Features of mixed birch-spruce stands interpretation on the example of the northern taiga region of the European part of the Russian Federation

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Abstract. The paper presents the structural features of birch forests in terms of diameter and the ratio of the average height of birch and spruce in mixed birch-spruce stands. In the work, the method of automated identification of crowns of individual trees was used for the subsequent analysis of the features of decoding birch-spruce stands. The result of the presented technique is a set of contours of tree crowns in a forest, obtained automatically. Works on the segmentation of aerial photographs obtained with the use of UAVs and the isolation of individual crowns, determination by the spectral characteristics of the species of each tree are presented quite rarely, but this direction is quite promising. The established deciphering features can be useful to specialists who decipher these forest stands. The article presents materials of trial plots and analysis of comparison with tabular materials, a calculation algorithm for determining the average height and diameter according to the obtained dependencies of decryption and taxation indicators.

1. Introduction

The purpose of the work is to improve the method of taxation by developing distinctive features of interpretation birch-spruce stands.

To achieve the goal of the study, the following tasks were set:
- Conduct a survey and analysis of the taxation characteristics of test plots in mixed birch-spruce stands;
- To establish the structural features of birch forests by diameter and compare with data from reference literature;
- Evaluate the regular relationship between the height of the birch and the accompanying spruce on the trial plots.

With the development of technologies for the accumulation of electric charge, electronics, the emergence of new materials for aerial photography and satellite imagery of detailed and ultra-detailed resolution, as well as in the process of technical improvement of unmanned aerial vehicles (UAVs), digital cameras, precision geolocation systems, new means of collecting relevant information about forest resources have appeared. However, the listed technical and technological innovations will not introduce changes into the existing forest management model without creating effective methods for processing, analyzing and interpreting the obtained highly detailed data.
2. Methods and Materials
In the Arkhangelsk Region, as of 2017, the share of birch stands is 22.4%. The distribution of the stock of soft-leaved forest stands by age groups reflects the influence of concentrated felling of coniferous stands.

The following forestries were selected for field work: Emetskoye; Severodvinskoe; Kholmogorskoje, located in the north-taiga flax area. In the forestries, work was carried out to establish and survey test plots in birch-spruce stands with subsequent renewal of birch and spruce. To study the morphological structure of the canopy of forest stands, the main taxation indicators in birch-spruce stands with the subsequent renewal of spruce, the following were used:
- field materials for the survey of forest stands on 17 trial plots laid in 2020.
- field materials of 22 trial plots laid in earlier periods.

The data obtained on the trial plots for their subsequent processing were compiled into an Excel document.

2.1. Features of the structure of birch forests in diameter
The distribution in steps of thickness is important for determining the assortment and commodity structure. Accordingly, the determination of the average diameter is of great practical importance for the characteristics of the stand.

All trial plots are grouped by average diameter. For the purpose of analyzing the structure of birch by diameter, series of distribution by thickness steps were compiled. Figure 1 shows the distribution of the number of trees in the bark by two-centimeter steps of diameter according to the materials of the sample plots and the distribution of the number of trees according to reference materials (solid line) [1].

According to Figure 1, the coefficients of variability of diameters in birch stands are quite high. The range of variability of diameters in birch stands depends on the average diameter. The use of diameter distribution in small-sized stands gives an unacceptable error. Distribution series at high average diameters are close to normal. The number of trees thinner than the average diameter decreases from 63% in stands with an average diameter of 10 cm to 58% in stands with a diameter of 20 cm. The nature of the distribution of the number of birch trees in steps of thickness depends on the average diameter of the stand [1].

As the age increases and the number of birch trees per hectare decreases, the difference in the diameters of the average and maximum tree thickness also decreases. So, with an average diameter of 20 cm, a thick birch is 1.8 times the thickness of an average tree, and with an average diameter of 12 cm - 2.33 times the thickness of an average tree (the age and diameter of the birch increase accordingly). The commodity structure of birch stands is also influenced by the type of forest, age and geographic location [2]. In the practice of forest interpretation, a great deal of experience has been accumulated in the establishment of decoding sample plots and the identification of dependencies between the inventory indicators of the forest stand elements. In the scientific literature, various equations of dependencies are given [3-7].

2.2. The ratio of the average height of birch and spruce in mixed birch-spruce stands on sample plots and reference literature
In order to identify the second tier of spruce for interpretation additional surveying is required during the period of absence of deciduous cover. In some cases, in conditions of low forest density, the interpretation of the second tier of stands is possible without attracting additional information.
Figure 1. Distribution of the number of trees in the bark by two-centimeter steps of diameter in birch stands of the European North and materials for laying test plots for an average diameter of 10, 12, 14, 16, 18, 20 cm.

Let us consider the regular relationship between the height of the birch and the accompanying spruce on the test plots. When growing together, tree species have a certain effect on each other. There is a certain regular relationship between the heights and diameters of the predominant and constituent rocks in mixed and complex stands [7-10]. The following are the equations for the relationship between the average height and the average diameter for the dominant species - birch and the component spruce [7].

To determine the average diameter of birch, it is proposed to use the formula (1):

$$D = 0.97H - 3$$  \hspace{1cm} (1)$$

where, $H$ is the average height of the dominant breed, m; $D$ is the average diameter of the dominant breed, cm.
To determine the average diameter and average height of the constituent species (spruce), depending on the height of the prevailing species (birch), are given in formulas (2 and 3):

\[ h = 0.023H^2 + 0.31H + 3 \]  
\[ d = 0.034H^2 + 0.219H + 2.9 \]  

(2) (3)

where, \( h \) is the average height of the constituent rock (spruce), m; 
\( d \) is the average diameter of the constituent rock (spruce), cm.

To determine the average diameter and average height of the tier II (spruce), depending on the height of the prevailing species (birch), the following formulas are proposed (4 and 5):

\[ h = 0.625H + 0.17 \]  
\[ d = 0.375H + 7.17 \]  

(4) (5)

Figure 2 shows the linear relationship between the average height and the average diameter for the dominant species (birch) according to the study plots and the values calculated using formula 1.

![Figure 2](image)

Figure 2. Linear relationship between mean height and mean diameter for the dominant species (birch) and values calculated using the formula.

Figure 2 shows that the deviation of the values of the average heights and diameters on the trial plots does not differ from those calculated by the equation by more than 10%.

Figure 3 shows the linear relationship between the average height and the average diameter for the dominant species (birch), the linear relationship between the average height and the average diameter for the accompanying species (spruce), the linear relationship between the average height and the average diameter for tier II spruce, calculated by the formulas 1-5 and values of the average height and average diameter of spruce on the test plots.

Interesting results of the study of the analysis of the relationship between the diameter, height and completeness of birch stands in Siberia were obtained by I M Danilin [5]. According to the results of the study, the author concludes that the average planting height has the greatest value in determining the average diameter at a height of 1.3 m. The effect of completeness was 7.2% and productivity was 6.4%. With an increase in the productivity of the plantation and stabilized values of height and fullness, a slight decrease in the average diameter of the stand is observed [5].
Figure 3. Linear relationship between average height and average diameter for the accompanying species (spruce) and tier II (spruce).

Based on figure 3, a clear idea of the growth of the main species (birch), the accompanying species (spruce) and spruce in the second tier is formed. It can be reliably concluded that, with the same average diameters, the birch, which has a rapid growth in diameter and height, overtakes the spruce in the main canopy, and affects the growth of the spruce in the second tier. This graph does not reflect the dynamics of the course of growth, but shows the values of the heights and diameters of the stand elements at the time of the survey.

2.3. Approbation of the revealed patterns

Aerial survey data were obtained on the territory of the established test plots using an unmanned aerial vehicle (UAV). The obtained digital images were processed and "stitched" into a single coverage.

In the course of the processing performed, the resulting images were aligned. Then a height map was built. As a result of the performed actions, a single orthomosaic was obtained for the territory of the established test plots. The resulting digital coverage was cropped within the boundaries of the trial plot of interest to us and loaded into the QGIS geographic information system (figure 4).

Figure 4. Borders of the trial plot in the aerial photograph.
Further, work was carried out on the segmentation of the aerial image to highlight individual crowns obtained using the UAV, in order to further analyze the features of the interpretation of birch-spruce stands. The applied new method is presented in article [11]. The result of the presented methodology will be a set of contours of tree crowns in the forest, obtained automatically using the methodology described in the article.

After obtaining the image with the outlined contours of the crowns, the procedure of vectorization of the obtained contours was carried out for the purpose of integration and subsequent processing in the geographic information system. A vertex was automatically determined for each tree. The resulting vector layer superimposed on the original image from the UAV is shown in figure 5.

Let us carry out interpretation based on the obtained dependencies.

On the example of the trial plot in the Yemetskoye forestry, the Brin-Navolotsky forestry in the 24th quarter, the 34th division, a trial plot was laid.

Having information about the number of visible trees according to the results of the survey of the trial plot and the average height, we calculate the stock and compare it with the data of the enumeration taxation. On the example of a trial plot in the Yemetsky forestry, Brin-Navolotsky forestry in the 24th quarter, 34 plots. The taxation characteristics of the trial plot are given in table 1.

| Brief          | Structure | $A$, years | $H$, m | $D$, cm | $G$, m$^2$/ha | Rel. fullness | Stock, m$^3$/ha | Stock of industrial wood, m$^3$/ha | Market ability class |
|----------------|-----------|------------|--------|---------|---------------|--------------|----------------|-----------------------------------|---------------------|
| S (visible)    |            | 13         | 80     | 11.2    | 11.6          | 5.4          | 0.24           | 35                                | 27                  | 2                        |
| S (invisible)  |            | 3          | 80     | 9.3     | 9.3           | 1.5          | 0.08           | 8                                 | 6                   | 2                        |
| B (visible)    |            | 83         | 62     | 19.9    | 16.2          | 22.2         | 0.74           | 226                               | 148                 | 2                        |
| B (invisible)  |            | 1          | 60     | 15.2    | 8.5           | 0.5          | 0.02           | 3                                 | 1                   | 3                        |
| Total          |            | 100.0      | -      | -       | 29.6          | 1.08         | 272            | 182                               | -                   |                          |

where, $A$-age, $H$-height, $D$-diameter, $G$-the sum of the cross-sectional areas of the stand at a height of 1.3 m.

Knowing the average height of birch (19.9 m) and the number of visible birch trees (135 pcs.) And spruce (64 pcs.), We will carry out work to determine the taxation indicators of a mixed birch-spruce stand.

Using equation 1, we find the average diameter of the dominant species (birch). $D = 0.97 \times 19.9 - 3 = 16.4$ cm.

Knowing the height and diameter, we will find the volume of one birch trunk from the taxator's reference book. By the number of trees, we can determine the volume of the entire tree stand per hectare: (0.193 m$^3$ * 135 pcs.)/0.125 ha = 208 m$^3$/ha.
Let us find the average height and average diameter of the spruce part of the stand according to the formulas 4, 5: \( h = 0.625 \times 19.9 + 0.17 = 126 \text{ m}, \ d = 0.375 \times 19.9 + 7.17 = 14.6 \text{ cm} \).

Knowing the volume of one spruce trunk of a known height and diameter and the number of trees, we can determine the volume of the entire tree stand per hectare:

\[ 0.112 \text{ m}^3 \times 64 \text{ pcs./ha} / 0.125 \text{ ha} = 57 \text{ m}^3/\text{ha} \]

As a result, the following taxation characteristics were obtained according to the results of interpretation in table 2.

**Table 2. Taxation characteristics of the studied stand.**

| Species | Structure | \( H, \text{ m} \) | \( D, \text{ cm} \) | Stock, \( \text{m}^3/\text{ha} \) |
|---------|-----------|-----------------|---------------|-----------------|
| Birch   | 79.4      | 19.9            | 16.4          | 208             |
| Spruce  | 20.6      | 12.6            | 14.6          | 57              |
| Total   | **100.0** | -               | -             | **265**         |

Analyzing the data in tables 2, it can be noted that the difference in the margin established by the instrumental method and decryption using the equations is within the standard accuracy.

### 3. Results and Discussion

When taxing by an interpretation method, birch-spruce stands have features that are important:

1) On aerial photographs, birch crowns have a yellow or yellow-orange color, the projections of the crowns are irregularly rounded in plan, the falling shadow is not noticeable, the bulge is hardly noticeable, the intervals of the crowns have a rounded shape, medium or low visibility in depth and an imperceptible shadow of its own [3].

2) In order to identify the second tier during interpretation, in addition to aerial imagery in the summer, additional surveys are also required in the spring-autumn period in the absence of deciduous cover. In some cases, in conditions of low forest density, the interpretation of the second tier of stands is possible without attracting additional information.

3) After reaching the age of 40-70 years, depending on the type of forest and subzone of the taiga, spruce begins to emerge singly in the first tier, therefore, from this age, the need for additional survey in the off-season decreases.

4) Birch-spruce stands with spruce of subsequent renewal should be taxed as two-tiered, with a separate definition of taxation indicators for tiers. Since the emergence of such a stand, it is advisable to tax the spruce as a "second tier", and not as "undergrowth". The middle ages of the first tier birch and spruce are, as a rule, very close. In most cases, the average age of the spruce of the second tier is 5-10 years lower than the average age of the birch layer.

5) In the first 5-10 years, 60-80% of the total number of trees in the stand with a large number of trees per 1 hectare settles in fresh and temporarily excessively moist forest types. In this regard, the period of birch renewal should be considered within the first 5 years. In excessively humid forest types in stands of different ages, the distribution of trees by age within the distribution range is more even [1].

6) The complete completion of the change of species occurs at 130-140 years. From 100-120 years there is a vigorous growth of spruce and rapid deciduous decay. According to Chuprov [1] the coefficient of variation in the age of birch in middle-aged stands of the Arkhangelsk region averages 16%, in ripening and ripe - 8%. In the first 10 years after a fire or felling, 50-100% (on average 80%) of spruce settles in fresh forest types, 20-85% (on average 50%) - in the northern and 15-80% (on average 35%) - in pre-tundra forests [2]. In excessively humid types, 15-80% (on average 40%) of spruce trees settle in the northern and 10-55% (on average 25%) in the sub-tundra in the first decade [1].

7) The distribution by diameter is important for determining the commercial structure of the growing stock. The tables of the distribution by the thickness steps are considered and the results of field studies are presented.
4. Conclusion
The presence of the extensive functionality presented in modern software products designed for thematic processing of remote sensing data often does not guarantee quick receipt of accurate and reliable information about the territory. In many cases, it is required to develop specialized methods and algorithms focused on solving a rather highly specialized problem. One of such examples is the method presented in the article for obtaining data on the stock of forest from the data of the UAV survey.

The developments described in the work and similar developments will significantly speed up the process of thematic interpretation and update of data on forest resources, increase the reliability of information about forests due to the emergence of new imaging tools and new methods of processing the received images by remote sensing methods. Peculiarities of interpretation of mixed birch-spruce stands are formulated.

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