Geographic gradients of forest biomass of two needled pines on the territory of Eurasia

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Abstract. On the basis of the compiled database in a number of 3020 sample plots with determinations of forest biomass of two-needled pines (subgenus Pinus) on the territory of Eurasia from Great Britain to southern China and Japan statistically significant transcontinental gradients of stem, roots, aboveground and total biomass are established. In the direction from North to South these biomass components change according to a bell-shaped curvewith a maximum in the third (the southern temperate) zonal belt, while the biomass of needles, branches and understory is monotonically increasing within this zonal gradient from subarctic to subequatorial zonal belts. In the direction from the Atlantic and Pacific coasts to the continentality pole in Siberia there is a biomass decrease as of all components of the wood story and the understory. The root: shoot ratio increases in the range between subarctic and southern temperate zone from 12 to 22% and then decreases to 16% in the subtropical zone, and within the southern temperate zone it monotonically increases from 20% on the oceanic coasts to 23% near continentality pole. The ratio of understory biomass to wood story biomass reduced from 4.0 to 2.5% ranging from subarctic to southern temperate zone and then rises to 3.5% in the subtropical zone, and within the south temperate zone it monotonically decreasing from the maximum value of 22% near Atlantic and Pacific coasts, approaching the level of 2-3% near the continentality pole. The results can be useful in the management of biosphere functions of forests undoubtedly.

Key words: Phytogeography, Pine Forests, Natural Zones, Climate Continentality Index.

1. Introduction

In connection with the problem of global climate change, forest biomass is seen as their main characteristic determining the course of processes in forest ecosystems and used for environmental monitoring, sustainable forest management, modelling forest productivity taking into account global changes, study the structure and biodiversity of forest cover as well as assessment of carbon-depositing capacity of forests. Biomass of plant cover is determined by many factors, of which the most important is the climatic one associated with the intensity of solar radiation and climate continentality (Grigoriev & Budyko, 1956; Nazimova, 1995). Both biomass and NPP are known to be linked to climatic patterns such as evapotranspiration (Rosenzweig, 1968; Lieth, 1974a, b) as well as the amount of precipitation and average annual temperature (Lieth, 1974a, b; Luyssaert et al., 2007). Such links have often been studied indirectly by using geographical gradients of single species of Europe (Oleksyn et al., 1999) and Asia (Shi, Sasa, & Koike, 2010). The first attempt to build a zonal profile of biomass productivity of forest vegetation of the European part of Russia have taken E.M. Lavrenko et al., 1955. V.L. Komarov (1921) was developed the doctrine of meridional zonation of vegetation, that complements the latitudinal zonation and should be taken into account in the allocation of biogeographical regions. He distinguishes between the two types of major continental floras: near oceanic, elongated along the coasts, and continental, developing in the distance from the first. The intersecting with known seven latitude zones, they give on the spaces of Old and New world 42 floral district.

Yearlier geographical regularities of pines were studied on a tree level (Usoltsev et al., 2016). Geographical Trans-Eurasian regularities of pines on forest stand level are not revealed yet. This paper is devoted to revealing of transcontinental climate-caused trends in the biomass structure of forest stands formed with two-needled pines (*Pinus* subgenus).

2. Study area

In 1990-2010 years the forest biomass database in a number of 8 thousand sample plots was compiled by the one of the authors, using own and literature sources, shown in the published databases (Usoltsev, 2010; Usoltsev, 2013a). From these databases the data of 3020 plots with biomass determination including 2125 - natural forests and 895 plantations are extracted for the analysis of geographic patterns of distribution of two-needled pine forest biomass on the territory of Eurasia. About 80% of the data refers to the territory of the former USSR. Biomass data is presented with different components (stems, branches, foliage, roots and understory including grass cover, bushes, shrubs and ingrowth).

Allocation of plots with determinations of pine forest biomass is shown on the map of Eurasia in Figure 1 and dividing to wood species and countries - in the Table 1. In the database for Japan, besides the native two-needled species (*Pinus densiflora* and *Pinus thunbergii*, respectively 23 and 10 plots), the 2-3-needled pine species (*Pinus taeda* and *Pinus elliottii*, respectively 9 and 7 plots) introduced from North America are included.



Figure 1. Allocation of sample plots with biomass (t/ha) determinations in a number of 3020 pine (subgenus *Pinus*) forest stands on the territory of Eurasia

Table 1. Distribution of plots	with determinations	of pine biomass	(t/ha) by	y
species and countries				

Species	Botanical title	Country	Plot quanti-
			ty
Scots pine	Pinus sylvestris	Russia, Kazakhstan, Belarus,	2580
	L.	Ukraine, Finland, Sweden, Swit-	
		zerland, Great Britain, Czech	
		Republic, Slovakia, Bulgaria,	
		China, Germany, Belgium,	
		Spain, Hungary, Lithuania, Nor-	
		way, Poland, Estonia	

Chinese pine	P. tabuliformis	China	165
	Carr.		
Masson's pine	P. massoniana	China	65
	Lamb.		
Taiwan red	P. taiwanensis	China	55
pine	Hayata		
Yunnan pine	P. yunnanensis	China	46
	Franchet		
Austrian pine	P. nigra Arn.	England, Hungary, France, Ger-	33
		many, Netherlands	
Japanese red	P. densiflora S.	Japan	23
pine	et Z.		
Maritime pine	Pinus pinaster	Russia, France, Italy	11
	Aiton		
Turkish pine	Pinus brutia	Russia	10
	var. pityusa		
	(Steven) Silba		
Japanese	P. thunbergii	Japan	10
Black pine	Parl.		
Loblolly pine	Pinus taeda L.	Japan	9
Slash pine	Pinus elliottii	Japan	7
	Engelm.		
Koch's pine	Pinus sylvestris	Georgia	3
	var. <i>hamata</i>		

	1
Aleppo pine <i>P. halepensis</i> Iraq	1
Mill.	
Pallas pinePinus nigraRussia	1
subsp. pal-	
lasiana (Lamb.)	
Holmboe	
Italian stone <i>Pinus pinea</i> L. France	1
pine	
Total	8020

3. Material and methods

All the data involved into the published database were obtained on forest sample plots on which sample trees were taken and the biomass data on the area were calculated by allometric method. Methodical peculiarities were given in the published database (Usoltsev, 2001; 2007; 2010). As plots for estimating biomass of forest stands are usually established in typical 'background' habitats, that are representative in relation to one and other type of forest-forming species, one can make on their basis a preliminary geographical analysis of biomass gradients of pine forests.

For analytical description of geographic distribution patterns of biomass productivity of forest cover, one must choose the geographical characteristics of the territory of Eurasia, that can be expressed by the quantity and measure. Global primary production dependencies of forest cover from evapotranspiration (Rosenzweig, 1968), as well as on the amount of precipitation and the average annual temperature (Lieth, 1974a,b) are known, but they are fulfilled on the basis of single regressions, excluding conjugate estimation of determining factors.

The same wood species cannot be grown throughout Eurasia, and habitats of different species are associated with specific eco-regions (e.g., Pinus nigra in the Balkans and Pinus densiflora in Japan). This phenomenon in plant communities chorology (Tolmachev, 1962) is known as the substitution of species: replacing or vicarious species of plants occur in the cases of geologically long-time separation of once continuous area. If we want to analyze the geography of biomass in the broadest geographic ranges, we encounter inevitable with the phenomenon of substitution of species. Therefore, geographical analysis is made at the level of the vicarious species within the subgenus *Pinus*.

Actual 3020 pine sample plot biomass allocations (see Figure 1) we related with five regional zones (subarctic, northern temperate, southern temperate, subtropical and subequatorial), coded by serial numbers 1, 2, 3, 4 and 5 (see Fig. 2), as well as according to continentality index on the territory of Eurasia by S.P. Khromov (1957) (Figure 3) by drawing on the maps the coordinates of each plot.



Figure 2. Allocation of sample plots having pine forest biomass (t/ha) according to zonal belts: 1 – subarctic, 2 – northern temperate, 3 – southern temperate, 4 – subtropical, 5 – subequatorial (Alisov, Poltaraus, 1974; Bazilevich, Rodin, 1967)



Figure 3. Isoline map of climate continentality of Eurasia (Khromov, 1957) with the situation of plots on which biomass of pine forests (t/ha) is estimated

Basic principles of modelling and the results obtained by means of regression analysis should have ecologic-geographical interpretation. Biological productivity of forests is depending on climatic factors, but only as a first approximation, since there are ontogenetic, cenotic, edaphical, and other levels of its variability. Therefore, we include in the regression equations the independent variables explaining the variability of the dependent variable, expressing not only with climatic parameters but also with forest age, tree density and stem volume. Then the technique of multivariate regression analysis according to two blocks of recursive equations is used: block of two mass-forming indices N and M and block of biomass Pi (arrows show the sequence of calculations);

$$N = f(A, Zon, IC) \rightarrow M = f(A, N, Zon, IC) \rightarrow Pi = f(A, N, M, Zon, IC), \quad (1)$$

where N - tree number, thousands of individuals per ha; A - forest age, yrs; M - stem volume, m³ per ha; P_i - dry biomass of stems above bark, branches, needles, roots, aboveground, total tree story and understory (correspondingly P_S , P_B , P_F , P_R , P_A , P_T and P_U), t per ha; *Zon* - zonal belt number: 1, 2, 3, 4 and 5, correspondingly subarctic, northern temperate, southern temperate, subtropical and subequatorial; *IC* - climate continentality index by S.P. Khromov (1957), %.

As tree density is included in equation (1) as one of the independent variable, natural forests and plantations, differing mostly by their density, are not subdivided, and calculation of equations (1) is made for generalized actual data pool. In indices of P_A and P_T the wood biomass

without understory is only involved. For the last component the equation (1) is calculated separately.

4. Results and discussion

Results of calculation of equations (1) are listed in the Table 2;

Dependent	Coefficients and independent variables					
variables	a_0	a_1 (lnA)	$a_2(\ln A)^2$	$a_3(\ln N)$	$a_4(\ln N)^2$	$a_5(\ln M)$
ln (<i>N</i>)	2.3672	-1.1322	-	-	-	-
ln (<i>M</i>)	-3.0366	3.6842	-0.3926	-0.0652	-	-
$\ln (P_S)$	0.9487	0.2182	-0.0153	0.0150	-	0.9335
$\ln (P_B)$	5.7294	-0.8188	0.0827	-0.0560	-0.0208	0.6120
$\ln\left(P_F\right)$	1.1499	-0.9942	0.0882	0.0414	-	0.8579
$\ln\left(P_{R}\right)$	-1.6828	0.9424	-0.0897	0.0875	-	0.6970
$\ln(P_A)$	2.9015	-0.2889	0.0389	-	-	0.7382
$\ln\left(P_{T}\right)$	2.6286	0.0553	-	0.0121	-	0.4854
$\ln (P_U)$	27.072	-2.2551	0.3356	-	-	-

Table 2. The characteristic of equations (1) to pine forests of Eurasia

Table 2 continued

Dependent	Coefficients and independent variables				D ²	CE
variables	$a_6(\ln M)^2$	$a_7 \ln (Zon)$	$a_8(\ln Zon)^2$	$a_9 \ln(IC)$	K-	SE
ln (<i>N</i>)	-	0.7326	-0.9818	0.6250	0.579	0.70
ln (<i>M</i>)	-	2.1820	-0.9872	-0.2745	0.533	0.65
$\ln(P_S)$	-	-0.3865	0.2125	-0.4319	0.967	0.17
$\ln (P_B)$	-	-1.5355	0.9599	-0.9209	0.648	0.40

$\ln\left(P_F\right)$	-0.0464	-1.0286	0.6861	0.0352	0.475	0.36
$\ln (P_R)$	-	0.9222	-0.3816	-0.3987	0.817	0.34
$\ln (P_A)$	0.0128	-0.5340	0.3210	-0.4101	0.951	0.18
$\ln(P_T)$	0.0369	0.1586	-	-0.3988	0.949	0.17
$\ln (P_U)$	-	0.4498	-	-5.1966	0.169	0.90

Only the variables that are significant at the level of probability of P_{95} and above are showed in the equations. The equations are tabulated in the sequence illustrated by arrows, using forest age, zonal number and continentality index values in the range from 20 up to 200 years old (not shown here). From the calculated age-related table the values of the desired indices for age 100 years are taken and they are presented as graphs of their relations to the zoning of the territory and its climate continental index (Figs 4 and 5).



Figure 4. Dependence of the estimated biomass of needles (*a*), branches (*b*), stems (*c*), roots (*d*), aboveground (*e*) and total tree story (*f*) at the age of 100 years from the zonal affiliation of pine forests in continentality index equal 80%



Figure 5. Dependence of the estimated biomass of needles (*a*), branches (*b*), stems (*c*), roots (*d*), aboveground (*e*) and total tree story (*f*) at the age of 100 years in the southern temperate climatic zone upon the continentality index after S.P. Khromov (1957)

According to the results obtained, biomass of needles and branches is monotonically increasing in the direction from 1st to 5th zonal belt (Fig. 4 *a*, *b*), the biomass of stems and roots is changes in the form of the bell-shaped curve with a maximum in the 3rd zonal belt (Fig. 4 *c*, *d*) and aggregate component indices-aboveground and total biomass are increasing from the 1st to the 3rd belt, and then, if somewhat reduced, but almost go to the plateau (Fig. 4 *e*, *f*). With a fixed zonal belt (in this case the zonal belt 3) all biomass components and their aggregated values are monotonically decreasing in the direction from the Atlantic and Pacific coasts to continentality pole in Yakutia (Fig. 5). A similar pattern has been established for cedar pine stand biomass (Usoltsev, 2013b). Change of calculated estimates of understory biomass according to transcontinental gradients, is mostly similar to changing the aboveground and total biomass of forest stands, i.e. is increasing from north to south (from 1st to 5th zonal belts), and decreases in direction from the Atlantic and Pacific coasts to continentality pole in Yakutia (Fig. 6).



Figure 6. Dependence of calculated values of understory biomass at the stand age of 100 years upon the zonal affiliation of pine forests in continentality index equal 80% (*a*) and upon continentality index after S.P. Khromov (1957) in the southern temperate zonal belt (*b*)

The root: shoot ratio (P_R/P_A) changes according to zonal belts in the form of the bell-shaped curve with the maximum at 3rd zonal belt and increases as climate continentality grows (Fig. 7). The share of the understory biomass in the total one is lowest in the 3rd zone and monotonously decreases towards the pole of climate continentality (Fig. 8).



Figure 7. Dependence of P_R/P_A ratio of pine forests in the age of 100 years upon serial number of climatic zone in continentality index after S.P. Khromov (1957) equal to 80% (*a*) and upon climate continentality in the southern temperate zonal belt (*b*)



Figure 8. Dependence P_U/P_T ratio of pine forests in the age of 100 years upon serial number of climatic zone in continentality index after S.P. Khromov (1957) equal to 80% (*a*) and upon climate continentality in the southern temperate zonal belt (*b*)

5. Conclusions

On the basis of the compiled database in a number of 3020 sample plots with determinations of forest biomass of two-needled pines (subgenus *Pinus*) on the territory of Eurasia from Great Britain to southern China and Japan statistically significant transcontinental gradients of stem, roots, aboveground and total biomass are established. In the direction from North to South these biomass components change according to a bell-shaped curve with a maximum in the third (the southern temperate) zonal belt, while the biomass of needles, branches and understory is monotonically increasing within this zonal gradient from subarctic to subequatorial zonal belts. In the direction from the Atlantic and Pacific coasts to the continentality pole in Siberia there is a biomass decrease as of all components of the wood story and the understory. The root shoot ratio increases in the range between subarctic and southern temperate zone from 12 to 22% and then decreases to 16% in the subtropi-14

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