

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

Vladimir Andreevich Usoltsev^{1,2}, Seyed Omid Reza Shobairi^{1*}, Viktor Petrovich Chasovskikh¹

¹Ural State Forest Engineering University, Sibirskii trakt 37 St,
Yekaterinburg, 620100 Russian Federation,
e-mail: Omidshobeyri214@gmail.com

²Botanical Garden of the Ural Branch of Russian Academy of Sciences,
Ural Branch, 8 Marta 202a St, Yekaterinburg, 620144 Russian Federation

Received: 5 March 2018 / Accepted: 17 April 2018

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 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 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.

Earlier 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.

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

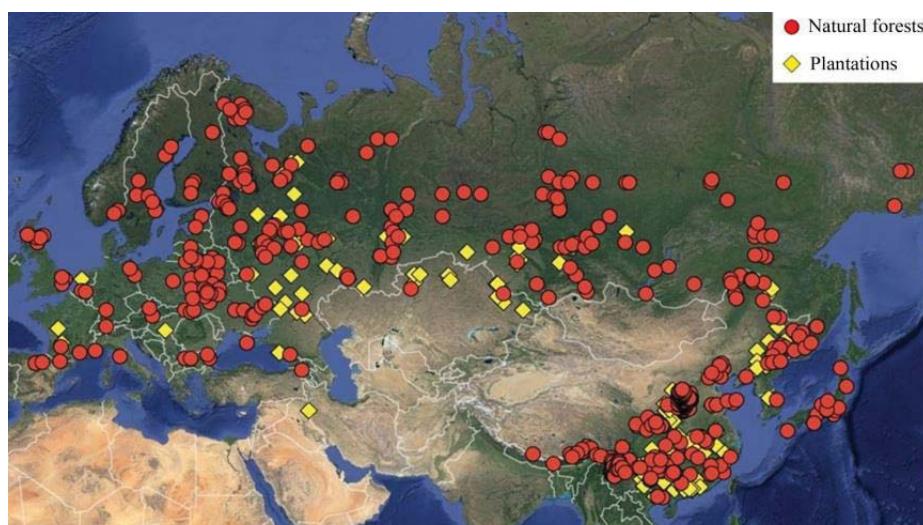


Figure 1. Allocation of sample plots with biomass (t/ha) determinations in a number of 3020 pine (subgenus *Pinus*) forest stands on the territory of Eurasia

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

Species	Botanical title	Country	Plot quantity
Scots pine	<i>Pinus sylvestris</i> L.	Russia, Kazakhstan, Belarus, Ukraine, Finland, Sweden, Switzerland, Great Britain, Czech Republic, Slovakia, Bulgaria, China, Germany, Belgium, Spain, Hungary, Lithuania, Norway, Poland, Estonia	2580
Chinese pine	<i>P. tabuliformis</i> Carr.	China	165
Masson's pine	<i>P. massoniana</i> Lamb.	China	65
Taiwan red pine	<i>P. taiwanensis</i> Hayata	China	55
Yunnan pine	<i>P. yunnanensis</i> Franchet	China	46
Austrian pine	<i>P. nigra</i> Arn.	England, Hungary, France, Germany, Netherlands	33
Japanese red pine	<i>P. densiflora</i> S. et Z.	Japan	23
Maritime pine	<i>Pinus pinaster</i> Aiton	Russia, France, Italy	11
Turkish pine	<i>Pinus brutia</i> var. <i>pityusa</i> (Steven) Silba	Russia	10
Japanese Black pine	<i>P. thunbergii</i> Parl.	Japan	10
Loblolly pine	<i>Pinus taeda</i> L.	Japan	9
Slash pine	<i>Pinus elliottii</i> Engelm.	Japan	7
Koch's pine	<i>Pinus sylvestris</i> var. <i>hamata</i> Steven	Georgia	3
Aleppo pine	<i>P. halepensis</i> Mill.	Iraq	1
Pallas pine	<i>Pinus nigra</i> subsp. <i>pallasiana</i> (Lamb.) Holmboe	Russia	1
Italian stone pine	<i>Pinus pinea</i> L.	France	1
Total			3020

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.

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);

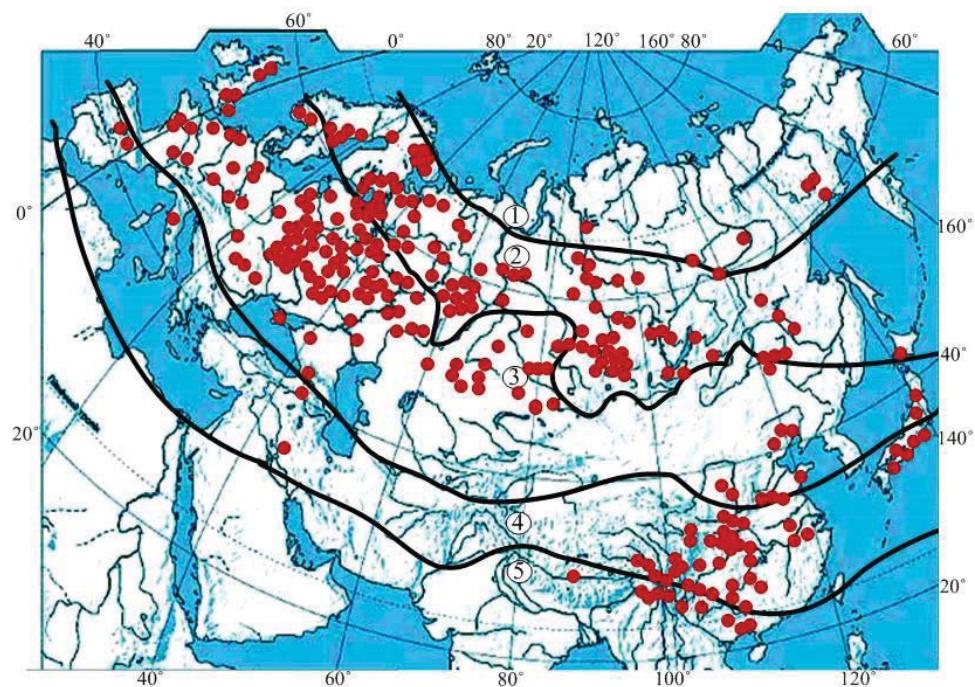


Figure 2. Allocation of sample plots having pine forest biomass (t/ha) according to zonal belts: 1 – subarctic, 2 – northern temperate, 3 – southern temperate, 4 – subtropical, 5 – subequatorial (Alisov & Poltarau, 1974; Bazilevich & Rodin, 1967)

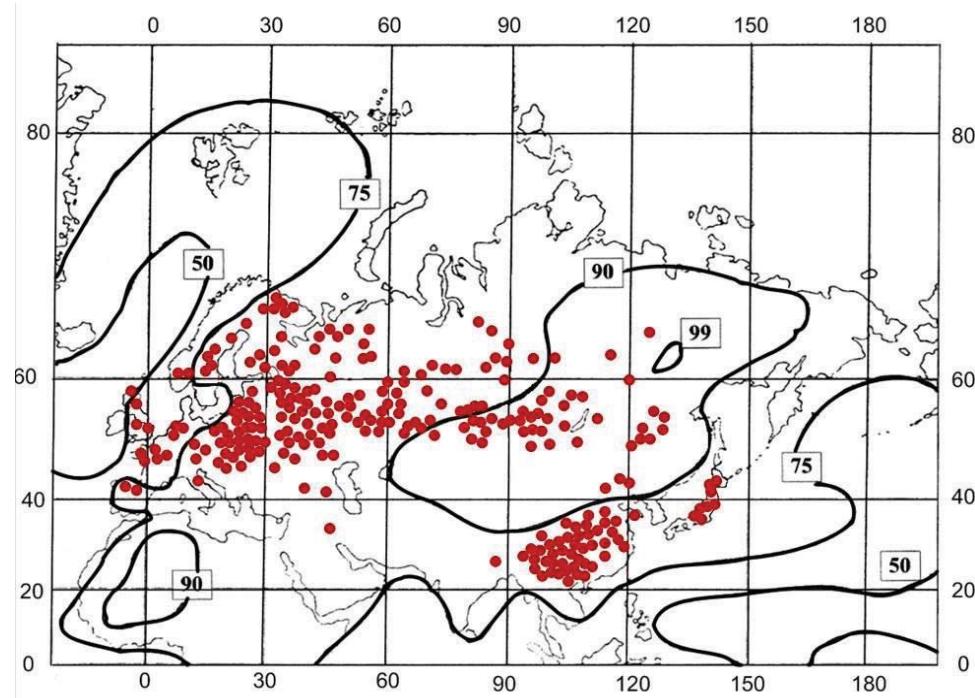


Figure 3. Isoline map of climate continentality of Eurasia (Khromov, 1957) with the situation of plots on which biomass of pine forests (t/ha) is estimated

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

where N – tree number, thousands of individuals per ha; A – forest age, yrs; M – stem volume, m^3 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_P , 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 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 with-

out 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;

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).

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

Dependent variables	Coefficients and independent variables					
	a_0	$a_1 (\ln A)$	$a_2 (\ln A)^2$	$a_3 (\ln N)$	$a_4 (\ln N)^2$	$a_5 (\ln M)$
$\ln(N)$	2.3672	-1.1322	-	-	-	-
$\ln(M)$	-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
$\ln(P_F)$	1.1499	-0.9942	0.0882	0.0414	-	0.8579
$\ln(P_R)$	-1.6828	0.9424	-0.0897	0.0875	-	0.6970
$\ln(P_A)$	2.9015	-0.2889	0.0389	-	-	0.7382
$\ln(P_T)$	2.6286	0.0553	-	0.0121	-	0.4854
$\ln(P_U)$	27.072	-2.2551	0.3356	-	-	-
$\ln(N)$	-	0.7326	-0.9818	0.6250	0.579	0.70
$\ln(M)$	-	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
$\ln(P_F)$	-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

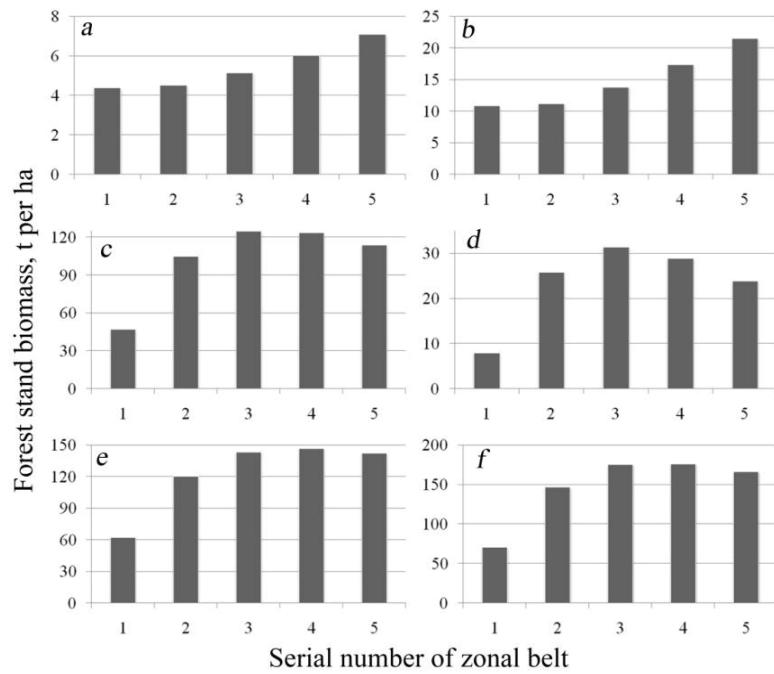


Figure 4. Dependence of the estimated biomass of needles (*a*), branches (*b*), stems (*c*), roots (*d*), aboveground (*e*) and total tree story (*f*) at the age of 100 years from the zonal affiliation of pine forests in continentality index equal 80%

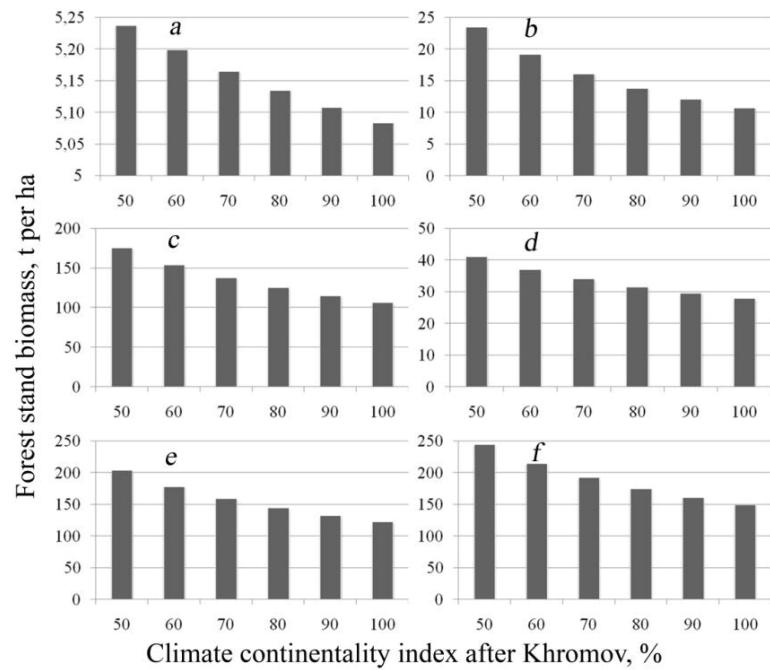


Figure 5. Dependence of the estimated biomass of needles (*a*), branches (*b*), stems (*c*), roots (*d*), aboveground (*e*) and total tree story (*f*) at the age of 100 years in the southern temperate climatic zone upon the continentality index after Khromov (1957)

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).

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 continen-

tality 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).

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

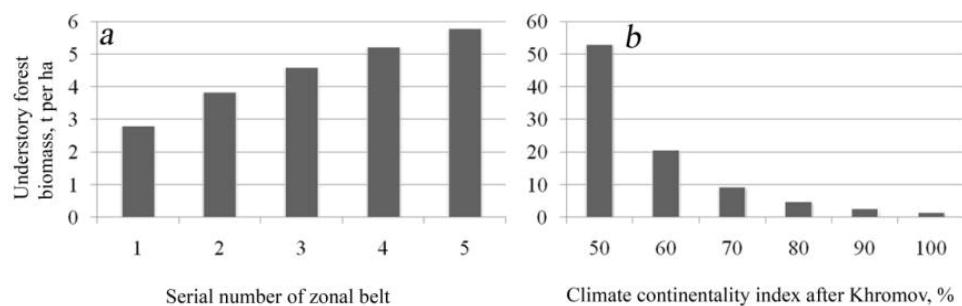


Figure 6. Dependence of calculated values of understory biomass at the stand age of 100 years upon the zonal affiliation of pine forests in continentality index equal 80% (a) and upon continentality index after Khromov (1957) in the southern temperate zonal belt (b)

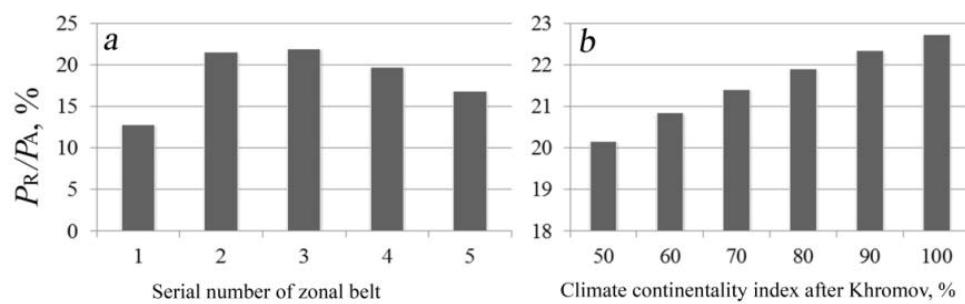


Figure 7. Dependence of P_R/P_A ratio of pine forests in the age of 100 years upon serial number of climatic zone in continentality index after Khromov (1957) equal to 80% (a) and upon climate continentality in the southern temperate zonal belt (b)

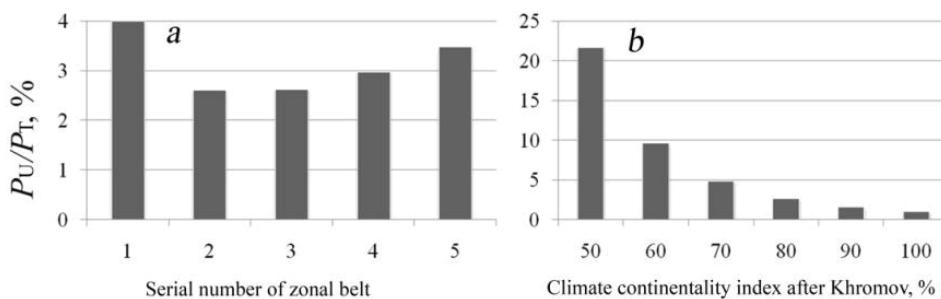


Figure 8. Dependence P_U/P_T ratio of pine forests in the age of 100 years upon serial number of climatic zone in continentality index after Khromov (1957) equal to 80% (a) and upon climate continentality in the southern temperate zonal belt (b)

subarctic and southern temperate zone from 12 to 22% and then decreases to 16% in the subtropical zone, and within the south 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. Later results of some authors devoted to zonal biomass and NPP changing were related to total values of biological productivity, without devising by species and without taxation indices accounting for (Anderson et al., 2006; Huston & Wolverton, 2009). The results obtained can be useful in the management of biosphere functions of forests, what is important when implementing activities on climate stabilization, as well as in the validation of the results of the simulations for assessing the carbon-depositing forest capacity. They also provide a preliminary indication of possible biases of forest biological productivity in connection with the shifts of latitudinal and meridional zoning under the influence of climate change.

Acknowledgements

We thank the anonymous referees for their useful suggestions. This paper is fulfilled according to the programs of current scientific research of the Ural Forest Engineering University and Botanical Garden of the Ural Branch of Russian Academy of Sciences.

References

Alisov B.P. & Poltarau B.V., 1974, Klimatologiya (Climatology). M.V. Lomonosov Moscow State University, Moscow: 1-300.

- Anderson K.J., Allen A.P., Gillooly J.F. & Brown J.H., 2006, Temperature-dependence of biomass accumulation rates during secondary succession. *Ecology Letters* 9: 673-682.
- Bazilevich N.I. & Rodin L.E., 1967, Schematic Maps of Productivity and Biological Turnover of Elements in the main Types of Land vegetation. *Izvestiya Vsesoyuznogo Geograficheskogo Obshchestva* 99(3): 190-194.
- Grigoriev A.A. & Budyko M.I., 1956, On the periodic law of geographical zoning. *Doklady Akademii Nauk SSSR* 110(1): 129-132.
- Huston M.A. & Wolverton S., 2009, The global distribution of net primary production: resolving the paradox. *Ecological Monographs* 79(3): 343-377.
- Khromov S.P., 1957, K voprosu o kontinental'nosti klimata (To a problem of climate continentality). *Izvestiya Vsesoyuznogo Geograficheskogo Obshchestva* 89(3): 221-225.
- Komarov V.L., 1921, Meridional'naya zonal'nost' organizmov (Meridional zonality of organisms), *Dnevnik I vserossiiskogo sezda russkikh botanikov v Petrograde* (Diary of the 1st All-Russian Congress of Russian botanists in Petrograd) 3: 27-28.
- Lavrenko E.M., Andreev V.N. & Leont'ev V.L., 1955, Profil' produktivnosti nadzemnoi chasti prirodnogo rastitel'nogo pokrova SSSR ot tundr k pustynym (Productivity profile of aboveground part of natural plant cover from tundras to deserts in the USSR). *Botanicheskiy Zhurnal* 40(3): 415-419.
- Lieth H., 1974, Modeling the Primary Productivity of the World. *Ekologiya* 2: 13-23.
- Lieth, H., 1974a, Modeling the primary productivity of the world. International Section for Ecol. Bulletin 4: 11-20.
- Lieth, H., 1974b, Modelling of the primary production of the Earth. *Soviet Journal of Ecology* 2: 13-23.
- Luyssaert S., Inglima I., Jung M., Richardson A.D., Reichstein M., Papale E. D., Piao S. L., Schulze E.-D., Wingate L., Matteucci G., Aragao L., Aubinet M., Beer C., Bernhofer C., Black K.G., Bonal D., Bonnefond J.-M.,

- Chambers J., Ciais P., Cook B., Davis K.J., Dolman A.J., Gielen B., Goulden M., Grace J., Granier A., Grelle A., Griffis T., Grünwald T., Guidolotti G., Hanson P.J., Harding R., Hollinger D.Y., Hutyra L.R., Kollari P., Kruijt B., Kutsch W., Lagergren F., Laurila T., Law B.E., LeMaire G., Lindroth A., Loustau D., Malhi Y., Mateus J., Migliavacca M., Misson L., Montagnani L., Moncrieff J., Moors E., Munger J.W., Nikinmaa E., Ollinger S.V., Pita G., Rebmann C., Roupsard O., Sangua N., Sanz M.J., Seufert G., Sierra C., Smith M.-L., Tang J., Valentini R., Vesala T. & Janssens I.A., 2007, CO₂ balance of boreal, temperate, and tropical forests derived from a global database. *Global Change Biology* 13: 2509-2537.
- Nazimova D.I., 1995, Climatic ordination of forest ecosystems as a basis of their classification. *Lesovedenie* 4: 63-73. (<https://geoscience.net/research/002/779/002779349.php>).
- Oleksyn J., Reich P.B., Chalupka W. & Tjoelker M.G., 1999, Different above- and belowground biomass accumulation of European *Pinus sylvestris* populations in a 12-year-old provenance experiment. *Scand. J. For. Res.* 14: 7-17.
- Rosenzweig M.L., 1968, Net primary productivity of terrestrial communities: Prediction from climatological data. *The American Naturalist* 102(923): 67-74. (<http://www.journals.uchicago.edu/doi/abs/10.1086/282523>).
- Shi F., Sasa K. & Koike T., 2010 Characteristics of larch forests in Daxingan mountains, Northeast China, [in:] A. Osawa, O.A. Zyryanova, Y. Matsuura, T. Kajimoto, R.W. Wein (eds.), *Permafrost Ecosystems: Siberian Larch Forests. Ecological Studies Vol. 209*. Springer, Dordrecht, Heidelberg, London, New York: 367-383.
- Tolmachev A.I., 1962, *Fundamentals of habitats: an introduction to plant horology*. State University Publishing Leningrad: 1-100.
- Usoltsev V.A., 2001, Forest biomass of Northern Eurasia: database and geography, Scientific issue. Ural Branch of Russian Academy of Sciences, Yekaterinburg: 1-708.
- Usoltsev V.A., 2007, Biological productivity of Northern Eurasia's forests: methods, datasets, applications. Ural Branch of Russian Academy of Sciences, Yekaterinburg: 1-637.
- Usoltsev V.A., 2010, Forest biomass and primary production database for Eurasia. Ural Branch of Russian Academy of Sciences, Yekaterinburg: 1-570. (<http://elar.usfeu.ru/handle/123456789/2606>).
- Usoltsev V.A., 2013a, Forest biomass and primary production database for Eurasia, CD-version. The second edition, enlarged and re-harmonized. Ural State Forest Engineering University, Yekaterinburg. (<http://elar.usfeu.ru/handle/123456789/3059>).
- Usoltsev V.A., 2013b, Geography of biological productivity of cedar pine ecosystems in Asia. *Eco-Potential* 1-2: 47-67. (<http://elar.usfeu.ru/handle/123456789/2716>).
- Usoltsev V.A., Chasovskikh V.P., Noritsina Y.V. & Kokh E.V., 2016, Methods and results of studying the geographical trends in the structure of single-tree biomass of larches and two-needed pines in Eurasia. *Russ. J. Ecol.* 47(5): 442-452.