

On some differences in the response of *Picea* spp. and *Abies* spp. single-tree biomass structure to changes in temperatures and precipitation in Eurasia

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Abstract Genera *Picea* spp. and *Abies* spp. grow together in most of the boreal zone, but it is still unknown whether there are differences in the response of their biomass structure to climate change. This article presents the first attempt to answer this question at the transcontinental level on a special case for these two genera. The research was carried out using the database compiled by the authors on the single-tree biomass structure for Eurasia, in particular, data of 666 and 359 sample trees for spruces and firs respectively. Multi-factor regression models are calculated after combining the matrix of initial data on the structure of tree biomass with the mean January temperature and mean annual precipitation, and their adequacy indices allow us to consider them reproducible. As a result of a comparative analyzing of the biomass structure of single-trees of two genera in the hydrothermal gradients of the territory of Eurasia, we cannot make a clear conclusion in favor of firs or spruces. When analyzing differences in the biomass trends of fir and spruce trees in relation to climate variables, it is stated that these differences are related only to changes in temperatures, but not in precipitation. The percentage excess of fir relative to spruce for all components of the biomass changes the sign from positive in cold regions to negative in warm ones. A number of uncertainties that arose during the modeling process, as well as the preliminary nature of the obtained regularities, are noted.

Keywords genera *Picea* spp. and *Abies* spp., tree biomass comparing, allometric models, mean January temperature, mean annual precipitation.

Introduction

Forest floor biomass is a key ecosystem component and an important part of the global carbon cycle. It plays a fundamental role in our knowledge of the carbon exchange between plant communities and the atmosphere in the face of anthropogenic climate shifts (Ni et al., 2001). Because climate violations affects the localization of natural areas, established during long-term evolution of vegetation (Emanuel et al., 1985; Kobak, Kondrasheva, 1992; Mäkipää et al., 2015; Kosanic et al., 2018; Roberts, 2019), this inevitably entails changes in plant cover productivity (Kobak, Kondrasheva, 1985; Dulamsuren et al., 2013; Bennett et al., 2015; Schaphoff et al., 2016; Fang et al., 2016; Duan et al., 2018), and accelerated dynamics of successions and dominated species in their course (Bolte et al., 2014). To forecast the impact of climate violations on forest area productivity, it is necessary to know the relations between forest biomass and climate indices (Stegen et al., 2011; Dymond et al., 2016). Today, climate-sensitive biomass models are being developed at the levels both forests stands (Manogaran, 1973; Lieth, 1974; DeLucia et al., 2000; Ni et al., 2001; Stegen et al., 2011; Fang et al., 2016), and single trees (Forrester et al., 2017; Zeng et al., 2017).

However, investigating relations between tree and stand bioproductivity and hydrothermal indices, in particular, temperature and rainfalls, are performed mainly at local or regional levels, often for indices that are depersonalized by age, forest structure, and also without taking into account species composition. How climate shifts affects the productivity of single-tree genera in continental gradients, and whether it affects, is not known today at all, because the available knowledge is sketchy and controversial.

Spruces and firs grow together in most of the boreal forests. Consequently, fir species, despite their almost universal distribution with spruce species have their own historical development characteristics and biological and ecological features. Fir is warm, water and nutrient dependent thereby its area limits goes southward while spruce area is limited to the north and usually lower – along the vertical profile in highlands. It forms a shrubby type of seed origin on the area altitude limits whereas on the latitude limits on the lowlands of European Russia, not being able to compete with spruce and moss formation it degrades and switches to vegetative reproduction shaping a layering form without cones. Fir has a deeper root system than spruce which makes it more wind resistant on lowlands and needs a better soil aeration. Unlike spruce, fir cannot exist next to excessively developed moss formation. It does not survive a stagnant moistening and is not generally attached to decaying windfall for reproduction (Usoltsev, 2019).

The response of these forests to climate change depends on individual characteristics of the resistance to climate change of each of the constituent species. However, these species-specific features are not sufficiently studied today. In Central Europe, Norway spruce (*Picea abies*) is a species with the most unpredictable response to a warmer and drier climate in the future, while silver fir (*Abies alba*) is likely to benefit from warming of climate if the frequency of climate extremes will be not excessive (Bošela et al., 2019). Raising of temperature of almost 2°C in Alaska over the past 50 years correlates with the substantial declines in white spruce tree growth (McGuire, 2010). Nevertheless, G. Rößiger et al. (2019) consider it unreasonable to simply extrapolate current changes in the state of spruce forests, as well as intensive renewal of fir, for the foreseeable future, since it is not known whether these trends are only related to climate shifts.

Recently, a comparative analysis of the accuracy and correctness of different methods for estimating the bio productivity of some tree species was fulfilled, and it was obtained that allometric equations designed at a tree scale give a smaller forecast error compared to models performed at a stand scale (Zeng et al., 2018). Such single-

tree allometric equations for mixed stands are particularly relevant. A climate-sensitive aboveground tree mass model led to higher forecast accuracy of tree mass than those without climatic variables for three larch

species (Fu et al., 2017). In the study of the sensitivity of the allometric equations for aboveground and root mass of larches in China to shifts in hydro- and thermal conditions, it was stated that raising average temperature by 1°C leads to increase in tree aboveground mass at 0.87% and reduce root one at 2.26 %, and raising average annual rainfalls by 100 mm causes a drop in aboveground and root mass at 1.52 and 1.09 % respectively (Zeng et al., 2017). In such studies, the task is to take off the climate signals from the residual dispersion of a dependence calculated. To made climatic factors to be predominant and "recoverable" from this "information noise", we need to involve in an equation, in addition to the diameter and height of a tree stem, also its age, which is a factor influencing structure of mass of a tree too (Nikitin, 1965; Kazaryan, 1966; Usoltsev, 1972; Tsel'niker, 1994; Vanninen et al., 1996; Bond-Lamberty et al., 2002; Genet et al., 2011; Fatemi et al., 2011; Ochał et al, 2013; Qiu et al., 2018), as well as climate sensitivity (Carrer&Urbinati, 2004; Yu et al., 2008).

We try first in our study to fulfil comparative analysis of changes in the biomass fraction structure of spruce (*Picea* spp.) and fir (*Abies* spp.) trees by Trans-Eurasian hydro- and thermal ranges on the base of allometry (more correctly, pseudo-allometry) using the unique Eurasian database of harvest tree biomass(Usoltsev, 2016). Since climate variables are geographically determined, it can be expected that the development of allometric biomass equations, including not only the stem age, height and diameter as independent variables, but also climate indices, will allow to isolate and quantify some violations in the structure biomass of equal-aged and equal-sized trees as related to climate indices and will provide climate-sensitivity of models designed (Forrester et al., 2017; Zeng et al., 2017; Fu et al., 2017).

Material and methods

From the biomass database, the data for the genera *Picea* spp. and *Abies* spp. in a number of 1025 trees, including 666 and 359 for spruces and firs respectively, were taken (Table 1). There were available only 180 definitions for root biomass.

Table 1. Distribution of the 1025 sample trees by species, countries, regions, and mensuration indices

| Regions | Species of the genera <i>Picea</i> spp. and <i>Abies</i> spp. | Ranges: | | | Data number |
|-------------------------------|--|-----------|----------|------------|----------------|
| | | ages, yrs | DBH, cm | heights, m | |
| <i>Picea</i> spp. | | | | | |
| West and Central Europa | <i>P.abies</i> (L.) Karst. | 10÷250 | 1.7÷67.6 | 2.1÷42.8 | 353 |
| The Ukraine and Belorussia | <i>P.abies</i> (L.) Karst. | 21÷66 | 5.7÷48.0 | 7.5÷32.0 | 75 |

| | | | | | |
|------------------|---------------------------------------|--------|----------|----------|-----|
| European Russia | <i>P.abies</i> (L.) Karst. | 18÷208 | 0.9÷51.5 | 1.7÷32.4 | 172 |
| Ural region | <i>P.obovata</i> L. | 28÷141 | 1.0÷37.9 | 1.4÷25.1 | 59 |
| Russian Far East | <i>Piceaajanensis</i> Fisch. ex Carr. | 63÷163 | 6.7÷30.7 | 5.8÷20.1 | 7 |
| Total | | | | | 666 |
| Abiesspp. | | | | | |
| Central Europa | <i>A. alba</i> Mill. | 51÷137 | 7.2÷38.3 | 9.5÷27.5 | 20 |
| The Ukraine | <i>A. alba</i> Mill. | 8÷94 | 1.4÷53.5 | 2.3÷30.6 | 193 |
| Ural region | <i>A.sibirica</i> L. | 20÷164 | 0.8÷45.3 | 1.6÷28.5 | 127 |
| Russian Far East | <i>A. nephrolepis</i> Maxim. | 56÷160 | 7.7÷31.7 | 5.3÷21.5 | 7 |
| Japan | <i>A.sachalinensis</i> Mast. | 20÷119 | 4.3÷52.0 | 4.5÷24.6 | 12 |
| | <i>A. veitchii</i> Lindl. | | | | |
| Total | | | | | 359 |

The joint analysis of different species of the same genus is caused by the impossibility of growing the same tree species throughout Eurasia, as a result of which their areas within the genus are confined to certain ecoregions. These are substitutive or vicariate species that arose in cases of geologically long-standing separation of a once-continuous area (Tolmachev, 1962) or as a result of climate-related morphogenesis (Chernyshev, 1974).

Each sample plot on which tree biomass estimating was made is positioned relatively to the isolines of the mean January temperature and relatively to the isolines of mean annual precipitation (Figs. 1 and 2). The use of evapotranspiration as a combined index in the assessment of tree production is futile, since it explains only 24% of its variability compared to 42%, which provides the relation to mean annual precipitation, and compared to 31%, which provides the relation to mean annual temperature (Ni et al., 2001). Therefore, the use of temperature and precipitation indices taken from World Weather Maps (2007) are preferable as of the most informative climatic factors.

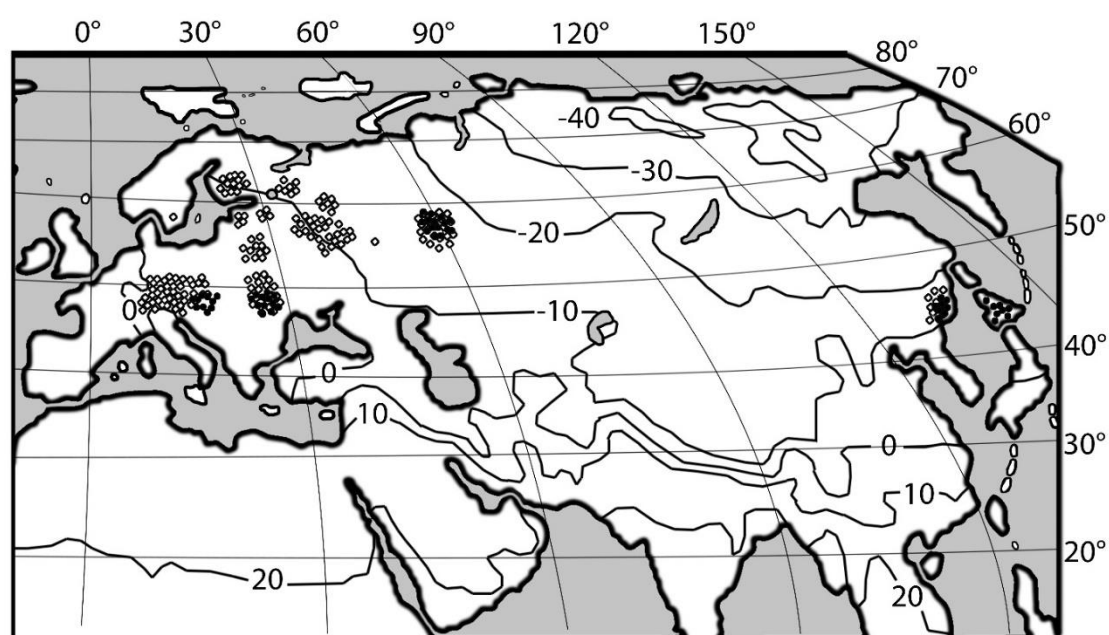


Figure 1. Distribution of sample plots, where 666 and 359 trees of spruces (squares) and firs (circles) correspondingly have been harvested, on the map of the mean January temperature, °C (World Weather Maps, 2007 https://store.mapsofworld.com/image/cache/data/map_2014/currents-and-temperature-jan-enlarge-900x700.jpg).

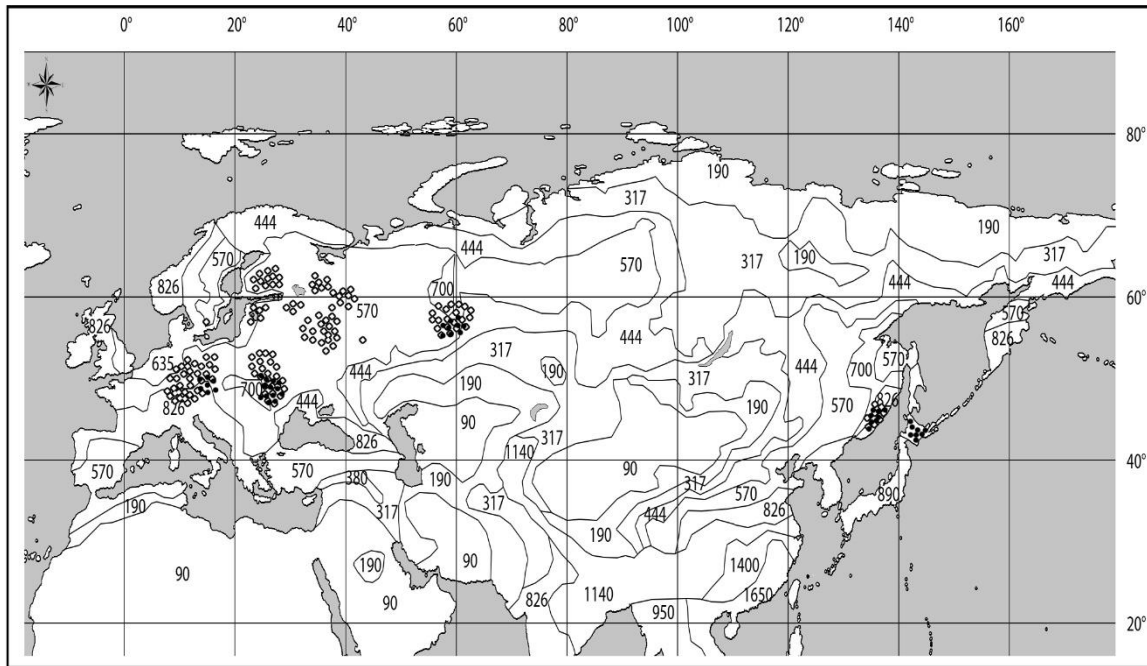


Figure 2. Distribution of sample plots, where 666 and 359 trees of spruces (squares) and firs (circles) correspondingly have been harvested, on the map of the mean annual precipitation, mm (World Weather Maps, 2007; <http://www.mapmost.com/world-precipitation-map/free-world-precipitation-map/>).

It was found that when estimating stem biomass growth by using the annual ring width, the greatest contribution to explaining its variability being made by summer temperature accounting for from 16% of the total dispersion (Berner et al., 2013) to 50% of the residual one (Bouriaud et al., 2005). Moreover, a specificity of the relationship between stand biomass the annual ring width depends on what intra-annual temperature was taken as a predictor (Bouriaud et al., 2005). It was established by Khan et al. (2019) that this relationship is positive with the maximum intra-annual temperature and negative with the minimum and average annual temperature. With an inter-annual time step, the predominant influence of summer temperature is quite normal. But against the background of long-term climatic shifts for decades, the prevailing influence is acquired by winter temperatures (Morley et al., 2017), because current temperatures have a greater limiting effect on growth in the North (Matala et al., 2006). Besides, it is well known that winter temperatures in the Northern hemisphere are increased faster than summer ones during the 20th century (Emanuel et al., 1985; Folland et al., 2001; Laing & Binyamin 2013; Felton et al. 2016).

The final structure of the equation includes only those mass-forming indices that are statistically significant for all biomass components, and it has the form:

$$\ln P_i = a_{0i} + a_{1i} (\ln A) + a_{2i} (\ln D) + a_{3i} (\ln H) + a_{4i} (\ln D)(\ln H) + a_{5i} B + a_{6i} B [\ln(T+40)] + a_{7i} B (\ln PR) + a_{8i} [\ln(T+40)] + a_{9i} (\ln PR) + a_{10i} [\ln(T+40)] \cdot (\ln PR), \quad (1)$$

where P_i is dry mass of i^{th} fraction, kg; A is age of a tree, yrs; D is diameter at breast height of a tree, cm; H is total height of a tree, m; i is the index of biomass fraction: stem over bark (P_s), foliage (P_f), branches (P_b) and aboveground (P_a); B is the binary variable coordinating the biomass data of spruces ($B = 1$) and firs ($B = 0$); T is average temperature of January, °C; PR is average annual rainfall, mm.

Along with the three main mass-forming variables - tree age A , diameter D and height H of a tree, the product $(\ln D)(\ln H)$ is introduced as an additional independent variable, due to the fact that as a tree height decreases, the height of the measurement of a stem diameter shifts to the stem apex, and the allometry is violated (Usoltsev et al., 2019). So we suggest to call this modified allometry as pseudo-allometry (because traditional allometry is not comply). Since the average temperature of January on the North of Eurasia has negative values, this independent variable is modified to be subjected to log-log procedure as $B+40$.

When we introduce only one binary variable B into equation (1), this means that the 3-D surface (temperature – precipitation – biomass) in X-Y-Z coordinates shifts along the Z (ordinate) axis by the value of the regression coefficient at the binary variable B . According to our assumption, the tree biomass of spruces and firs reacts differently to changes in temperature and rainfalls. In order to take these differences into account in the designed model, in (1), along with B , we introduce the synergisms $B[\ln(T+40)]$ and $B(\ln PR)$ as independent variables. If there is no statistical significance of the named synergism, the ratio of tree biomass in spruces and firs remains constant throughout the temperature and precipitation ranges, and in the case of its statistical significance, the named ratio of biomass changes according to these ranges.

Results and Discussion

The regression coefficients of the multiple regression equation (1) are calculated using the Statgraphics software (see <http://www.statgraphics.com/> for more information) and then are given in Table 2 after the correction for logarithmic transforming by Baskerville (1972) and anti-log transformation procedure. The synergism $B(\ln PR)$ as independent variable was not significant. The most of regression coefficients at numeric variables of equations (1) are characterized by the level of significance on 0.05 and better, and the resulting equations are adequate to the original values presented in the available database. Some regression coefficients that are significant at the level 0.10 were not excluded from the calculation of the equations in order to ensure consistency of the obtained patterns.

Table 2. Characteristics of regression model (1) calculated

| P_i | Regression model calculated | | | | | |
|-------|-----------------------------|---------------|--------------|---------------|---------------------|---------------|
| P_s | 1.404E-23 | $A^{0.0961}$ | D^{10607} | $H^{0.3313}$ | $D^{0.2614(\ln H)}$ | $e^{4.8406B}$ |
| P_f | 10.03E+3 | $A^{-0.361}$ | $D^{1.7093}$ | $H^{-0.9509}$ | $D^{0.2390(\ln H)}$ | $e^{3.0139B}$ |
| P_b | 1.18E+21 | $A^{-0.0795}$ | $D^{1.6259}$ | $H^{-0.9650}$ | $D^{0.2745(\ln H)}$ | $e^{1.1553B}$ |
| P_a | 9.63E-18 | $A^{0.0147}$ | $D^{1.1251}$ | $H^{-0.1484}$ | $D^{0.3015(\ln H)}$ | $e^{4.6809B}$ |

Table 1 continued

| P_i | Regression model calculated | | | | $adjR^2*$ | $SE*$ |
|-------|-----------------------------|---------------------|----------------|----------------------------|-----------|-------|
| P_s | $(T+40)^{-1.3803B}$ | $(T+40)^{13.7654}$ | $PR^{7.0694}$ | $(T+40)^{-1.9161(\ln PR)}$ | 0.988 | 1.23 |
| P_f | $(T+40)^{-0.9277B}$ | $(T+40)^{-2.4242}$ | $PR^{-1.7101}$ | $(T+40)^{0.4420(\ln PR)}$ | 0.894 | 1.57 |
| P_b | $(T+40)^{-0.3692B}$ | $(T+40)^{-15.5488}$ | $PR^{-7.2930}$ | $(T+40)^{2.2881(\ln PR)}$ | 0.875 | 1.72 |
| P_a | $(T+40)^{-1.3462B}$ | $(T+40)^{10.3407}$ | $PR^{5.3138}$ | $(T+40)^{-1.4141(\ln PR)}$ | 0.985 | 1.23 |

* The abbreviation $adjR^2$ is a coefficient of determination adjusted for the number of parameters; SE – equation standard error.

The results of tabulating the equations (1) represent a rather cumbersome table. We took from it the calculated data of biomass fractions for the age of 100 years, D equal to 20 cm and H equal to 18 m and built 3D-graphs of their dependence on temperature and rainfalls (Fig. 3).

Since the quantity of trees with measured root mass is 7 times less than the quantity of trees that have aboveground biomass, we risk getting fake patterns that logically contradict (do not correspond) to the patterns shown in Fig. 3. It is known that relative (dimensionless) indices are more unified than absolute values (T. Detlaf & A. Detlaf, 1982), and have genetically determined stability (Lyr et al., 1967). Therefore, we will try to use the regression method to explain the variability of the ratio of underground to aboveground biomass (R/S as root:shoot ratio). Initially, the structure of the model (1) is adopted for the analysis of the R/S ratio. But, as expected, a part of the regressors of the model (1) was not significant, and the equation (2) is finally obtained (see Table 2).

Table 3. Characteristics of regression model (2) calculated

| | Regression model calculated | | | | | | $adjR^2$ | SE |
|-------|-----------------------------|----------------|---------------------|----------------|--------------------|--------------------|----------|------|
| R/S | 24490 | $D^{-0.44167}$ | $D^{0.1449(\ln D)}$ | $e^{-4.8635B}$ | $(T+40)^{1.3922B}$ | $(T+40)^{-3.2982}$ | 0.418 | 1.38 |

Its graphical interpretation is shown in Fig. 4. Equation (2) is characterized by a fairly low coefficient of determination, since it is known that the closer the relationship between two factors, the less their relationship is explained by known determining factors (Usoltsev, 1985). However, the Student's criteria determining the significance of the coefficients of the model (2) are quite high and are 3.5, 5.4, 2.1, 2.1 and 5.1, which is more than 2.0. We can see that as we move from warm to cold zones, the R/S ratio for thin trees ($D = 8$ cm) increases from 0.12 to 0.47, and for thick trees ($D = 32$ cm) from 0.21 to 0.77, but in percentage terms it does not depend on the tree thickness and increases by 2.7 times.

When analyzing the 3D-surfaces shown in Fig. 3, we will distinguish two stages: in the first of them, we note the patterns common to trees in fir and spruce stands, and then, when considering in detail, we establish what and how the resulting patterns between fir and spruce trees differ.

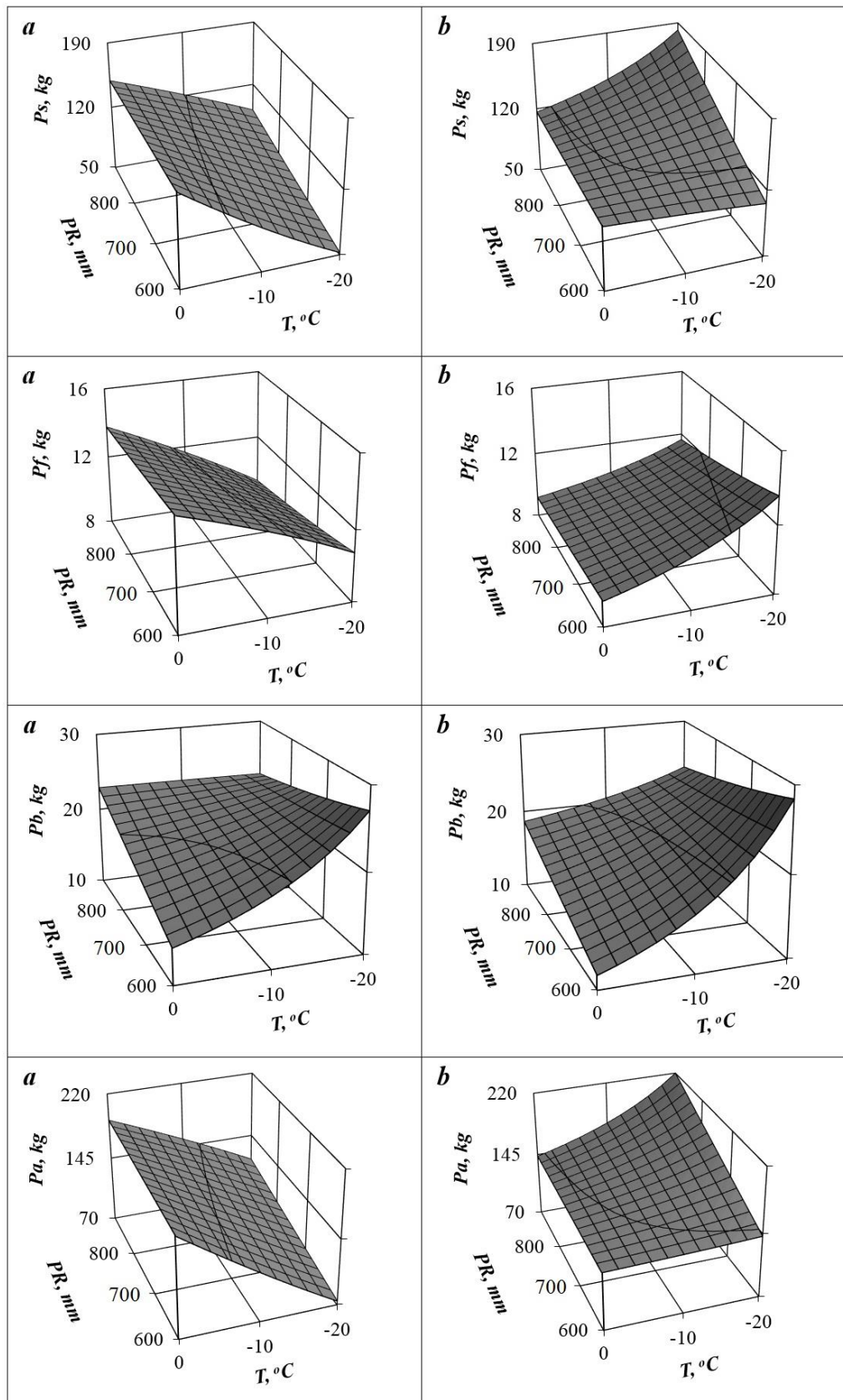


Figure 3. Dependence of single-tree biomass in fir (a) and spruce (b) upon the mean January temperature (T) and mean annual precipitation (PR). Designations: P_s , P_f , P_b and P_a are respectively dry biomass of stem, foliage, branches and aboveground, kg.

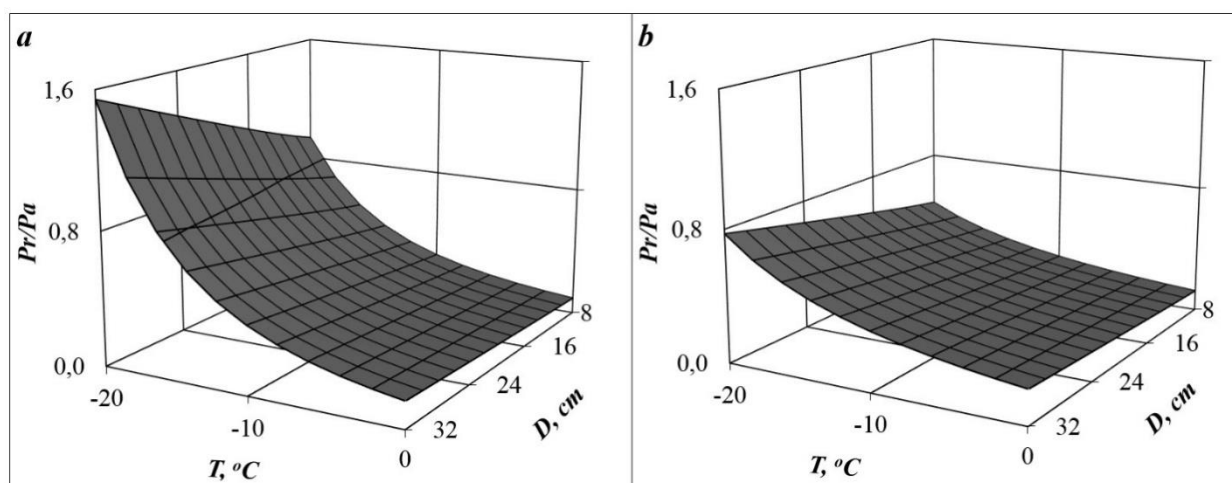


Fig. 4. Change of the theoretical R/S ratio of fir (a) and spruce (b) in relation to tree stem diameter under different mean January temperature (T).

With regard to stem and aboveground biomass, we can see that it increases with increasing precipitation in cold zones and stays without difference in warm ones, but as temperature rises, their trends differ significantly. As one moves from warm to cold zones, the mass of branches in both species increases, but only in areas of moderate moisture, and in areas of abundant moisture, this trend decreases in spruces and is leveled in firs. As one moves from warm zone to cold one, the mass of spruce and fir foliage changes in the opposite ways, and as the moisture level increases, it changes slightly in both species.

Turning to the analysis of differences in the biomass trends of fir and spruce trees according to the second stage, it should be noted that, judging by the structure of the calculated equation (1), these differences are related only to changes in temperatures, but not in precipitation, since the synergism $B \cdot (\ln PR)$ was not statistically significant. Changes in the excess percentage of different components biomass of fir trees above spruce ones due to changes in January temperature are shown in Table 3.

Table 4. Change in the excess percentage of different components biomass of fir trees above spruce ones due to changes in January temperature

| Biomass component | Mean January temperature, $^{\circ}C$ | | | | | | |
|-------------------|---------------------------------------|------|------|-------|-------|-------|-------|
| | -20 | -16 | -12 | -8 | -4 | 0 | 4 |
| Stems | 50.6 | 36.5 | 21.4 | 5.5 | -11.1 | 28.5 | -46.6 |
| Foliage | 20.9 | 6.3 | -8.1 | -22.3 | -36.4 | -50.4 | -64.3 |
| Branches | 4.8 | -1.8 | -7.8 | -13.2 | -18.2 | -22.9 | -27.3 |
| Aboveground | 47.7 | 33.1 | 17.7 | 1.5 | -15.4 | -33.0 | -51.2 |

We can see that the percentage excess of fir relative to spruce for all components of the biomass changes the sign from positive in cold regions to negative in warm ones. This excess is equal to zero, i.e. the biomass of firs and spruces is the same, at an average winter temperature of about $-10^{\circ}C$, which corresponds to the territory of European Russia.

The most interesting question is how much the structure of forest biomass will change with an assumed temperature deviation, for example, by $1^{\circ}C$ and with a deviation of precipitation from the usual norm, for example, by 100 mm per year. The constructed model gives the answer to such question in relation to forest trees. To do

this, we take the first derivative of our 3-dimensional surfaces (Fig. 3), and not analytically, but graphically, i.e. we take off the biomass difference interval (Δ , %) corresponding to temperature interval 1°C and precipitation interval 100 mm directly from the graphs or from the corresponding tables, and get the answer in the form of three-dimensional surfaces divided into plus and minus areas that correspond to the increase or decrease in the biomass of trees having the age of 100 years, *DBH* equal to 20 cm and *H* equal to 18 m. (Figs. 5 and 6).

In this case, the differences between the biomass of fir and spruce trees become more obvious (Figs. 5 and 6). If the stem, foliage and aboveground biomass of fir trees increases when the temperature grows by 1°C (the entire 3D surface is located above the zero plane), then branches biomass in the same conditions decreases (located below the zero plane). Opposite these regularities, almost all biomass components in spruces decrease in the same conditions (located below the zero plane) (Fig. 5).

When the rainfalls grow by 100 mm at the same initial regional values of temperature and precipitation, between fir and spruce biomass there is no differences. In the total range from 600 to 800 mm, aboveground and stem, as well as partly branches biomass increase (the entire 3D surface is located above the zero plane), but foliage biomass decreases (located below the zero plane) (Fig. 6).

Regardless of the stem diameter and the level of precipitation in thermal zones in the range from 0 to -20°C , when the temperature is expected to increase by 1°C , the R/S ratio decreases, and most strongly in fir (Fig. 7).

Besides, we have some uncertainties related to obtained regularities.

1) The patterns of biomass amount change under assumed changed climatic conditions (Fig. 5 and 6) are hypothetical. They reflect long-term adaptive responses of forest stands to regional climatic conditions and do not take into account rapid trends of current environmental changes, which place serious constraints on the ability of forests to adapt to new climatic conditions (Givnish, 2002; Alcamo et al., 2007; Berner et al., 2013; Schaphoff et al., 2016; Spathelf et al., 2018; Vasseur et al., 2018; DeLeo et al., 2019; Denney & Anderson, 2019; Sperry et al., 2019). The law of limiting factors (Liebig, 1840; Shelford, 1913) works well in stationary conditions. With a rapid change in limiting factors (such as air temperature or precipitation), forest ecosystems are in a transitional (non-stationary) state, in which some factors that were still not significant may come to the fore, and the end result may be determined by other limiting factors (Odum, 1975).

2) In equations (1), three mass-determining factors (*A*, *D*, and *H*) take upon himself the main share of the explained variance: for the masses of stems, foliage, branches, and aboveground 72, 91, 85, and 74 %, respectively. Climate variables and differences between fir and spruce trees account for only 9 to 28% of the variability. The structure of these "residual" variables is highly variable and heterogeneous. In addition to the uneven filling the initial data matrix (Figs. 1 and 2), there are discrepancies between the age periods of mapping and calendar ages of different biomass components, between the large step of temperature and precipitation isolines on the maps and local topography features, as well as local soil differences, despite the fact that the soil zoning reflects the action of climatic factors (Dokuchaev, 1948; Rukhovich et al., 2019).

Taking into account the stated methodological and conceptual uncertainties, the results presented in this study provide a solution to the problem only in the first approximation and should be considered as preliminary ones and having not so much factual as methodological significance. They can be modified if the biomass database will be enlarged by additional data, mainly site-specific and stand-specific characteristics as well as by more advanced and correct methodologies.

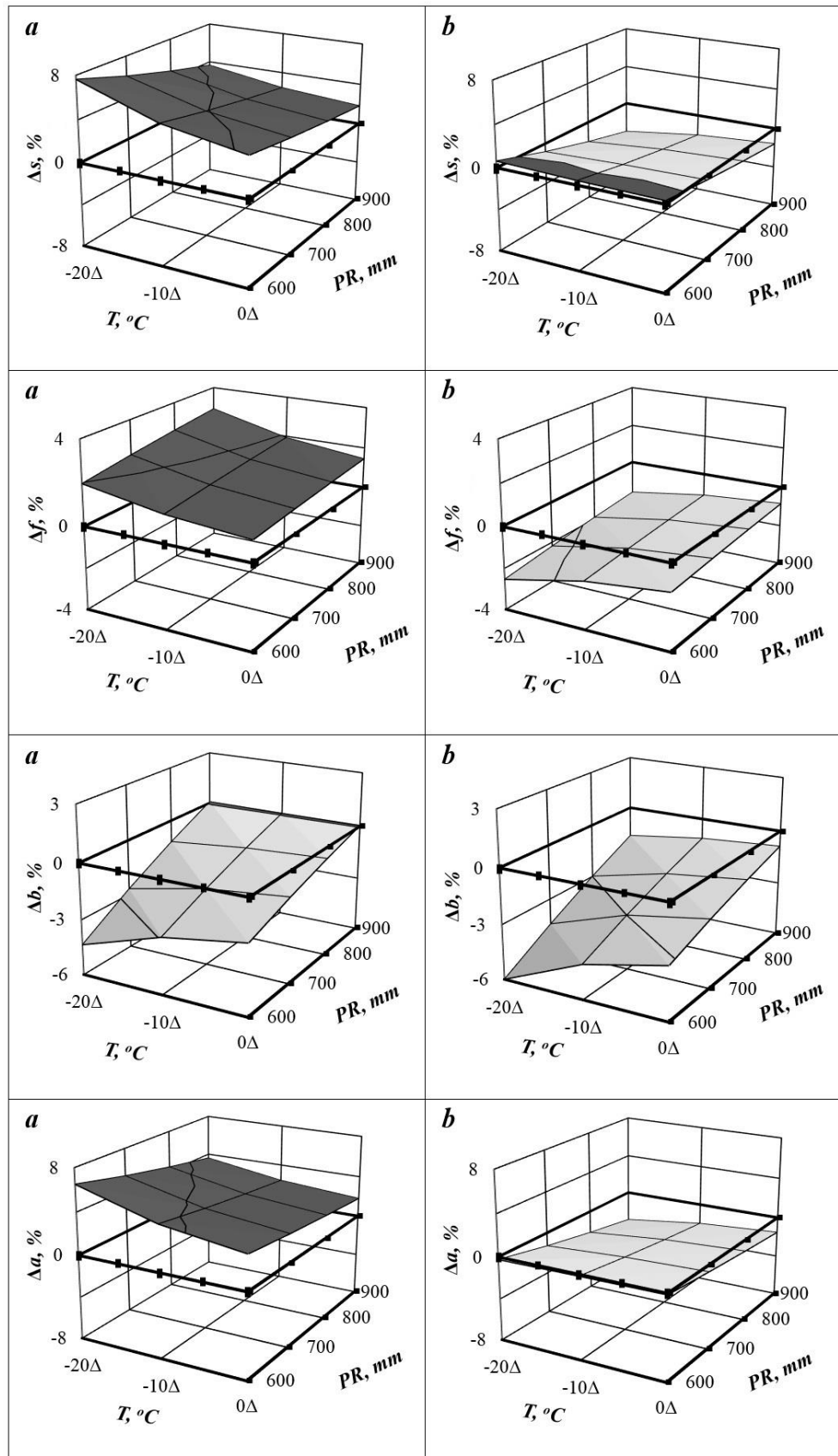


Fig. 5. Change of tree biomass in firs (a) and spruces (b) when temperature assumes to be increase by 1 °C due to the expected climate change at different territorial levels of temperature and precipitation. Symbols Δs , Δf , Δb and Δa on the ordinate axes mean the change (\pm %) of biomass of stems, foliage, branches and aboveground, respectively, with the temperature increase by 1 °C and at the constant precipitation.

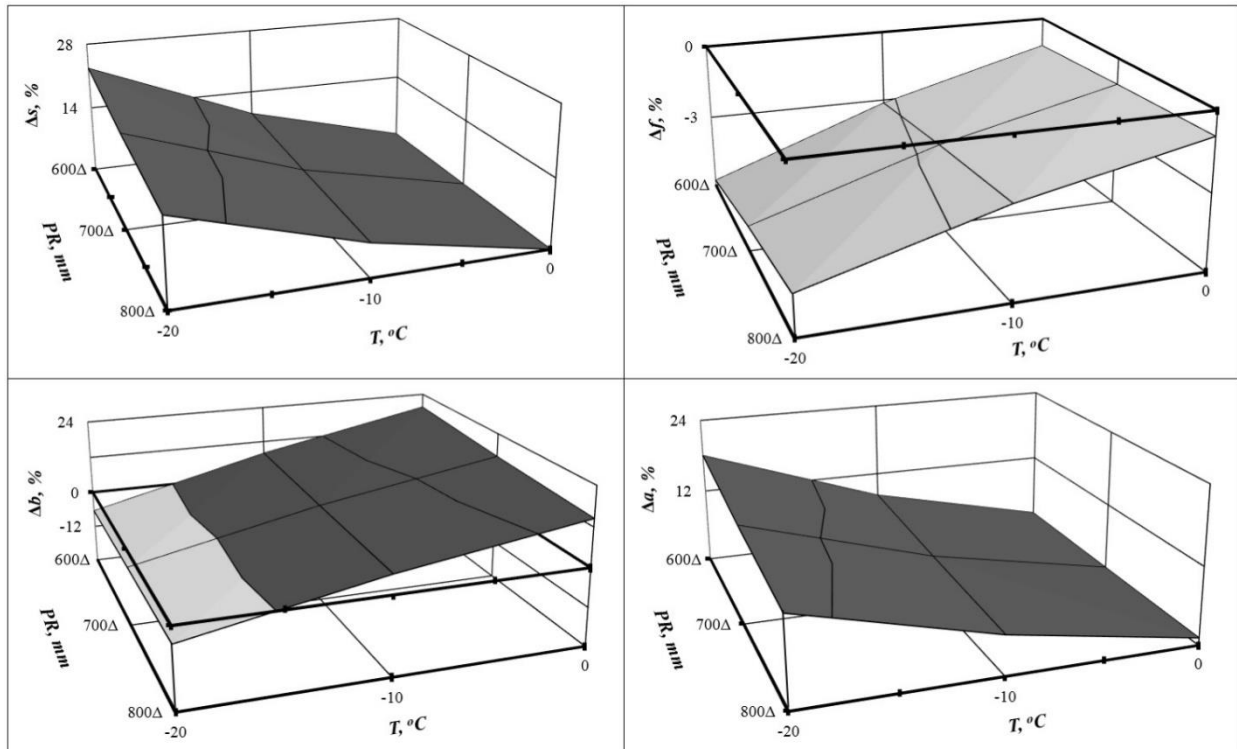


Fig. 6. Change of tree biomass in firs (a) and spruces (b) when precipitation assumes to be increase by 100 mm due to the expected climate change at different territorial levels of temperature and precipitation. The symbols Δs , Δf , Δb and Δa along the ordinate axes represent the change (\pm %) of biomass of stems, foliage, branches and aboveground, respectively, with precipitation increase by 100 mm and at the constant mean temperatures of January.

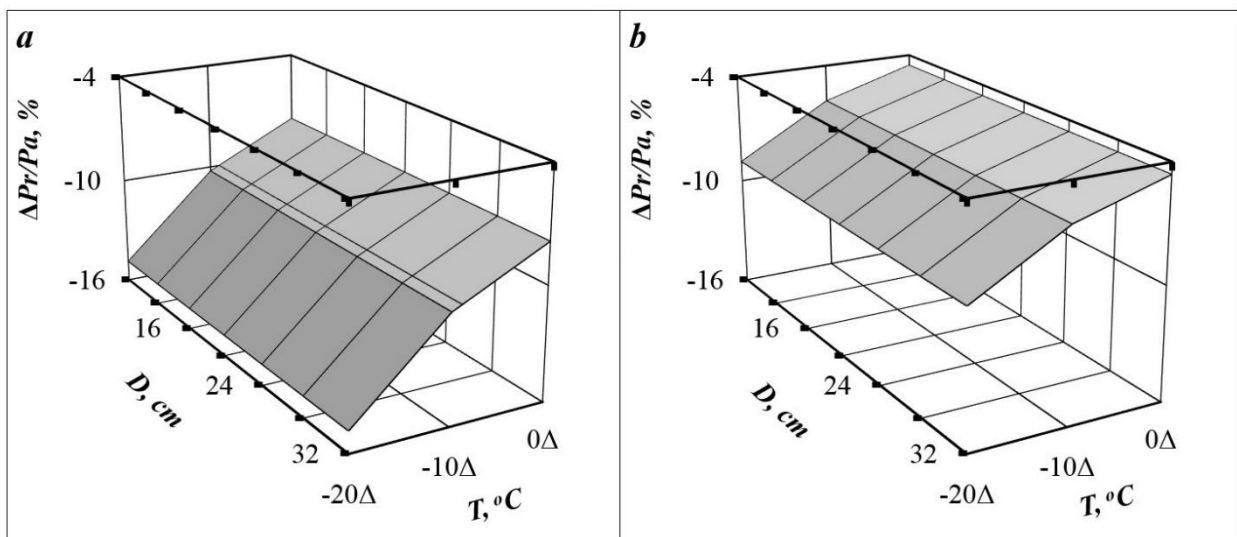


Fig. 7. Change of R/S ratio in firs (a) and spruces (b) when temperature assumes to be increase by 1 °C due to the expected climate change at different territorial levels of temperature.

Conclusions

1. 1 As a result of a comparative study of the biomass structure of single-trees of genera *Picea* spp. and *Abies* spp. in the hydrothermal gradients of the territory of Eurasia, we cannot make a clear conclusion in favor of firs or spruces.
2. 2 When analyzing differences in the biomass trends of fir and spruce trees in relation to climate variables, it is stated that these differences are related only to changes in temperatures, but not in precipitation.
3. 3 It is found that stem and aboveground biomass of equal-sized and equal-aged spruce and fir trees increases with increasing precipitation in cold zones and stays without visible difference in warm ones, but as temperature rises, their trends differ significantly.
4. 4 With moving from warm to cold zones, the mass of branches in both species increases, but only in areas of moderate moisture, and in areas of abundant moisture, this trend decreases in spruces and is leveled in firs.
5. 5 As one moves from warm zone to cold one, the mass of spruce and fir foliage changes in the opposite ways, and as the moisture level increases, it changes very slightly in both species.
6. 6 The percentage excess of fir relative to spruce for all components of the biomass changes the sign from positive in cold regions to negative in warm ones.
7. 7 Regardless of the level of precipitation in thermal zones in the range from 0 to -20°C, when the winter temperature is expected to increase by 1°C, the R/S ratio decreases, and most strongly in fir.
8. 8 The results presented can be accounted for as the first approximation only.

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