Analysis of the number, height and spatial allocation of the Norway spruce undergrowth on the cutting area using aerial photography done by unmanned aerial vehicle (UAV)

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Abstract. The assessment of the undergrowth state in cuttings is of great interest from the point of view of assessing the success of the subsequent stands restoration. The number, height and spatial location of the undergrowth in the clearing can be effectively studied by using ultra-high-resolution UAVs aerial photography. The aim of the study was to determine of Norway spruce undergrowth parameters on the territory of the allotment after continuous logging on the basis of aerial photography from UAVs. The image was captured using 4 rotary quadrocopter platforms of the Mavic PRO and Phantom 4 PRO V1.0 models with a spatial resolution of 2.56 cm/pixel. Based on the survey materials, an orthophotoplan and a digital terrain model were constructed, which were used to determine the height and number of Norway spruce undergrowth, which turned out to be different from the official data. The spatial placement of the Norway spruce undergrowth was studied using the Poisson method and turned out to be a group one, which requires additional forestry measures to align the placement of the undergrowth over the area of the allotment in order to grow a full-fledged stand of the target breed in the future.

1. Introduction
Recently, the UAVs have become widely used for various purposes in the field of forest inventory and forest management. High spatial resolution aerial photographs are successfully used to assess forest resources [1-4], identify soil damage after logging operations [5], build up and use 3D digital models of the territory for forest inventory purposes [6-9] as well as for another aims.

The assessment of the state of undergrowth in cuttings is of great interest from the point of view of assessing the success of the subsequent restoration of tree stands of target species on them. The number, height and spatial location of the undergrowth in the clearing can be also effectively studied by using ultra-high-resolution aerial photography done with the help of UAVs [10]. The number of undergrowth for guaranteed renewal of stands of the target breed should not be less than the standard value, and its height should correspond to the age. Of great importance for the further cultivation of stands is the spatial placement of undergrowth over the area of cutting. From the point of view of the theory, there are 3 main types of spatial placement of objects on the territory: random, uniform (regular) and group. In artificial reforestation, regular placement of planting material over the area of the allotment is usually used, while in natural reforestation, random or group placement of undergrowth over the territory is most common. If the placement of undergrowth in the area of cutting...
will be a group, it will usually require its addition with forest crops in order to align the spatial placement for growing on the stand of the target species.

2. Methods and Materials

The object of the study was the territory after selective logging in a mixed spruce-pine-aspen plantation, located in the 29th allotment, 137 block of the Novinsky local forestry district of the Tikhvin forestry district. The considered forest is protective, the category of protection is forests located in water protection zones, the type of forest is oxalis, the bonitet is 1. Logging was carried out in 2004 on an area of 8.8 hectares, 350 m²/ha was cut down. Currently, according to the 2020 survey, there are individual aspen trees in this allotment with an age of 120 years, with an average height of 31 m, a diameter of 40 cm and a reserve of 50 m³/ha, on the allotment of 440 m² and the 3rd class of marketability. According to the 2020 survey, there is a 15-year-old spruce undergrowth with a height of 2.0 m and an amount of 1 thousand pieces/ha. The target species on the allotment is Norway spruce.

The aim of the study was to determine the number, height and spatial distribution of spruce undergrowth on the territory of the allotment on the basis of aerial photography from UAVs.

The image was captured using 4 rotary quadrocopter platforms of the Mavic PRO and Phantom 4 PRO v1.0 models with a spatial resolution of 2.56 cm/pixel. The Agisoft Metashape Professional program was used to build an orthophotoplan and a digital terrain model.

The spatial distribution of spruce undergrowth in the clearing was studied using the Poisson method [11]. To do this, the entire area of the allotment was covered with a regular network of cells measuring 4.5x4.5 meters, and in each of them the number of spruce undergrowth specimens was determined. According to the theory, the size of the cells should be small in comparison with the studied area, it was selected in such a way that no more than 5 copies of the spruce undergrowth fell into each of them. The ratio of the cell area (20.25 m²) to the allotment area (88 000 m²) was 0.00023. Then the probabilities of getting a given number of undergrowth trees into the cell were calculated – \( p_k \).

In the case of random placement of trees on the territory of the studied allotment, the values \( p_k \) should correspond to the Poisson distribution:

\[
p_k = \frac{m^k}{k!} e^{-m},
\]

where, \( m \) is the average number of Norway spruce undergrowth trees per 1 cell.

For the Poisson distribution, the following important relation is satisfied:

\[
m = s^2,
\]

where \( s^2 \) is the variance of the Poisson distribution. The criterion for determining the type of spatial placement of objects on the territory is based on this ratio. The average number of trees of Norway spruce undergrowth at the 1 cell \( m \) and variance \( s^2 \) was calculated by the following formulas:

\[
m = \sum_{k=0}^{5} k \cdot p_k,
\]

\[
s^2 = \sum_{k=0}^{5} (k - m)^2 \cdot p_k.
\]

if \( m = s^2 \), then the placement is random, since it corresponds to the Poisson distribution, if \( m > s^2 \), then the placement is uniform, if \( m < s^2 \) – group or contagious.

Example is represented on figure 1 where regular, random and group types of spatial distribution of the 25 objects over 25 area units are demonstrated with \( m = 1 \). In case a) of the example which corresponding regular distribution: \( m = k = 1 \) therefore \( s^2 = 0 \) and \( m > s^2 \). In case b) corresponding to random distribution the number of empty cells should be equal to \( 25 \cdot p_0 = 9 \), where \( p_0 = e^{-1} = 0.37 \), number of cells with 1, 2, 3 and 4 objects are equal to 9, 5, 2 and 0 respectively and Poisson criteria \( m = s^2 = 1 \) corresponds to random distribution of objects over the area. In case c) corresponding to group distribution the number of cells with 0, 1, 2, 3 and 4 objects are equal to 17, 1, 2, 0, 5
respectively and Poisson criteria $m = 1 < s^2 = 107$ corresponds to contagious distribution of objects over the area.

![Graph showing three types of distribution](image)

*Figure 1.* Three types of distribution of the objects over the area (25 objects over 25 area units): a) regular $m > s^2$, b) random $m = s^2$, c) group $m < s^2$.

### 3. Results and Discussion

Figures 2 and 3 show respectively an orthophotoplan and a digital terrain model of the selective logging area which was done in 2004, quarter 137 and compartment 29 of the Novinsky local forestry district of the Tikhvin forestry District.

![Orthophotoplan](image)

*Figure 2.* The orthophotoplan of the selective logging area quarter 137, compartment 29 of the Novinsky local forestry district of the Tikhvin forestry district (red line demonstrates the compartment border).

On the basis of these materials, the number of Norway spruce undergrowth on the allotment was determined as much as 5631 trees, which corresponds to 640 trees/ha and its average height was assessed as much as 2.5 meters. These results differ from the data of the allotment survey of 2020, and if the difference in average height of 0.5 meters can be considered as not significant, then the number of undergrowth appears to be as much as 36% less. Undergrowth of this number falls into the category of rare, since its number is less than 2 thousand trees/ha. In terms of height, the undergrowth is classified as large, since it exceeds 1.5 m in height.
Figure 3. The digital 3D terrain model of the selective logging area quarter 137, compartment 29 of the Novinsky local forestry district of the Tikhvin forestry district.

Table 1 shows the results of calculating the probabilities of a given number of Norway spruce undergrowth trees falling into 1 cell.

**Table 1.** The results of calculating the probabilities of hitting a given number of spruce undergrowth trees in 1 cell.

| Number of trees per one cell - $k$ | 0   | 1   | 2   | 3   | 4   | 5   | Sum |
|-------------------------------|-----|-----|-----|-----|-----|-----|-----|
| Number of cells with $k$ trees |     |     |     |     |     |     |     |
| 2719                          | 815 | 534 | 346 | 305 | 298 | 5017 |
| Probabilities of falling into one cell $k$ trees - $p_k$ | 0.542 | 0.162 | 0.106 | 0.070 | 0.061 | 0.059 | 1 |

From the data in table 1, it follows that a large number of cells in the study area were empty, which preliminarily indicates that the placement of Norway spruce undergrowth on the territory of the allotment is group-based. This conclusion is also confirmed by the Poisson test described above, which is based on the calculation of the average number of undergrowth trees per cell and the variance around the average. The mean $m = 1.12$, the variance $s^2 = 2.41$, which proves the fact of group placement of spruce undergrowth on the territory of the studied allotment.

4. Conclusion

As a result of the conducted research, it can be concluded that the studied allotment after logging left an insufficient amount of Norway spruce undergrowth 640 trees / ha and it is very unevenly placed on the territory of the allotment by separate groups. In terms of height, the found undergrowth belongs to the category of large. In this regard, it should be recommended to plant forest crops on this allotment in order to supplement the number of Norway spruce undergrowth to standard values and align its spatial placement in order to grow a full-fledged stand of the target species in the future.

The use of ultra-high-resolution aerial photography, performed with the help of UAVs, and following treatment using special digital technologies is an effective way to survey the undergrowth in cuttings in order to determine its characteristics and develop the necessary forestry measures with minimal time and labor loads and with high confidence. In addition to the survey of natural regeneration and forest crops, UAVs can be effectively used for photo fixing the results of reforestation, as required by modern regulatory documents.
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