sukaczewii* N.Dyl.	0	1	0	0	0	0	0	0	0	0	0	12÷55	0.81÷6.27	5.2÷22.0	4.8÷21.1	13
WSn	*L. sibirica* L.	0	0	1	0	0	0	0	0	0	0	0	25÷350	0.46÷10.7	3.5÷32.0	2.8÷31.5	19
MSn	*L. gmelinii* Rupr.	0	0	0	1	0	0	0	0	0	0	0	30÷380	0.12÷5.70	3.2÷36.0	2.5÷34.0	50
MSs	*L. sibirica* L.	0	0	0	0	1	0	0	0	0	0	0	10÷200	0.36÷7.19	6.0÷30.0	8.9÷24.0	17
TB	*L. gmelinii* Rupr.	0	0	0	0	0	1	0	0	0	0	0	40÷190	0.11÷4.73	4.0÷28.4	4.0÷25.0	41
ESn	*L. cajanderi* Mayr.	0	0	0	0	0	0	1	0	0	0	0	22÷380	0.24÷50.8	3.0÷29.0	5.4÷24.0	53
FEn	*L. cajanderi* Mayr.	0	0	0	0	0	0	0	1	0	0	0	15÷250	0.20÷52.2	1.1÷54.0	4.0÷26.0	30
FEs	*L. olgensis* A.Henry	0	0	0	0	0	0	0	0	1	0	0	30÷160	0.37÷12.6	9.7÷29.4	12.0÷28.2	12
Ch	*L. gmelinii* Rupr. *L. principis-rupprechtii*	0	0	0	0	0	0	0	0	0	1	0	21÷186	0.21÷9.30	4.7÷37.6	5.9÷30.0	33
Jap	*L. leptolepis* Gord.	0	0	0	0	0	0	0	0	0	0	1	9÷53	0.37÷6.74	6.2÷28.6	5.4÷23.6	45

*Region designations: WME – West and Middle Europe; ER – European part of Russia, central territory; Tst – Turgay steppe; WSn – Western Siberia, northern taiga; MSn – Middle Siberia, northern taiga; MSs – Middle Siberia, southern territory; TB – Trans-Baikal lake; ESn – Eastern Siberia, northern taiga; FEn – Far East, northern taiga; FEs – Far East, Primorie; Ch – Northeast China; Jap – Japanese islands.

Figure 1. Allocation of sample plots with measured biomass (t/ha) of 384 stands of larch (genus *Larix* Mill.) on the territory of Eurasia
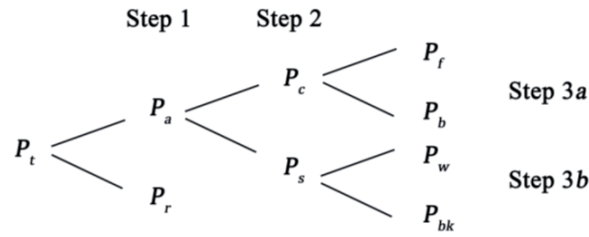
Figure 2. The pattern of disaggregating three-step proportional weighting additive model. Designation: P_t, P_r, P_a, P_c, P_s, P_f, P_b, P_w and P_{bk} are stand biomass respectively: total, underground (roots), aboveground, crown (needles and branches), stems above bark (wood and bark), needles, branches, stem wood and stem bark correspondingly, t per ha

3. Results and discussion

The initial allometric models are calculated;

$$\ln P_i = a_i + b_i(\ln A) + c_i(\ln A)^2 + d_i(\ln H) + e_i(\ln D) + f_i(\ln N) + \Sigma g_{ij}X_j, \qquad (1)$$

where P_i – biomass of i-th component, t per ha; A – stand age, years; H – mean stand height, m; D – mean tree diameter, cm; N – tree number, 1000/ha; a-g – regression coefficients; i – index of biomass component: total (t), aboveground (a), roots (r), crowns (c), stems above bark (s), needles (f), branches (b), stem wood (w) and stem bark (bk); j – index (code) in the block of dummy variables coding the ecoregions, from 0 to 11 (see Table 1).

Model (1) after anti-log transformation is given to the form

$$P_i = a_i A^{bi} A^{ci(\ln A)} H^{di} D^{ei} N^{fi} e^{\Sigma gijXj} \qquad (2)$$

Characteristic of equations (1) obtained by its approximation using actual biomass data, after the introduction of correction to the logarithmic transformation after Baskerville (1972) and the subsequent anti-log transformation to (2) are given in the Table 2. All the regression coefficients of the equations (2) with numerical variables are significant at the level of probability of 0.95 or higher, and the equations are adequate to actual data.

The equations (2) are modified according to the algorithm proposed by Chinese researchers (Dong et al., 2015b) (Table 3), and the final transcontinental additive model of larch biomass component composition on the level of forest stand is given in the Table 4. The model is valid in the range of actual data of stand age, mean tree height, mean stem diameter and tree density, listed in the Table 1, and is characterized by a double harmonization: one of which provides the principle of biomass component

additivity, and the second one relates to the introduction of dummy variables, localizing the model according to ecoregions of Eurasia.

At the next stage of the study a comparison of the adequacy of additive model (see Table 4) and independent equations shown in the Table 2. For their correct comparing the sample plots with incomplete biomass component structure are deleted from the initial harvest data, i.e. only those records are left in which the data are available on both aboveground and underground biomass. The equations (2) are approximated according to such "methodized" data, and their final forms are given in the Table 5. As the "methodized" additive model, and "methodized" independent equations, are tabulated according to actual mass-forming indices of the modified data and the obtained values are compared with harvest biomass data using the formula:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(Y_i - \bar{Y}_i)^2}{\sum_{i=1}^{N}(Y_i - \bar{Y}_i)^2}, \qquad (3)$$

where Y_i is observed value; $\hat{Y}_i$ is predicted value; $\bar{Y}$ is the mean of N observed values for the same component.

The results of comparison of the adequacy of two modeling methods are summarized in the Table 6 and they indicate that the adequacy of the two systems of equations for aboveground biomass, underground one and stem biomass are similar and the indices of additive equations for mass of crown, needles and branches are slightly worse. This corresponds to the view (Cunia & Briggs, 1984; Reed & Green, 1985), that the correction of internal inconsistency of biomass equations by ensuring their additivity does not necessarily means improvements in the accuracy of biomass estimating.

Table 2. Characteristic of initial allometric equations for larch stands

Biomass component	Independent variables and the regression model coefficients	$adjR^2$
P_t	$0.1178 A^{-0.0045} H^{0.4126} D^{1.9276} N^{0.8816} e^{0.5449 X1} e^{0.4893 X2} e^{0.3044 X3} e^{0.3895 X4} e^{0.5867 X5} e^{0.6192 X6} e^{0.4966 X7} e^{0.5633 X8} e^{0.4223 X9} e^{0.3616 X10} e^{0.2468 X11}$	0.929
Step 1		
P_a	$0.1403 A^{-0.0615} H^{0.5003} D^{1.8952} N^{0.8307} e^{0.2220 X1} e^{0.1519 X2} e^{0.0258 X3} e^{0.0308 X4} e^{0.5183 X5} e^{0.2958 X6} e^{0.2559 X7} e^{-0.2578 X8} e^{-0.1512 X9} e^{0.0399 X10} e^{-0.0457 X11}$	0.937
P_r	$0.0391 A^{0.1389} H^{0.4954} D^{1.4246} N^{0.7492} e^{0.5892 X1} e^{0.2886 X2} e^{0.1678 X3} e^{0.7926 X4} e^{0.6324 X5} e^{0.8049 X6} e^{0.3876 X7} e^{0.9782 X8} e^{0.2912 X9} e^{0.4791 X10} e^{0.5403 X11}$	0.765
Step2		
P_c	$0.3620 A^{-0.3316} H^{-0.0678} D^{1.9388} N^{0.7538} e^{-0.0961 X1} e^{-0.3647 X2} e^{-0.4123 X3} e^{0.0005 X4} e^{0.1177 X5} e^{0.0393 X6} e^{-0.2755 X7} e^{-0.0631 X8} e^{-0.3609 X9} e^{-0.3598 X10} e^{-0.4764 X11}$	0.833
P_s	$0.0532 A^{0.0234} H^{0.7736} D^{1.7536} N^{0.8332} e^{0.3015 X1} e^{0.3440 X2} e^{0.1616 X3} e^{0.1067 X4} e^{0.6391 X5} e^{0.3240 X6} e^{0.3843 X7} e^{-0.4261 X8} e^{-0.0708 X9} e^{0.1581 X10} e^{0.1073 X11}$	0.929
Step 3a		
P_f	$0.1317 A^{-0.5524} H^{-0.1686} D^{2.0176} N^{0.8425} e^{0.3427 X1} e^{0.0103 X2} e^{-0.0706 X3} e^{0.6045 X4} e^{0.7496 X5} e^{0.6777 X6} e^{0.3760 X7} e^{0.6083 X8} e^{-0.2398 X9} e^{0.2200 X10} e^{-0.2458 X11}$	0.824
P_b	$0.2323 A^{-0.2655} H^{-0.0383} D^{1.9205} N^{0.7200} e^{-0.2118 X1} e^{-0.4288 X2} e^{-0.4760 X3} e^{-0.1666 X4} e^{-0.0145 X5} e^{-0.1403 X6} e^{-0.4521 X7} e^{-0.2590 X8} e^{-0.3827 X9} e^{-0.5037 X10} e^{-0.5138 X11}$	0.804
Step 3b		
P_w	$0.0432 A^{-0.0843} H^{1.0759} D^{1.5216} N^{0.7924} e^{0.7106 X1} e^{0.6344 X2} e^{0.4098 X3} e^{0.4705 X4} e^{0.9685 X5} e^{0.9157 X6} e^{0.6740 X7} e^{0.6655 X8} e^{-0.0387 X9} e^{0.5357 X10} e^{0.3935 X11}$	0.913
P_{bk}	$0.0217 A^{-0.0595} H^{0.8140} D^{1.3568} N^{0.8048} e^{0.3719 X1} e^{0.7681 X2} e^{0.5487 X3} e^{0.5371 X4} e^{1.0496 X5} e^{1.1993 X6} e^{0.8018 X7} e^{0.2922 X8} e^{-0.4083 X9} e^{0.3324 X10} e^{0.2078 X11}$	0.865

Table 3. The structure of three-step additive model built by proportional weighting (Dong et al., 2015b). Symbols here and further see Figure 2 and equation (1)

Table 4. Three-step additive model of biomass component composition for larch forest stands, built by proportional weighing

Step 1	$Pt = 0{,}1178\ A^{-0.0045} H^{0.4126} D^{1.9276} N^{0.8816} e^{0.5449X1} e^{0.4893X2} e^{0.3044X3} e^{0.3895X4} e^{0.5867X5} e^{0.6192X6} e^{0.4966X7} e^{0.5633X8} e^{0.4223X9} e^{0.3616X10} e^{0.246\dots}$
	$Pa = \dfrac{1}{1+0.2791\ A^{0.2004} H^{-0.0050} D^{-0.4706} N^{-0.0815} e^{0.3672x1} e^{0.1366x2} e^{0.1420x3} e^{0.7618x4} e^{0.1140x5} e^{0.5090x6} e^{0.1317x7} e^{1.2360x8} e^{0.4424x9} e^{0.4392x10} e^{0.5860x11}} \times Pt$
	$Pr = \dfrac{1}{1+3.5833\ A^{-0.2004} H^{0.0050} D^{0.4706} N^{0.0815} e^{-0.3672x1} e^{-0.1366x2} e^{-0.1420x3} e^{-0.7618x4} e^{-0.1140x5} e^{-0.5090x6} e^{-0.1317x7} e^{-1.2360x8} e^{-0.4424x9} e^{-0.4392x10} e^{-0.5860x11}} \times Pt$
Step 2	$Pc = \dfrac{1}{1+0.1470\ A^{0.3551} H^{0.8414} D^{-0.1853} N^{0.0794} e^{0.3975x1} e^{0.7087x2} e^{0.5740x3} e^{0.1063x4} e^{0.5214x5} e^{0.2847x6} e^{0.6598x7} e^{-0.3629x8} e^{0.2901x9} e^{0.5179x10} e^{0.5836x11}} \times Pa$
	$Ps = \dfrac{1}{1+6.8026\ A^{-0.3551} H^{-0.8414} D^{0.1853} N^{-0.0794} e^{-0.3975x1} e^{-0.7087x2} e^{-0.5740x3} e^{-0.1063x4} e^{-0.5214x5} e^{-0.2847x6} e^{-0.6598x7} e^{0.3629x8} e^{-0.2901x9} e^{-0.5179x10} e^{-0.5836x11}} \times Pa$
Step 3a	$Pf = \dfrac{1}{1+1.7637\ A^{0.2869} H^{0.1303} D^{-0.0971} N^{-0.1225} e^{-0.5545x1} e^{-0.4390x2} e^{-0.4054x3} e^{-0.7711x4} e^{-0.7641x5} e^{-0.8180x6} e^{-0.8281x7} e^{-0.8673x8} e^{-0.1429x9} e^{-0.7237x10} e^{-0.2681x11}} \times Pc$
	$Pb = \dfrac{1}{1+0.5670\ A^{-0.2869} H^{-0.1303} D^{0.0971} N^{0.1225} e^{0.5545x1} e^{0.4390x2} e^{0.4054x3} e^{0.7711x4} e^{0.7641x5} e^{0.8180x6} e^{0.8281x7} e^{0.8673x8} e^{0.1429x9} e^{0.7237x10} e^{0.2681x11}} \times Pc$
Step 3b	$Pw = \dfrac{1}{1+0.5022\ A^{0.0249} H^{-0.2619} D^{-0.1648} N^{0.0124} e^{-0.3387x1} e^{0.1337x2} e^{0.1388x3} e^{0.0666x4} e^{0.0811x5} e^{0.2836x6} e^{0.1277x7} e^{-0.3733x8} e^{-0.3696x9} e^{-0.2033x10} e^{-0.1857x11}} \times Ps$
	$Pbk = \dfrac{1}{1+1.9911\ A^{-0.0249} H^{0.2619} D^{0.1648} N^{-0.0124} e^{0.3387x1} e^{-0.1337x2} e^{-0.1388x3} e^{-0.0666x4} e^{-0.0811x5} e^{-0.2836x6} e^{-0.1277x7} e^{0.3733x8} e^{0.3696x9} e^{0.2033x10} e^{0.1857x11}} \times Ps$

Table 5. The characteristics of "methodized" independent allometric equations for larch stands

Biomass component	Independent variables and the regression model coefficients													
P_t	0.1178	$A^{-0.0045}$	$H^{0.4126}$	$D^{1.9276}$	$N^{0.8816}$	$e^{0.5449X1}$	$e^{0.4893X2}$	$e^{0.3044X3}$	$e^{0.3895X4}$	$e^{0.5867X5}$	$e^{0.6192X6}$	$e^{0.4966X7}$	$e^{0.5633X8}$	$e^{0.4223X9}$	$e^{0.3616X10}$	$e^{0.2468X11}$
P_a	0.0757	$A^{-0.0492}$	$H^{0.4535}$	$D^{2.0332}$	$N^{0.9117}$	$e^{0.5466X1}$	$e^{0.4213X2}$	$e^{0.3744X3}$	$e^{0.1716X4}$	$e^{0.6023X5}$	$e^{0.4402X6}$	$e^{0.5745X7}$	$e^{0.3411X8}$	$e^{0.4569X9}$	$e^{0.3528X10}$	$e^{0.2034X11}$
P_r	0.0391	$A^{0.1389}$	$H^{0.4954}$	$D^{1.4246}$	$N^{0.7492}$	$e^{0.5892X1}$	$e^{0.2886X2}$	$e^{0.1678X3}$	$e^{0.7926X4}$	$e^{0.6324X5}$	$e^{0.8049X6}$	$e^{0.3876X7}$	$e^{0.9782X8}$	$e^{0.2912X9}$	$e^{0.4791X10}$	$e^{0.5403X11}$
P_c	0.1331	$A^{-0.2764}$	$H^{-0.0875}$	$D^{1.9877}$	$N^{0.7660}$	$e^{0.8054X1}$	$e^{0.2260X2}$	$e^{0.4462X3}$	$e^{0.3673X4}$	$e^{0.3624X5}$	$e^{0.4652X6}$	$e^{0.3334X7}$	$e^{0.5287X8}$	$e^{-0.0584X9}$	$e^{0.3173X10}$	$e^{0.1162X11}$
P_s	0.0392	$A^{-0.0104}$	$H^{0.8086}$	$D^{1.7957}$	$N^{0.8930}$	$e^{0.5083X1}$	$e^{0.5503X2}$	$e^{0.3955X3}$	$e^{0.3852X4}$	$e^{0.6948X5}$	$e^{0.4551X6}$	$e^{0.6744X7}$	$e^{0.3366X8}$	$e^{0.4773X9}$	$e^{0.3873X10}$	$e^{0.3094X11}$
P_f	0.0688	$A^{-0.4916}$	$H^{-0.2355}$	$D^{2.0358}$	$N^{0.8899}$	$e^{1.0055X1}$	$e^{0.3484X2}$	$e^{0.6702X3}$	$e^{0.9501X4}$	$e^{0.6501X5}$	$e^{1.0035X6}$	$e^{0.7977X7}$	$e^{0.9110X8}$	$e^{-0.3078X9}$	$e^{0.7013X10}$	$e^{0.1395X11}$
P_b	0.0719	$A^{-0.2033}$	$H^{-0.0024}$	$D^{1.9407}$	$N^{0.7338}$	$e^{0.7667X1}$	$e^{0.2628X2}$	$e^{0.4350X3}$	$e^{0.2447X4}$	$e^{0.3355X5}$	$e^{0.3620X6}$	$e^{0.2520X7}$	$e^{0.4468X8}$	$e^{-0.0486X9}$	$e^{0.2370X10}$	$e^{0.1645X11}$
P_w	0.0432	$A^{-0.0843}$	$H^{1.0759}$	$D^{1.5216}$	$N^{0.7924}$	$e^{0.7106X1}$	$e^{0.6344X2}$	$e^{0.4098X3}$	$e^{0.4705X4}$	$e^{0.9685X5}$	$e^{0.9157X6}$	$e^{0.6740X7}$	$e^{0.6655X8}$	$e^{-0.0387X9}$	$e^{0.5357X10}$	$e^{0.3935X11}$
P_{bk}	0.0217	$A^{-0.0595}$	$H^{0.8140}$	$D^{1.3568}$	$N^{0.8048}$	$e^{0.3719X1}$	$e^{0.7681X2}$	$e^{0.5487X3}$	$e^{0.5371X4}$	$e^{1.0496X5}$	$e^{1.1993X6}$	$e^{0.8018X7}$	$e^{0.2922X8}$	$e^{-0.4083X9}$	$e^{0.3324X10}$	$e^{0.2078X11}$

Table 6. The comparison of adequacy indices of independent and additive equations for larch stand biomass calculated with their regionalization by introducing dummy variables

Index	Biomass components								
	P_t	P_a	P_r	P_s	P_w	P_{bk}	P_c	P_b	P_f
Independent equations									
R^2	0.950	0.958	0.768	0.958	0.959	0.677	0.793	0.808	0.672
Additive equations									
R^2	0.950	0.952	0.770	0.955	0.957	0.664	0.685	0.671	0.599

Table 7. Characteristics of auxiliary recursive equations for mass-forming indices

Mass-forming indices	Independent variables and the regression model coefficients															$adjR^2$
$\ln H$	0.9617	0.4808 $\ln A$	-		-0.0342 $X1$	-0.0294 $X2$	-0.6824 $X3$	-0.9385 $X4$	-0.3890 $X5$	-0.3641 $X6$	-0.8561 $X7$	-0.8834 $X8$	0.0088 $X9$	-0.2439 $X10$	-0.0957 $X11$	0.502
$\ln D$	-0.1481	0.2529 $\ln A$	0.8315 $\ln H$	-	-0.3687 $X1$	-0.1247 $X2$	-0.5305 $X3$	-0.6245 $X4$	-0.4754 $X5$	-0.4684 $X6$	-0.6799 $X7$	-0.6115 $X8$	-0.4697 $X9$	-0.4823 $X10$	-0.1420 $X11$	0.887
$\ln N$	3.8383	-0.3753 $\ln A$	1.2774 $\ln H$	-2.0894 $\ln D$	0.4003 $X1$	0.5361 $X2$	-0.0170 $X3$	0.0163 $X4$	0.2376 $X5$	-0.3495 $X6$	0.1233 $X7$	0.1519 $X8$	0.5846 $X9$	-0.1540 $X10$	0.0706 $X11$	0.691
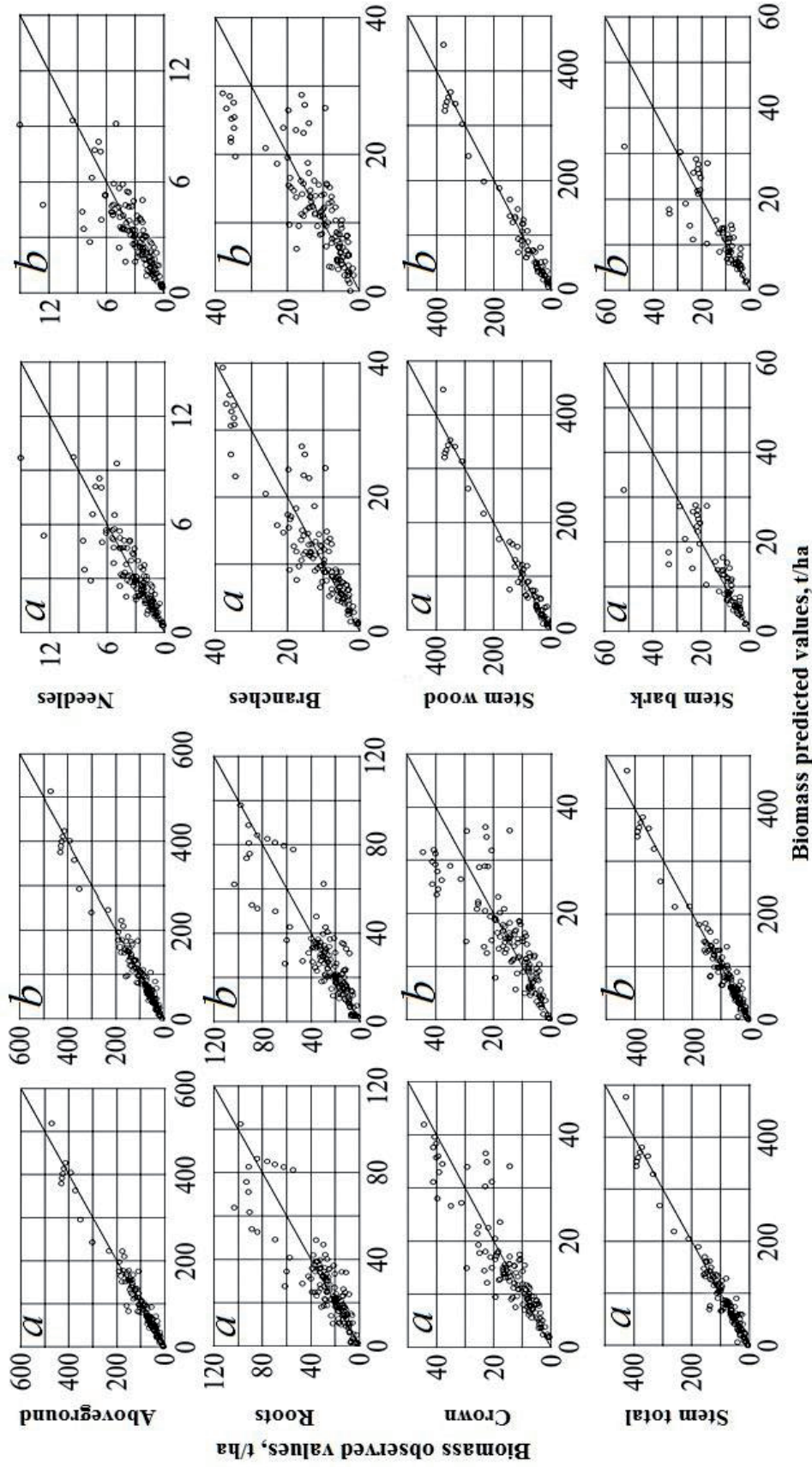
Figure 3. The ratio of observed values and the values derived by calculation of independent (a) and additive (b) models of stand biomass

The ratio of actual values and derived ones by tabulating independent and additive stand biomass models (Fig. 3) shows the degree of correlativeness of the actual and calculated values and, in many cases, the absence of visible differences in the structure of residual variances obtained on two named models. More or less the value of R^2 of one or the other model is determined by the random position of actual values of maximum stand biomass in confidence range and uneven dispersion, namely accidental because of their small number and the greatest contribution to the residual variance (see Fig. 3).

The additive model built (Table 4) includes four numeric independent variables. When its tabulating, there is a problem, which is that we can know and give the value of stand age only of four variables, and the remaining three variables can be entered into the table in the form of calculated values obtained by the system of auxiliary recursive equations (Usoltsev et al., 2017b). Such equations are approximated using the original data and are shown in the Table 7.

The results of sequential tabulations of the equations of the Table 7 and 4 give the unacceptably voluminous table, the size of which exceeds the format of journal article. Therefore, a comparative analysis of the biomass structure of larch stands of different ecoregions we limit by the stand age of 100 years (Table 8). According to the table. 8, the greatest values of biomass (210-450 t/ha) correspond to the regions adjacent to the Atlantic and Pacific coasts, as well as to the regions, located at the southern limit of larch growing area and the lowest – to northern taiga regions of Siberia, where larch grows on permafrost. The biomass indices of different ecoregions differed not only in absolute value but also in biomass ratios of different components; for example, the proportion of needles in the aboveground biomass is maximum (5.0-7.3%) in the northern taiga of Central Siberia and the Far East on permafrost and is minimum (1.4-1.9%) in larch forests of upper productivity having biomass values 210-450 t/ha.

4. Conclusion

When using the unique in terms of the volumes of database on the level of a stand of the genus *Larix* Mill., the trans-Eurasian additive allometric models of biomass for Eurasian larch forests are developed for the first time, and thereby the combined problem of model additivity and generality is solved. The additive model of forest biomass of *Larix* is harmonized in two levels, one of which provides the principle of additivity of biomass components, and the second one is associated with the introduction of dummy independent variables localizing model for ecoregions of Eurasia. The proposed model and corresponding tables for estimating stand biomass makes them possible to calculate larch stand biomass on Eurasian forests when using measuring taxation.

Table 8. Fragment of additive transcontinental table of larch stand biomass for the age of 100 years, localized on the ecoregions of Eurasia

Region	Species	H, m	D, cm	N, 1000/ha	Stand biomass, t/ha								
					Pt	Pa	Pc	Pf	Pb	Pr	Ps	Pw	Pbk
WME	*L. decidua*	25.7	42.0	0.3	181.0	159.8	25.7	2.8	23.0	21.2	134.1	118.9	15.2
ER	*L. sukaczewii*	24.8	28.2	0.9	407.4	336.7	34.0	6.5	27.5	70.7	302.7	275.3	27.4
Tst	*L. sukaczewii*	24.9	36.2	0.6	447.0	387.7	31.5	5.4	26.1	59.3	356.2	309.1	47.1
WSn	*L. sibirica*	13.0	14.0	1.1	77.0	62.6	7.7	1.3	6.4	14.4	54.9	45.2	9.7
MSn	*L. gmelinii*	10.1	10.3	1.5	56.7	38.3	7.8	1.9	5.9	18.4	30.5	24.9	5.6
MSs	*L. sibirica*	17.4	19.0	1.1	206.1	172.7	18.8	4.3	14.5	33.4	153.9	130.7	23.3
TB	*L. gmelinii*	17.9	19.3	0.6	132.0	101.6	14.0	3.2	10.8	30.4	87.7	72.2	15.5
ESn	L. cajanderi	10.9	10.4	1.8	78.8	63.1	7.5	1.9	5.6	15.8	55.6	45.0	10.5
FEn	*L. cajanderi*	10.6	10.9	1.6	83.2	47.7	13.4	3.5	9.9	35.5	34.3	30.0	4.3
FEs	*L. olgensis*	25.9	26.4	1.2	450.5	367.4	38.1	5.3	32.8	83.1	329.3	300.2	29.1
Ch	*L. gmelinii*	20.1	21.2	0.7	147.0	116.4	12.0	2.6	9.4	30.6	104.4	92.7	11.7
Jap	*L. leptolepis*	23.3	33.6	0.4	208.8	166.2	16.2	2.3	13.9	42.6	150.0	134.7	15.3

Acknowledgments

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