Decoding of forest belts using satellite images

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Abstract. The paper presents the results of decoding the current condition of protective forest plantations of the Volgograd region and their digital inventory mapping on the basis of remote sensing methods and GIS technologies. We have applied a three-level analysis of the system of forest belts located within an administrative district, a farmstead, and a single forest belt. The laboratory visual interpretation of space images has allowed us to analyze the horizontal projection of the forest belts canopy and crowns, their placement in the canopy, as well as pattern and structure. We have also deciphered the signs of the prevailing patterns of tree species mixing. As a result of the research, we have created digital cartographic models of forest belts, compiled digital standards of elm stands in a given age period, assess taxational and reclamation features of the current state of plantations. The results obtained can be used to monitor the state of plantings and create a local agroforestry GIS.

1. Introduction

The use of satellite images for assessing the state of protective forest plantations (PFP) began in the mid-1980s. The forest management enterprise Lesoproekt of the Volgograd region developed technical guidelines for the inventory of protective plantings using aerospace photographs. However, space photographs allowed for determining only spatial distribution and geometric characteristics of forest belts. Other taxational and reclamation parameters (height, trunk and crown diameters, species composition, density, etc.) were determined using large-scale aerial photographs, since space photographs of that time had lower deciphering characteristics as compared to modern ones [1-3].

Development of digital technologies has contributed to improvement of modern space images up to the level of aerial photographs in terms of object specification [4-6]. High-resolution satellite images allow analyzing the crowns of detached trees, including on the basis of their spectral response [7-9]. The main advantage of satellite images is their continuous shooting at any time of year. This fact makes it possible to carry out seasonal space monitoring of agroforestry systems, depending on the tasks set. For example, in winter images, a system of protective afforestation is displayed in contrast against the background of snow, and by the distribution of snow plumes in inter-belt squares, one can determine their role in snow distribution.

Today, the use of digital aerial photographs for large-scale inventory is an economically costly way due to high prices for aviation services [10,11]. However, it is possible to use unmanned aerial vehicles (UAVs), which have been widely used in forestry, to solve local agroforestry tasks, such as assessing the state of one or several forest belts, a system of forest belts of an agricultural landscape or a farming.
UAVs are widely used in forestry during monitoring of forest fires [12,13], the parameters of the stand in forests [14-16], reforestation [17,18].

However, the use of geoinformation technologies in the study of PFP with the use of remote sensing methods is insufficiently developed and requires further research, especially in agroforestry mapping and anti-erosion measures development. This is due to the fact that from the standpoint of automated decoding, forest belts are a difficult object of decoding, since they represent narrow strips along fields, roads, ravines. Satellite images display a horizontal projection of plantation canopy, in which the projections of tree crowns are quite densely located as compared to forest tracts occupying large areas [5,19]. Vegetation indices are also used for massive forest plantations rather than narrow forest belts [20,21]. The above circumstances reduce research interest in the problem of studying the state of PFP using space images. Today, forest belts are studied in the context of their ameliorative impact on adjacent territories [22-24] and their impact on the carbon cycle [25,26].

The aim of our research is to decipher the current state of protective forest plantations in the Volgograd region and conduct digital inventory mapping based on remote sensing methods and GIS technologies.

2. Methods and materials
The research object is represented with the field-protective forest belts of the Kachalino test site. The Kachalino test site is located in the southern part of the Ilovinsky district of the Volgograd region on the territory of the Kachalinskoe experimental production farm (figure 1).

In terms of landscape zoning, territory of the test site relates to the Ilovlnsko-Volzhsky gently-undulating ravine landscape area. The soils are shallow chestnut and have different granulometric composition. They were formed on medium and light loams. Alkali soils and chestnut alkaline varieties are widespread in the area under study.

The methodological basis for agroforestry assessment of protective forest plantations is represented with a three-level analysis of the system of forest belts within an administrative district, a farm, and a separate forest belt. The analysis has been carried out on the basis of remote sensing data and GIS technologies [19,27].

2.1 Preliminary laboratory decoding of space images
At this stage, we determine the prevailing schemes of species composition in PFP, age and design typical of the research area, and organize taxation-decoding study plots [5,19].

The analysis of shapes and projections of crowns is carried out according to the classification by G G Samoylovich [19]. We have used the main types of tree crowns for a simplified characterization: round, ellipsoidal (oval) and patterned.

2.2 Field standardization of PFP and laboratory decoding of space images
Standardization in agroforestry research is an important method of obtaining objective information on the state of agroforestry funds.

The study of plantings is carried out on taxation and decoding test sites. All field work with subsequent laboratory decoding of the data obtained is carried out using the methods, instructions and guidelines on forest inventory and agroforestry, taking into account the use of space information [3,5,19].

As a result of field standardization, the planting scheme and mixing scheme, species composition as well as the parameters of height, structure, age, density are determined, and a forestry-reclamation assessment is given.

Laboratory decoding of the obtained materials for subsequent extrapolation of data on the state of plantings requires determining taxation indicators that are of the greatest importance in decoding forest belts from satellite images (average trunk diameter, average crown diameter, average planting height, number of trunks per hectare, horizontal degree of canopy density, viability of plantings). These indicators are also the main ones in determining the subsequent taxation parameters of plantations (forest
site quality (bonitet), density, timber stock, etc.). The number of parameters depends on the tasks set. The next operation at this stage consists in identifying and studying the relationship between the taxation and decoding indicators of plantings.

Based on the comparison of the established decoding signs with the actual data characterizing the state of the plantings in a given age period, standards of the prevailing mixing patterns in the test areas under study are compiled. The composition of tree species is determined on the basis of previously developed standards and established deciphering signs characteristic of a given type of species composition, according to the shapes of visible crowns in the horizontal projection and an image tone, which is different for each species. Canopy density and viability of plantations are determined on the basis of a histogram analysis of the pixel distribution by the relative density of a canopy.

The essence of this method is that the canopy of a normal closed plantation and the canopy of a decaying plantation have different brightness characteristics. These differences are visible on the histogram of the pixel distribution, which makes it possible to quantify the state of the forest belt by the average value of phototone. According to this method, patent No. 2330242 of the Russian Federation ‘Method for determining the state of protective forest plantations’ was registered [13].

Viability of plantations is characterized by the presence of dyewood along the entire longitudinal profile of the forest belt and is expressed as a percentage of the plantation area. The horizontal closeness of the canopy characterizes the degree of canopy formation by tree crowns and is expressed both in percents and in fractions.

The relative density of the canopy is expressed by the ratio of the total area of tree crowns in the stand (i.e. only in the canopy area) to the area of the entire forest belt. The value of this criterion determines the relative area of the horizontal projection of the stand canopy and allows us to take into

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Figure 1. Space diagram of the Kachalino test site. The coordinates of extreme points of the site: North – N 49°08'30.0"; E 44°06'37.6"; East – N 49°06'00.1"; E 44°12'03.3"; South – N 49°03'57,6"; E 44°08'08.1"; West – N 49°06'33.5"; E 44°06'19.8".
account the loss of this area relative to the total area of afforestation. Based on this model, it is possible to calculate viability of the forest belt with ranges of 25%, 50%, 75% and 100%.

A 6-point scale of forest-reclamation assessment developed by Academician E S Pavlovsky [14] has been used for a qualitative characteristics of the state of plantations. The scale is adapted for this method, taking into account species composition, height and design of plantings peculiar of specific forest conditions. As a result, we obtain distribution of forest belts according to status categories depending on age and species composition.

The final step of the second stage is assessment of the system of protective forest plantations. At this stage, the parameters characterizing the system of protective afforestation (protective forest cover of arable land, degree of protection of arable land, degree of completeness of the system) and the correctness of forest belts location relative to the directions of prevailing harmful winds are assessed. These parameters determine the need and feasibility of taking appropriate measures aimed at increasing the protective functions of the forest belt system itself and the ecological sustainability of agricultural landscapes.

Upon completion of the decoding process and analysis of space images, cards of decoding signs of plantings are compiled, and a database of taxation and reclamation indicators is formed for all plantations located on the test sites and areas under study for subsequent geoinformation mapping.

2.3. Geoinformation mapping of the state of plantings and creation of a geoinformation database using space information

Upon completion of field standardization and laboratory decoding, an agroforestry geoinformation system is created using the data obtained, which allows keeping the database up to date with taxation and reclamation characteristics of each forest belt and cartographic information, ensuring the prompt introduction of current changes to the natural growth of plantations and economic activities. Cartographic models of field-protective forest belts are compiled, which make it possible to assess the spatial distribution of plantings and determine the types, volumes and sequence of forestry activities aimed at increasing the durability of forest belts with a spatial reference to each plantation.

On the basis of the agroforestry geoinformation system, it is advisable to monitor the state of plantings and update forest maps, to plan and design forestry activities.

3. Results and discussion

Protective forest belts had been created in the Kachalinskoe experimental production farm from 1985 to 1992. When creating the PFP system, the area of rainfed arable land was divided into 3 crop rotation areas. In the first two areas, protective forest belts were created along the field borders, and in the third area, part of the land was allotted for the creation of stock-regulating forest belts, and the other part remained for control.

The area of the test site is 3950 hectares. The total area of field-protective forest belts is 91.9 hectares. The main forest belts are located across the dominant southeastern dry winds, every 250-300 m and 500-550 m, and auxiliary forest belts – every 900-2300 m and 700-2200 m.

The forest belts consist of 4 rows, the row spacing makes 3 m with a total belt width of 15 m. Two inner rows are occupied by forest-forming species of stocky elm, pseudoacacia robinia, thornless gledichia, pedunculate oak, Crimean pine, and two outer rows are occupied by shrubs, mainly golden currant.

To decode forest belts of small-leaved elm using satellite images, five study plots were laid at the Kachalino test site.

As a result of visual decoding of plantations from satellite images and field standardization, the standards of forest belts have been compiled, which allows identifying the species composition of the stand by the image of the canopy’s horizontal projection and crown projections. The standards contain description of the deciphering signs as well as taxation and reclamation indicators that determine the state forest belts in the given forest conditions and a specific age period. Figure 2 shows an example of a forest belt consisting of small-leaved elms. Description of the decoding signs is given below.
The study plot was laid in 2016 at the Kachalino test site of the Ilovinsky district of the Volgograd region in a forest belt consisting of stocky elm trees (figure 2), planted in the 1990s. The study plot coordinates: N 49°06'29.8"; E 44°10'12.4".

The general view of the horizontal projection of the elm plantation canopy is composed of projections of irregularly rounded and rounded crowns. The arrangement of trees in the canopy is uniform, but with a lumpy structure. The outlines of the crown borders are indistinct, but the rows can be traced. The average diameter of the crown projections is 3-4 m. The canopy density is high (0.75 and more), the spaces between the crowns are small and oval. In the horizontal projection of the canopy, the elm trees are homogeneous in phototone and have a light green tint. According to the histogram of pixel distribution in the in the colors Red Green Blue (RGB) range, the canopy tone has an average value of 78.1 with a deviation of 15.1, a median of 79. The projection of tree shadows has the following values: the average phototone value is 29.5, deviation is 11.9, and a median is 30.

At the age of 23 years, the elm forest belt is characterized by the following taxation and forest reclamation indicators: 4-row field-protective forest belt of openwork design, consists of Siberian elms and shrubs (golden currant, wild rose). The width of the forest belt is 12 m, the length is 2080 m. The viability of the forest belt is 99%. The average tree height is 7.5 m, the average trunk diameter is 14.9 cm. Class 2 of the forest site quality corresponds to this age period. With a density of 830 trees/ha, the total stock of stem wood amounts to 35.7 m³/ha.

The belt is in a satisfactory condition with 10% of dry-top trees. The belt is thickened with golden currants, in some areas where the row is broken, a live above-ground cover is developed.

In case of forest-reclamation assessment, it is recommended to carry out selective sanitary felling to remove dry and damaged trees, and perform agrotechnical soil maintenance.

Based on the results obtained in the QGIS software environment, a map of the spatial distribution of forest belts in the test site has been created. The map has been superimposed on a digital elevation model created using Shuttle Radar Topography Mission data (figure 3).
At this stage of research, within the framework of the developed author's methodology for a three-level analysis of the system of forest belts [19], the standards of the prevailing mixing patterns of tree species in forest belts have been compiled, and the spatial distribution of the forest zones has been mapped at the Kachalino test site.

Figure 3. Map of forest belts spatial distribution in the test site.

4. Conclusion

We have developed the methodology for remote assessment of forest shelter belts in agroforestry landscapes of the Volgograd region. The methodology includes a three-level analysis of forest belt systems in agricultural landscapes. As a result of the research, we have created digital cartographic models of forest belts, compiled digital standards of elm stands in a given age period, assess taxation and reclamation features of the current state of plantations. The results obtained can be used to monitor the state of plantings and create a local agroforestry GIS. Research on this problem will be continued to form a base of standards for the prevailing mixing patterns of species composition in forest belts for the given forest growing conditions with the aim to extrapolate decoding of forest belts to the Ilovinsky district of the Volgograd region.

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