Spatial organization of forest fund

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Abstract. In the process of forest management in a particular constituent entity of the Russian Federation, unique regional features have formed that increase the effectiveness of forest management, the multi-purpose use of forests, their conservation, protection and reproduction, due to landscape-geographical and economic reasons. The aim of the research is to analyze the prevailing spatial forest land division by example of the Tomsk region. Scientific novelty lies in the development of methodological approaches to identify the spatial forest land organization. The object of our study is the Tomsk Region forest fund lands, divided into districts, forestries and district forestries according to the principle of three-level hierarchical division. The subject of the study is the spatial characteristics of 75 local forest districts located in 26 forest districts and in 17 administrative districts of the Tomsk Region. A set of methods is applied in our research, such as: abstract-logical, analytical, cartographic and mathematical modeling. In the course of the statistical analysis it is concluded, a hierarchical structure of the territorial division of the forest fund lands has been revealed according to the principles of MAUP. It is shown that the hierarchical levels of forest management overlap, breaking the General pattern.

1. Introduction
A set of scientific studies is considered in the European Union within the framework of the international program ESPON 2020 [1]. The studies are caused by the problem of variable scale (modifiable areal unit problem – MAUP). In particular, the related comparative analysis of territorial management systems and spatial planning in Europe is also examined.

Forest planning is the basis of forest developing [2], their protection [3-5] and evaluation [6]. Preservation, renewal, increasing of productivity and use of forests are taken into account during its implementation. Features of their structure and forest conditions; assessment of the natural-ecological, social and economic significance of forests; affordability; prospects for possible development while maintaining continuity of use [7] are also estimated.

At the beginning of the 20th century, due to the nature of spatial division of territories and the scope of the study [8] the problem of data aggregation was equationed [9]. It was established that, depending on the unit of scale and the form of division of the territory, the arithmetic mean and mean
square values are changing. The nature of the territory division into spatial units depends on the scale, which is called characteristic. The shape of the plots, their areal sizes affect the statistical reporting of forestries.

The spatial correspondence of the two levels of the hierarchical organization of the forest fund only are considered in this study. These are local forest districts (level 1) that make up the territory of the forestry (level 2). It is expected that the area of forest plots depends on the value of the scale unit according to the power law, and the coefficient under its logarithm of the function reflects the range of change in the scale dimension.

Organization of the successful use of the forest complex is possible only in the forest inventory territory. It involves land surveying for individual economic units (forestry, local forestry and quarters), taking into account all the existing and planned objects of the forest and processing industry. The spatial organization of the territory is determined in a view of the forests' distribution by planned development zones, and use and intensity of development by type as forests belong to a certain land plot, so by establishing planned forest development zones, the purpose of the territories there have been determined. The basic principles of spatial planning of the forest territory are regulated by the Forest inventory instruction [10]. The hierarchical division of the forest fund lands is determining the normal size of the forest block, the approximate size of the average forest taxation stand, etc. It should be built taking into account a set of organizational and technical indicators, such as the minimum area of natural forest stands, mature forest among young trees, not covered by forest lands; the presence of roads, clearings, hayfields, power lines and other non-forest lands, as well as unused lands. All these indicators reflect the fragmentation of forest areas, reducing their resistance to the effects of climatic and anthropogenic factors.

At the same time, in the process of forest management in a particular constituent entity of the Russian Federation, unique regional features have formed that increase the effectiveness of forest management, the multi-purpose use of forests, their conservation, protection and reproduction, due to landscape-geographical and economic reasons.

**The aim** of the research is to analyze the prevailing spatial forest land division by example of the Tomsk region.

**Scientific novelty** lies in the development of methodological approaches to identify the spatial forest land organization.

2. Methods and Materials
The object of our study is the Tomsk Region forest fund lands (figure 1), divided into districts, forestries and district forestries according to the principle of three-level hierarchical division.

The subject of the study is the spatial characteristics of 75 local forest districts located in 26 forest districts and in 17 administrative districts of the Tomsk Region.

Data from the website of the Department of Forestry of the Tomsk region [11] are used as the source material. A set of methods is applied in our research, such as: abstract-logical, analytical, cartographic and mathematical modeling. Using the Statistics software package, the probability of the random nature of the territorial division of forestry areas located in the Tomsk region the zero-hypothesis was verified.

The legitimacy analysis of such territory division of the and the ratio of hierarchical levels, depending on the scale [12] is conducted.

3. Results and Discussion
A preliminary analysis of the sizes, shape and geographic location of forestries (figure 1) shows that the Ob River is the axis of symmetry with respect to the shape of the stands. With the advancement to the north-west, west and east of the regional center (Tomsk), the sizes of forest districts are increasing, and the form is stretching.
Figure 1. A map of the Tomsk region with the boundaries of forestries and the forest fund lands [13].

Based on general theoretical considerations, factors that affect on the size of forestries are:

- the remoteness of the territories from the regional administrative center – the closer to the center (the city – Tomsk), the more fractional the forest area division, the more forest areas and their smaller area; and vice versa,
- the degree of knowledge of the forests' taxation characteristics – so the northern territories, for example, Vasyugan and Aleksandrovsk forestry, having a sufficiently large area, are divided into only 1-2 sites, due to the swampiness and inaccessibility of the territory,
- geographical factor - the northern territories, having a sufficiently large area, are divided into 1-2 sites only,
- the geometrical factor caused by the change in the scale measure explains the geometrical changes in the size of the area, both forestries and the local forestries included in them, by the scale unit change of the studied territories.

In the course of the statistical analysis, a hierarchical structure of the territorial division of the forest fund lands has been revealed (table 1). Some of forest's territories belong to the same administrative region, or occupy several territories at once. There are forestries with large number of regions (Kargasoksk, Verkhneletsk and Timiryazevsk) and large forestries with one or two sites (Vasyugan, Zyryansk, Aleksandrovsk and Tomsk). In a whole, the forestry in the Tomsk Region local areas vary within 282-2,332,087 ha.

Single-factor dispersive analysis of variance of areas has showed a low probability of zero hypothesis, less than 1%. An alternative hypothesis that the distribution of areas in forestry areas is not accidental, but is due to the human factor has been checked. The desirability profile constructed at the next stage of the study revealed a critical value of the average area equal to 71,255 ha, to which the plots correspondence with a probability of 63% is.
Table 1. Spatial division of forest lands in the Tomsk region.

| Administrative district | Forestry     | Local Forestry | Total area, ha |
|-------------------------|--------------|----------------|----------------|
| Alexandrovsky           | Alexandrovsky| Strezhovskiy   | 2 332 087      |
| Kargasoksky             | Vasyugansky  | Vasyugansky    | 2 983 376      |
| Verkhneletsy            | Verkhneletsy | Kataiginsky    | 676 175        |
|                         |              | Maksimoyarski  | 523 972        |
|                         |              | Klyukvinski    | 286 376        |
|                         |              | Druzhninsky    | 891 171        |
|                         |              | Lisitsinsky    | 1 316 889      |
|                         |              | Beloyarsky     | 331 660        |
|                         |              | Yagodninsk     | 278 958        |
| Zyryansky               | Zyryansky    | Okuneevskiy    | 140 529        |
|                         | Kargasoksky  | Cherdatsky     | 66 739         |
| Kargasoksky             | Kargasoksky  | Bolshegrivskiy | 247 639        |
|                         |              | Verkhne-Tymsk  | 2 325 120      |
|                         |              | Kargasoksky    | 718 345        |
|                         |              | Nyurolskyski   | 582 993        |
|                         |              | Tevrizsky      | 602 716        |
|                         |              | Tymsk          | 270 166        |
|                         |              | Chizhapsky     | 675 818        |
| Molchanovsky            | Asinovsk     | Baturinski     | 27 994         |
|                         | Krasnoyarsky | Baturinski     | 27 994         |
|                         | Asinovsk     | Baturinski     | 27 994         |
|                         | Molchanovsk  | Molchanovsk    | 136 279        |
|                         |              | Sulzatksk      | 130 703        |
|                         |              | Suiginsky      | 162 503        |
|                         |              | Eltyrevsk      | 728 578        |
|                         |              | Shudelsk       | 533 660        |
|                         | Ulu-Yulsks   | Ulu-Yulsks     | 60 650         |
| Tomsk                   | Kornilovsk   | Tomsk-Ob       | 45 962         |
|                         | Egorovsk     | 124 778        |
|                         | Prikulsk     | 58 401         |
|                         | North-Altays | 72 779         |
|                         | Kornilovsk   | 54 355         |
|                         | Krasnoyarsk  | 58 099         |
|                         | Moryakovsk   | 38 364         |
|                         | Bogorodsky   | 29 752         |
|                         | Temerchinski | 79 798         |
|                         | Kaltaysky    | 96 595         |
|                         | Bogashrevsk  | 34 381         |
|                         | Mezhnenovsky | 19 230         |
| Shegarsky               | Shegarsko    | Shegarsky      | 124 903        |
|                         | Ilovsy       | 184 986        |
The estimated volume of wood withdrawal in forestry was studied as a factor taken into account when dividing the territory. The corresponding histograms showed the heterogeneity of the distribution over all the studied parameters (figure 2).

Figure 2. Distribution of the various indicators occurrence frequency in the Tomsk region forestries.

The allocation of the total forest area among forestries differs from the normal one. The general average value of the total forest area is 175 000 ha. There are “dips” and “tails”. According to all indicators, the forest area of the Kargasoksk forestry is significantly “knocked out” (total area, area of hardwood and coniferous forests, stocks of merchantable wood), that proves the randomness of the territory breaking up once again.

The main forest area in forestry doesn’t exceed 15 000 ha. The general average value of the coniferous forests’ area in forestries is 6,000 ha, and hardwood – 11 000 ha. The main area of coniferous forests in forestries is concentrated in the range of 0-8000 ha, and deciduous in the ranges of 4 000-10 000 ha and 16 000-20 000 ha. The frequency distribution of the stock of merchantable wood is also heterogeneous. It should be noted that the stock of merchantable wood means the
predominant part of the total stock of planting wood, equal to the volume of all stored up forest products minus waste (bark of the main part of trunks, tree tops);

The Tomsk Region forestromies are characterized by a total stock of merchantable wood, ranging from 0-1000 thousand m$^3$ and 1 500-2 000 thousand m$^3$, which is due to the spatial division of the territory. The general average value of the stock of coniferous forests’ merchantable wood in forestromies is 600 thousand m$^3$, and the reserves of deciduous forests’ wood in forestry 1 100 thousand m$^3$.

The total forest area in forestromies is distributed unevenly. The distribution is close to the lognormal model. The largest number of areas is in the range from 0 to 15 thousand ha. Large areas of more than 30 thousand ha are very rare. The fragmentation of coniferous forests is high. The modal size of the plot is 2 thousand to 4 thousand ha. Large tracts of forest are quite rare. The hardwood forests’ area has a poly modal appearance and is divided into 3 parts: from 0 to 2 thousand ha, from 4 thousand ha to 120 thousand ha, from 14 thousand ha to 20 thousand ha. This indicates that there are small groves, medium-sized tracts and large forests. One forest massif can be attributed to a very large one (more than 32 thousand ha).

The total stock of merchantable wood is concentrated in the range from 0 to 2 000 m$^3$. The modal value ranges from 1 500 m$^3$ to 2 000 m$^3$. An interval of 3 000 m$^3$– 3 500 m$^3$ is noted. Very high wood reserves of 5500 m$^3$ are present in individual cases. The stock of coniferous forests’ merchantable wood, as well as the coniferous forests’ area, is pressed to the origin, which indicates low value stocks of these forests. The maximum reaches at values of 2000 m$^3$ - 2200 m$^3$. The stock of merchantable wood in deciduous forests is such, as in the case of polymodal areas. A modal interval with a very low reserve of 200-400 m$^3$ is distinguished, and they do not exceed 1600 m$^3$. There are rare cases of an average reserve of 2000 m$^3$ to 3600 m$^3$.

The dependence of the area on the ordinal number of the forest area and the district forest area in their ordered sequences is studied. The resulting graph of the exponential function is converted to linear form by logarithmizing the area of the plot (\(\text{Lg}(S)\)). The result is an almost linear relationship (figure 3), showing changes in the relative sizes of sections. It is noted that for neighboring hierarchical levels, the graphs differ in the slope of the straight line: at the hierarchical level of forest areas, it is -0.07, and at the level of precinct forest areas -0.04. Moreover, at the hierarchical level of forest areas, 4 plots are close to the area of local forest areas. There is an intersection of hierarchical levels of organization of the spatial structure, expressed by a sharp change in the natural course of the graph. In our opinion, this contradicts the expected distribution and indicates a certain voluntarism in the division of territory. The explanation of the total forestry area lognormal distribution is explained by the logarithmic dependence of the allocation area on the serial number of the allotment when sorting them in descending order. It has been established that the squares of forest areas (\(S\)) in general obey tosome logarithmic relationship (figure 3 (a)).

The coefficient of determination (\(R^2\)) of dependencies has a value greater than 0.9.

According to the dependence slope, there are distinguished large and medium forest areas:

\[
\text{Lg}(S) = -0.0783(x) + 6.75, \quad (1)
\]

where, \(x\) is the serial number of the allotment in the descending order of the forestry area.

Four small forestromies with a steeper slope of the model line relative to (1) are got out of the general pattern:

\[
\text{Lg}(S) = -0.6402(x) + 18.398 \quad (2)
\]

designations— see equation (1).

The slope of the line is determined by the coefficient of the logarithm, which is differed by an order of magnitude. The reason for such difference is that small one become comparable in size to the local forest districts into which the forestry area has been divided.
Figure 3. General patterns of reducing the logarithm of the area ($Lg(S)$) forestry, depending on the serial number, ordered sequence in descending order: (a) – forestry, (b) – district forestry.

The coefficient of determination ($R^2$) of dependencies has a value greater than 0.9. Kargasoksk (5 630 065 hectares) and Verkhneketkskoye (4 305 201 hectares) can be distinguished as the largest forestry areas. Forestry areas of very small sizes are: Krivosheinsk (58 100 ha), Tomsky (27 500 ha), Timiryazevsk (9 900 ha), Shegarsk (600 ha). They are less than the median area value of district forestries 140 529 ha, and have a different dimension. There have been selected 43 district forestries area distribution randomly to find out the patterns of regularity. When they are ordered by area, the following equation is obtained:

$$Lg(s) = -0.0461 + 6.26$$

Comparing equations (1) and (3), it can be seen that the tilt angle is straight for the local forestry and it is almost 2 times smaller than that one of forestries. Consequently, four very small forestry units
having regularity (3) do not fall under the natural form of dependence (2) following from the MAUP theory. Apparently, such a clear hierarchical violation of spatial division during the allocation of small forestries is explained by the economic reason (the high cost of wood).

4. Conclusion
Thus, the study identified factors affecting the degree of the territory segmentation; the maximum, minimum and average values of the forestry's area are determined; a mathematical model has been developed showing that the division of Tomsk Region forest fund into forestries is submitted to a simple logarithmic dependence in accordance with the MAUP rules. The graphs of their distribution differ depending on the group of sites according to their size (large and medium, small). The smallest four sites do not be in coherence with the geometric factor, then economic reasons can be assumed: the more valuable forest then higher the demand for timber, the more fragmented the quarterly network, then more often the division into forestry areas.

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References
[1] Applied Research Projects, available at: https://www.espon.eu/applied-research
[2] Kovyazin V F, Romanchikov A Ju and Pasko O A 2015 Comparative analysis of forest landcadstral appraisal estimated with regards to wood and food resources IOP Conference Series: Earth and Environmental Science DOI: 10.1088/1755-1315/27/1/012039
[3] Kovyazin V F and Pasko O A 2019 Why are forests burning in Russia? Bulletin of MANEB vol 24 chapter 2 pp 23-29
[4] Pasko O A, Kovyazin V F and Lebedeva N A 2020 Influence of Environmental Conditions on the Susceptibility of the Territories to the Occurrence of Forest Fires: Forest Fire Danger Predicting, Monitoring, and Assessing Forest Fire Dangers and Risks 13 pp 294-320 DOI: 10.4018/978-1-7998-1867-0.ch013
[5] Pasko O A, Kovyazin V F and Lebedeva N A 2020 The Influence of Fires on Forest Ecosystems Predicting, Monitoring, and Assessing Forest Fire Dangers and Risk, 13 pp 345-366 DOI: 10.4018/978-1-7998-1867-0.ch015
[6] Kovyazin V F, Belyaev V N, Pasko O A and Romanchikov A Ju 2014 Taxation indices of forest stand as the basis for cadastral valuation of forestlands, IOP Conference Series: Earth and Environmental Science, vol 21 012026 DOI: 10.1088/1755-1315/21/1/012026
[7] Shawna J D and Bram D 2018 The modifiable areal unit problem (MAUP) in physical geography California State University, Northridge, CA 91330, USA
[8] Zakharchenko A V A scale-invariant ecosystem model 2005 Forest management, ecology and forest protection: fundamental and applied aspects. Mat. of the international scient.-pract. conf. TUSUR, Tomsk, pp 229-231
[9] Phillips J D and Marion D A, 2005 Biomechanical effects, lithological variations, and local pedodiversity in some forest soils of Arkansas Geoderma 124 pp 73–89
[10] Order of the Ministry of natural resources of the Russian Federation from February 6, 2008 N 31 About the approval of the forest Management instruction, available at: http://pravo.gov.ru/ipsdata/?doc_itself=&backlink=1&nd=102123487&page=1&rdk=0#I0
[11] Resource and environmental atlas of the Tomsk region, available at: https://ogbu.green.tsu.ru/wp-content/uploads/2016/04/%D0%A0%D0%BD%0%BE-%D1%81%D0%BE-%D0%BB%0%BE-%D0%BD%83%D1%80%D1%81%D0%BD%0%BE-%D1%8D%D0%BA%0%BE-%D0%BB%0%BE-%D0%B3%0%BD%87%D0%BD%0%BE-%D1%81%D0%BA%0%BB%0%BA%0%BE-%D0%BA%0%BD%9-%D0% B0%D1%82%D0%BB%0%B0%D1%81%D0%A2%D0%BE-%D0%BC%0%D1%81%D0%BA%0%BE-%D0%BD%89-%D0% B0%D1%82%D0%BB%0%B0%D1%81%D0%A2%D0%BE-%D0%BC%0%D1%81%D0%BA%0%BE-%D0%BD%89-%D0% BD%0%BE%0%B1%0%BB%0%B0%D1%81%D1%82%0%D0%
[12] Website of the Department of forestry of the Tomsk region, available at: https://deples.tomsk.gov.ru

[13] Zakharchenko A V, Alexeev V I and Ipatova D V 2016 Hierarchical concept of soil heterogeneity and planning the scale of investigation Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering pp 149-63