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Prediction of Allometric Models of Stand Biomass of *Betula* sp. in Eurasia

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Abstract: When using the unique in terms of the volume of database on the level of stand of the genus *Betula* sp., the trans-Eurasian additive allometric models of biomass of stands for Eurasian birch 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 *Betula*is harmonized in two ways: it eliminated the internal contradictions of the component and the total biomass equations, and in addition, it takes into account regional differences of forest stands not only on total, aboveground and underground biomass, but also on its component structure, i.e. it reflects the regional peculiarities of the component structure of biomass.

Keywords: Allometric models, Biological productivity, Biomass of tree and forests, *Betula*, Sample plots

In recent years, the world forest ecology is experiencing unprecedented information splash in the assessment of forest biological productivity in relation to climate change observed since 1960-80ies, predicted at the end of the 19th century in the works of "the father of global warming" Svante Arrhenius (1896). The current hype surrounding the problem of breached the carbon balance of the biosphere and questionable hopes for his recovery by means of a total afforestation of planet, passes into the common paradigm of sustainable development, which the first is biosphere-stabilizing function of forests, bu ttraditional resource forest management is seen as a subordinate task. Estimating of biological productivity or carbon-depositing ability of forests is going on the global level, and its increase is one of the major factors of climate stabilization.

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 2015) and towards transition from "pseudo-generic" allometric models to really generic, 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. 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. The additive principle is implemented only for local models of forest stand biomass (Bi et al 2010). Its complexity and structural unwieldiness 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* sp.) and fir (*Abies* sp.) 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 birch (genus *Betula* sp.) 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.

MATERIAL AND METHODS

Of the database mentioned the material in a number of 520 sample plots with estimations of birch forest stand biomass (t/ha) is extracted. Genus *Betula* sp. is introduced by five species (correspondingly *B. alba* L., *B. tortuosa* Ldb., *B.*

platyphylla Suk., *B. ermanii* Cham., *B. costata* Trautv.), distributed across 11 eco-regions and designated respectively with the 11 dummy variables from X_0 to X_{10} (Table 1). The distribution of sample plots, on which the birch forest biomass is measured in ecoregions of Eurasia, is shown in Figure 1.

Analysis of biomass forest stands is made on the basis of allometric additive models. According to the structure of disaggregation three-step model (Tang et al 2000, Dong et al2015), 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 additive biomass of all the components-total, intermediate and initial (Dong et al 2015).

RESULTS AND DISCUSSION

The initial allometric model is calculated;

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

where *Pi* – 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, 1000ha^{-1}; *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 10 (see Table 1).

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

Fig. 1. Allocation of sample plots with measured biomass (t ha^{-1}) of 520 stands of birch (genus *Betula* sp.) on the territory of Eurasia

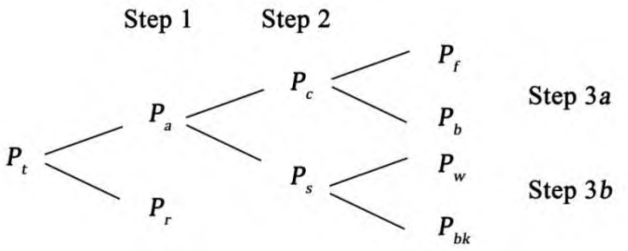

Fig. 2. The pattern of disaggregating three-step proportional weighting additive model. Designation: *Pt, Pr, Pa, Pc, Ps, Pf, Pb, Pw* and *Pbk* are stand biomass respectively:total, underground (roots), aboveground, crown (needles and branches), stems above bark (wood and bark), needles, branches, stem wood and stem bark correspondingly, t ha^{-1}

Table 1. The encoding scheme of the regional actual biomass data sets of 520 birch forest stands

Region *	Species of. *Betula* sp.	Block of dummy variables										Ranges of:				Plot quantity
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Stand age (yrs)	Tree number (1000 ha^{-1})	Mean diameter cm)	Mean height (m)	
WME	*B. alba* L.	0	0	0	0	0	0	0	0	0	0	8÷80	0.35÷14.15	1.8÷28.5	2.1÷26.5	89
ERn	*B. alba* L.	1	0	0	0	0	0	0	0	0	0	10÷110	0.69÷27.6	1.9÷20.3	2.0÷25.1	41
ERs	*B. alba* L.	0	1	0	0	0	0	0	0	0	0	5÷95	0.28÷304.0	1.1÷31.2	1.7÷30.3	161
Ural	*B. alba* L.	0	0	1	0	0	0	0	0	0	0	5÷67	0.77÷42.9	1.1÷22.0	2.6÷23.4	44
WSst	*B. alba* L.	0	0	0	1	0	0	0	0	0	0	5÷100	0.29÷43.4	2.0÷33.0	3.1÷25.8	66
MSn	*B. alba* L. *B. tortuosa* L.	0	0	0	0	1	0	0	0	0	0	37÷100	0.38÷5.92	5.0÷24.0	4.0÷23.6	20
MSs	*B. alba* L.	0	0	0	0	0	1	0	0	0	0	15÷100	0.33÷10.17	4.4÷30.2	1.5÷25.1	68
ES	*B. alba* L. *B. ermanii* Ch.	0	0	0	0	0	0	1	0	0	0	13÷175	0.26÷83.6	1.0÷32.4	2.0÷19.0	9
FEs	*B. costata* Tr.	0	0	0	0	0	0	0	1	0	0	60÷190	0.15÷5.34	25.0÷48.2	15.3÷26.1	10
Ch	*B. platyphylla* S.	0	0	0	0	0	0	0	0	1	0	35÷100	0.50÷1.64	12.3÷20.0	10.6÷20.0	5
Jap	*B. platyphylla* S. *B. ermanii* Ch.	0	0	0	0	0	0	0	0	0	1	10÷47	0.27÷20.06	2.7÷23.5	4.3÷22.5	7

*WME – West and Middle Europe; ERn – European part of Russia,northern territory;ERs – European part of Russia, southern territory;Ural – Midle and Southern Ural;WSst – Western Siberia, steppe and forest-steppe; MSn – Middle Siberia, northern territory; MSs – Middle Siberia, southern territory; ES - Eastern Siberia, northern taiga; FEs – Far East, southern territory (Primorie); Ch – Northeast China; Jap – Japanese islands

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

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 2015) (Table 3), and the final transcontinental additive model of birch 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.

Table 3. The structure of three-step additive model built by proportional weighting (Dong et al 2015)

Step 1	$Pa = \frac{1}{1+\frac{a_r D^{br} H^{Cr}}{a_a D^{ba} H^{Ca}}} \times P_t$	$Pr = \frac{1}{1+\frac{a_r D^{br} H^{Cr}}{a_a D^{ba} H^{Ca}}} \times P_t$
Step 2	$Pc = \frac{1}{1+\frac{a_s D^{bs} H^{Cs}}{a_c D^{bc} H^{Cc}}} \times P_a$	$Ps = \frac{1}{1+\frac{a_c D^{bc} H^{Cc}}{a_s D^{bs} H^{Cs}}} \times P_a$
Step 3a	$Pf = \frac{1}{1+\frac{a_b D^{bb} H^{Cb}}{a_f D^{bf} H^{Cf}}} \times P_c$	$Pb = \frac{1}{1+\frac{a_f D^{bf} H^{Cf}}{a_b D^{bb} H^{Cb}}} \times P_c$
Step 3b	$Pw = \frac{1}{1+\frac{a_{bk} D^{bbk} H^{Cbk}}{a_w D^{bw} H^{Cw}}} \times P_s$	$Pbk = \frac{1}{1+\frac{a_w D^{bw} H^{Cw}}{a_{bk} D^{bbk} H^{Cbk}}} \times P_s$

See Figure 2 and equation 1 for details

At the next stage of the study, a comparison of the adequacy of additive model (Table 4) and independent equations shown in the Table 2. For the 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:

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

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 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 (Table 6). The ratio of actual values and derived ones by tabulating independent and additive stand

Table 2. Characteristic of initial allometric equations for birch stands

Biomass component	Independent variables and the regression model coefficients														adjR^2*
P_t	2.3124	$A^{-0.1332}$	$H^{0.7126}$	$D^{0.9612}$	$N^{0.3588}$	$e^{-0.1815X1}$	$e^{-0.0816X2}$	$e^{-0.0775X3}$	$e^{0.0661X4}$	$e^{0.3945X5}$	$e^{-0.0498X6}$	$e^{-0.1197X7}$	$e^{0.1164X8}$	$e^{-0.3918X9}$	$e^{-0.1753X10}$	0.871
Step1																
P_a	0.2549	$A^{0.0108}$	$H^{0.9030}$	$D^{1.2480}$	$N^{0.6494}$	$e^{-0.1516X1}$	$e^{-0.0801X2}$	$e^{-0.0091X3}$	$e^{-0.0204X4}$	$e^{0.3098X5}$	$e^{0.0039X6}$	$e^{-0.0822X7}$	$e^{0.1106X8}$	$e^{-0.0593X9}$	$e^{-0.0457X10}$	0.914
P_r	1.0952	$A^{-0.0407}$	$H^{0.0956}$	$D^{1.1485}$	$N^{0.3720}$	$e^{-0.2283X1}$	$e^{-0.1424X2}$	$e^{-0.2414X3}$	$e^{0.2012X4}$	$e^{1.1840X5}$	$e^{-0.1361X6}$	$e^{0.1736X7}$	$e^{-0.1831X8}$	$e^{-0.6657X9}$	$e^{-0.2145X10}$	0.604
Step 2																
P_c	0.2001	$A^{-0.0124}$	$H^{0.2602}$	$D^{1.3483}$	$N^{0.5597}$	$e^{-0.1540X1}$	$e^{-0.0767X2}$	$e^{-0.0698X3}$	$e^{0.1202X4}$	$e^{0.2007X5}$	$e^{-0.0350X6}$	$e^{-0.1553X7}$	$e^{0.3886X8}$	$e^{0.0674X9}$	$e^{-0.0807X10}$	0.750
P_s	0.1376	$A^{0.0388}$	$H^{1.1076}$	$D^{1.1667}$	$N^{0.6653}$	$e^{-0.1950X1}$	$e^{-0.1092X2}$	$e^{-0.0131X3}$	$e^{-0.0592X4}$	$e^{0.2511X5}$	$e^{0.0004X6}$	$e^{-0.0960X7}$	$e^{0.0470X8}$	$e^{-0.0790X9}$	$e^{-0.0457X10}$	0.916
Step 3a																
P_f	0.1013	$A^{-0.2180}$	$H^{0.3149}$	$D^{1.1582}$	$N^{0.5968}$	$e^{0.4276X1}$	$e^{0.2404X2}$	$e^{0.1721X3}$	$e^{0.2360X4}$	$e^{0.5130X5}$	$e^{-0.0860X6}$	$e^{-0.0706X7}$	$e^{0.2496X8}$	$e^{0.1213X9}$	$e^{-0.0978X10}$	0.576
P_b	0.1077	$A^{0.0577}$	$H^{0.3090}$	$D^{1.3592}$	$N^{0.5348}$	$e^{-0.3063X1}$	$e^{-0.1497X2}$	$e^{-0.1323X3}$	$e^{0.1195X4}$	$e^{0.1323X5}$	$e^{-0.0064X6}$	$e^{-0.1586X7}$	$e^{0.3405X8}$	$e^{0.0681X9}$	$e^{-0.0374X10}$	0.774
Step3b																
P_w	0.0605	$A^{0.0259}$	$H^{1.5599}$	$D^{0.9264}$	$N^{0.6999}$	$e^{-0.0257X1}$	$e^{-0.0545X2}$	$e^{-0.0343X3}$	$e^{-0.0912X4}$	$e^{0.7036X5}$	$e^{0.1160X6}$	$e^{0.1125X7}$	$e^{0.0471X8}$	$e^{0.0403X9}$	$e^{0.1949X10}$	0.946
P_{bk}	0.0380	$A^{0.0388}$	$H^{1.3128}$	$D^{0.7136}$	$N^{0.5922}$	$e^{-0.3615X1}$	$e^{-0.0878X2}$	$e^{-0.0074X3}$	$e^{0.1872X4}$	$e^{0.2607X5}$	$e^{0.3638X6}$	$e^{-0.5749X7}$	$e^{0.1232X8}$	$e^{-0.0709X9}$	$e^{0.0639X10}$	0.859

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.

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

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

$$Pt = 2.3124\, A^{-0.1332} H^{0.7126} D^{0.9612} N^{0.3588} e^{-0.1815X1} e^{-0.0816X2} e^{-0.0775X3} e^{0.0661X4} e^{0.3945X5} e^{-0.0498X6} e^{-0.1197X7} e^{0.1164X8} e^{-0.3918X9} e^{-0.1753X10}$$

Step 1

$$Pa = \frac{1}{1+4.2973\, A^{-0.0514} H^{-0.8074} D^{-0.0995} N^{-0.2774} e^{-0.0767X1} e^{-0.0623X2} e^{-0.2322X3} e^{0.2216X4} e^{0.8742X5} e^{-0.1400X6} e^{0.2558X7} e^{-0.2937X8} e^{-0.6064X9} e^{-0.1688X10}} \times Pt$$

$$Pr = \frac{1}{1+0.2327\, A^{0.0514} H^{0.8074} D^{0.0995} N^{0.2774} e^{0.0767X1} e^{0.0623X2} e^{0.2322X3} e^{-0.2216X4} e^{-0.8742X5} e^{0.1400X6} e^{-0.2558X7} e^{0.2937X8} e^{0.6064X9} e^{0.1688X10}} \times Pt$$

Step 2

$$Pc = \frac{1}{1+0.6875\, A^{0.0512} H^{0.8474} D^{-0.1816} N^{0.1056} e^{-0.0410X1} e^{-0.0325X2} e^{0.0568X3} e^{-0.1794X4} e^{0.0504X5} e^{0.0354X6} e^{0.0594X7} e^{-0.3417X8} e^{-0.1464X9} e^{0.0350X10}} \times Pa$$

$$Ps = \frac{1}{1+1.4546\, A^{-0.0512} H^{-0.8474} D^{0.1816} N^{-0.1056} e^{0.0410X1} e^{0.0325X2} e^{-0.0568X3} e^{0.1794X4} e^{-0.0504X5} e^{-0.0354X6} e^{-0.0594X7} e^{0.3417X8} e^{0.1464X9} e^{-0.0350X10}} \times Pa$$

Step 3*a*

$$Pf = \frac{1}{1+1.0638\, A^{0.2756} H^{-0.0060} D^{0.2011} N^{-0.0619} e^{-0.7339X1} e^{-0.3901X2} e^{-0.3044X3} e^{-0.1165X4} e^{-0.3807X5} e^{0.0796X6} e^{-0.0880X7} e^{0.0909X8} e^{-0.0531X9} e^{0.0605X10}} \times Pc$$

$$Pb = \frac{1}{1+0.9401\, A^{-0.2756} H^{0.0060} D^{-0.2011} N^{0.0619} e^{0.7339X1} e^{0.3901X2} e^{0.3044X3} e^{0.1165X4} e^{0.3807X5} e^{-0.0796X6} e^{0.0880X7} e^{-0.0909X8} e^{0.0531X9} e^{-0.0605X10}} \times Pc$$

Step 3*б*

$$Pw = \frac{1}{1+0.6275\, A^{0.0128} H^{-0.2471} D^{-0.2128} N^{-0.1077} e^{-0.3358X1} e^{-0.0334X2} e^{0.0269X3} e^{0.2784X4} e^{-0.4428X5} e^{0.2478X6} e^{-0.6875X7} e^{0.0760X8} e^{-0.1112X9} e^{-0.1309X10}} \times Ps$$

$$Pbk = \frac{1}{1+1.5937\, A^{-0.0128} H^{0.2471} D^{0.2128} N^{0.1077} e^{0.3358X1} e^{0.0334X2} e^{-0.0269X3} e^{-0.2784X4} e^{0.4428X5} e^{-0.2478X6} e^{0.6875X7} e^{-0.0760X8} e^{0.1112X9} e^{0.1309X10}} \times Ps$$

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

Biomass component	Independent variables and the regression coefficients of the model														
P_t	2,3124	$A^{-0,1332}$	$H^{0,7126}$	$D^{0,9612}$	$N^{0,3588}$	$e^{-0,1815X1}$	$e^{-0,0816\,X2}$	$e^{-0,0775\,X3}$	$e^{0,0661\,X4}$	$e^{0,3945\,X5}$	$e^{-0,0498\,X6}$	$e^{-0,1197\,X7}$	$e^{0,1164\,X8}$	$e^{-0,3918\,X9}$	$e^{-0,1753\,X10}$
P_a	1,6517	$A^{-0,2090}$	$H^{0,8778}$	$D^{0,9361}$	$N^{0,3510}$	$e^{-0,1431\,X1}$	$e^{-0,0550\,X2}$	$e^{-0,0165\,X3}$	$e^{-0,0069\,X4}$	$e^{-0,6064\,X5}$	$e^{-0,0722\,X6}$	$e^{-0,2394\,X7}$	$e^{0,2173\,X8}$	$e^{-0,3372\,X9}$	$e^{-0,1601\,X10}$
P_r	1,0952	$A^{-0,0407}$	$H^{0,0956}$	$D^{1,1485}$	$N^{0,3720}$	$e^{-0,2283\,X1}$	$e^{-0,1424\,X2}$	$e^{-0,2414\,X3}$	$e^{0,2012\,X4}$	$e^{1,1840\,X5}$	$e^{-0,1361\,X6}$	$e^{0,1736\,X7}$	$e^{-0,1831\,X8}$	$e^{-0,6657\,X9}$	$e^{-0,2145\,X10}$
P_c	1,1172	$A^{-0,1776}$	$H^{0,2397}$	$D^{0,9756}$	$N^{0,2975}$	$e^{-0,0648\,X1}$	$e^{-0,0078\,X2}$	$e^{-0,1091\,X3}$	$e^{0,0754\,X4}$	$e^{-0,7359\,X5}$	$e^{-0,2624\,X6}$	$e^{-0,5189\,X7}$	$e^{0,7750\,X8}$	$e^{-0,0917\,X9}$	$e^{-0,0870\,X10}$
P_s	0,9788	$A^{-0,2058}$	$H^{1,0103}$	$D^{0,9320}$	$N^{0,3677}$	$e^{-0,1655\,X1}$	$e^{-0,0752\,X2}$	$e^{-0,0080\,X3}$	$e^{-0,0320\,X4}$	$e^{-0,5999\,X5}$	$e^{-0,0420\,X6}$	$e^{-0,1966\,X7}$	$e^{0,0914\,X8}$	$e^{-0,3836\,X9}$	$e^{-0,1809\,X10}$
P_f	0,4269	$A^{-0,4483}$	$H^{0,4385}$	$D^{0,7928}$	$N^{0,4014}$	$e^{0,5982\,X1}$	$e^{0,3858\,X2}$	$e^{0,2480\,X3}$	$e^{0,2668\,X4}$	$e^{0,0045\,X5}$	$e^{0,2816\,X6}$	$e^{-0,0717\,X7}$	$e^{0,0151\,X8}$	$e^{0,1340\,X9}$	$e^{-0,0361\,X10}$
P_b	0,6606	$A^{-0,1105}$	$H^{0,2412}$	$D^{1,0120}$	$N^{0,2620}$	$e^{-0,2149\,X1}$	$e^{-0,0941\,X2}$	$e^{-0,2147\,X3}$	$e^{0,0854\,X4}$	$e^{-0,8552\,X5}$	$e^{-0,3673\,X6}$	$e^{-0,5935\,X7}$	$e^{0,7557\,X8}$	$e^{-0,1344\,X9}$	$e^{-0,0521\,X10}$
P_w	0,0605	$A^{0,0259}$	$H^{1,5599}$	$D^{0,9264}$	$N^{0,6999}$	$e^{-0,0257\,X1}$	$e^{-0,0545\,X2}$	$e^{-0,0343\,X3}$	$e^{-0,0912\,X4}$	$e^{0,7036\,X5}$	$e^{0,1160\,X6}$	$e^{0,1125\,X7}$	$e^{0,0471\,X8}$	$e^{0,0403\,X9}$	$e^{0,1949\,X10}$
P_{bk}	0,0380	$A^{0,0388}$	$H^{1,3128}$	$D^{0,7136}$	$N^{0,5922}$	$e^{-0,3615\,X1}$	$e^{-0,0878\,X2}$	$e^{-0,0074\,X3}$	$e^{0,1872\,X4}$	$e^{0,2607\,X5}$	$e^{0,3638\,X6}$	$e^{-0,5749\,X7}$	$e^{0,1232\,X8}$	$e^{-0,0709\,X9}$	$e^{0,0639\,X10}$

Table 6. The comparison of adequacy indices of independent and additive equations for birch 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

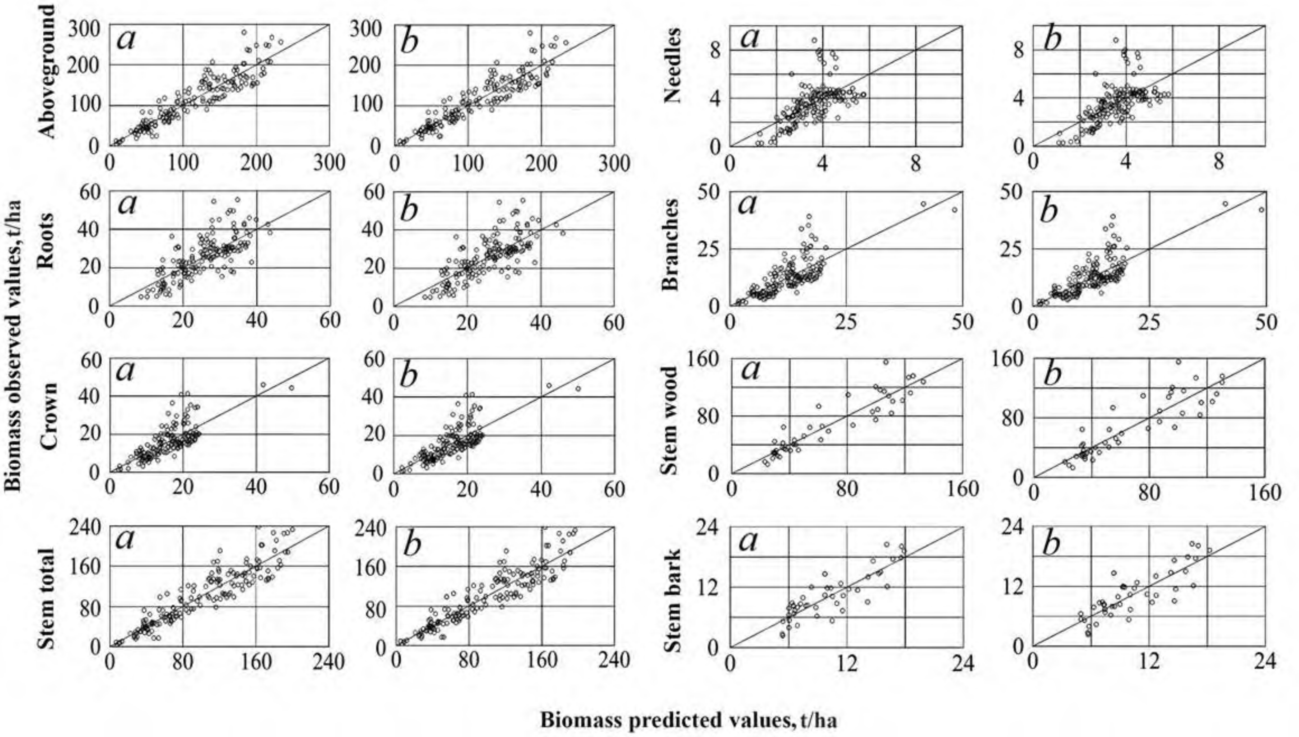

Fig. 3. The ratio of observed values and the values derived by calculation of independent (a) and additive (b) models of birch stand biomass

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

Mass-forming indices	Independent variables and the regression coefficients of the model														$adjR^2$
ln*H*	-0,0217	0,7812ln*A*	-	-	-0,5836*X1*	-0,0720*X2*	-0,1720*X3*	-0,1480*X4*	-0,7952*X5*	-0,2341*X6*	-0,7854*X7*	-0,5169*X8*	-0,4123*X9*	0,0198*X10*	0,669
ln*D*	-1,1075	0,3700ln*A*	0,8906ln*H*	-	-0,1841*X1*	-0,2138*X2*	-0,1628*X3*	-0,1072*X4*	-0,3604*X5*	-0,0708*X6*	-0,2018*X7*	0,1380*X8*	0,1007*X9*	-0,0516*X10*	0,940
ln*N*	3,8571	-0,0983ln*A*	1,0101ln*H*	-2,2386ln*D*	0,1218*X1*	0,2071*X2*	0,1503*X3*	0,0031*X4*	-0,3848*X5*	-0,1110*X6*	-0,0637*X7*	0,3165*X8*	-0,0928*X9*	-0,2960*X10*	0,888

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 50 years (Table 8). According to the table 8, the greatest values of total biomass (202 t ha^{-1}) correspond to the European regions adjacent to the Atlantic coast, and the lowest (65-94 t ha^{-1}) – to northern taiga regions of Russia. An intermediate position in terms of total biomass (140-177 t ha^{-1}) occupy birch stands of the southern part of their Eurasian areal. 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 foliage in the aboveground biomass is maximum (3.6-4.6%) in the northern taiga of Russia and is minimum (1.9-2.1%) in birch forests adjacent to the Atlantic and Pacific coasts.

CONCLUSION

When using the unique in terms of the volume of database on the level of a stand of the genus *Betula* sp., the trans-Eurasian additive allometric model of biomass for birch forests is developed for the first time, and thereby the combined problem of model additivity and generality is solved. The additive model of forest biomass of *Betula* is harmonized in two levels, one of which provides the principle

Table 8. Fragment of additive transcontinental table of birch stand biomass for the age of 50 years, localized on the ecoregions of Eurasia

Region	Species	H (m)	D (cm)	N (1000 ha^{-1})	Stand biomass (t ha^{-1})								
					Pt	*Pa*	*Pc*	*Pf*	*Pb*	*Pr*	*Ps*	*Pw*	*Pbk*
WME	*B. alba* L.	20.8	21.0	0.8	201.5	162.3	22.7	3.4	19.4	39.2	139.6	119.5	20.1
ERn	*B. alba* L.	11.6	10.4	2.3	83.9	65.4	11.7	3.6	8.1	18.5	53.7	47.0	6.7
ERs	*B. alba* L.	19.3	15.9	1.6	177.2	147.6	20.0	4.4	15.6	29.6	127.6	109.8	17.8
Ural	*B. alba* L.	17.5	15.3	1.5	155.6	131.0	17.7	3.7	14.0	24.6	113.3	96.1	17.2
WSst	*B. alba* L.	17.9	16.5	1.1	177.0	134.9	22.7	3.9	18.8	42.1	112.1	91.0	21.1
MSn	*B. alba* L. *B. tortuosa* L.	9.4	7.2	2.5	93.6	49.9	9.0	2.3	6.7	43.7	40.9	35.7	5.2
MSs	*B. alba* L.	16.5	15.8	1.0	137.1	110.4	16.6	2.4	14.1	26.7	93.8	76.0	17.8
ES	*B. alba* L. *B. ermanii* Ch.	9.5	8.5	2.4	65.2	44.4	8.1	1.6	6.5	20.7	36.3	32.7	3.6
FEs	*B. costata*Tr.	12.4	15.2	1.3	138.3	111.1	26.7	4.0	22.8	27.2	84.4	69.8	14.6
Ch	*B. platyphylla* S.	13.8	16.1	0.8	81.1	68.5	13.8	2.2	11.6	12.6	54.7	46.6	8.1
Jap	*B. platyphylla* S. *B. ermanii* Ch.	21.2	20.3	0.6	154.5	127.4	17.3	2.4	14.9	27.1	110.1	95.7	14.4

of additivity of biomass components, and the second one is associated with the introduction of dummy independent variables localizing model according to eco-regions of Eurasia. The proposed model and corresponding table for estimating stand biomass make them possible to calculate birch stand biomass on Eurasian forests when using measuring taxation.

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REFERENCES

Arrhenius S 1896. On the influence of carbonic acid in the air upon the temperature of the ground. *Philosophical Magazine* **41**: 237-276.

Baskerville GL 1972. Use of logarithmic regression in the estimation of plant biomass. *Canadian Journal of Forest Research* **2**: 49-53.

Bi H, Long Y, Turner J, Lei Y, Snowdon P, Li Y, Harper R, Zerihun A and Ximenes F 2010. Additive prediction of above ground biomass for *Pinus radiata* (D. Don) plantations. *Forest Ecology and Management* **259**: 2301-2314.

Budyko MI 1977. *Global Ecology*. Moscow «Mysl'» Publishing, 328 pp.

Cunia T and Briggs RD 1984. Forcing additivity of biomass tables: Some empirical results. *Canadian Journal of Forest Research* **14**: 376-384.

Dong L, Zhang L and Li F 2015. A three-step proportional weighting system of nonlinear biomass equations. *Forest Science* **61**(1): 35-45.

Fu LY, Zeng WS, Tang SZ, Sharma RP and Li HK 2012. Using linear mixed model and dummy variable model approaches to construct compatible single-tree biomass equations at different scales: A case study for Masson pine in Southern China. *Journal of Forest Science* **58**(3): 101-115.

Jacobs MW and Cunia T 1980. Use of dummy variables to harmonize tree biomass tables. *Canadian Journal of Forest Research* **10**(4): 483-490.

Reed D D and Green EJ 1985. A method of forcing additivity of biomass tables when using nonlinear models. *Canadian Journal of Forest Research* **15**: 1184-1187.

Tang S, Zhang H and Xu H 2000. Study on establish and estimate method of compatible biomass model. *ScientiaSilvaeSinica* **36**: 19-27 (in Chinese with English abstract).

Usoltsev VA 2010 .Eurasian forest biomass and primary production data. Ural Branch of Russian Academy of Sciences, Yekaterinburg, 574 pp. (http://elar.usfeu.ru/handle/123456789/2606).

Usoltsev VA 2013. Forest biomass and primary production database for Eurasia. CD-version. The second edition, enlarged and re-harmonized. Yekaterinburg, Ural State Forest Engineering University (http://elar.usfeu.ru/handle/123456789/3059).

Usoltsev VA, Voronov MP, Kolchin KV, Malenko AA and Kokh EV 2017a. Transcontinental additive model and weight table for estimating spruce-fir forests biomass on the area of Eurasia. *Bulletin of Altai State Agricultural University* **9**(155): 91-100.

Usoltsev VA, Voronov MP, Shobairi SOR, Dar JA, Kolchin KV, Chasovskikh V P and Markovskaya EV 2017b. Comparative analysis of ordinary and additive models of component composition of tree and forest biomass (on the example of *Picea* sp. and *Abies* sp.). *Eco-Potencial* **3**(19): 9-31.

Utkin AI 1995. Carbon cycle and forestry. *Lesovedenie* **5**: 3-20.

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