Funded by Global Environment Facility (GEF)

MINISTRY OF FORESTRY OF THE REPUBLIC OF BELARUS

FOREST INVENTORY REPUBLICAN UNITARY ENTERPRISE
“BELGOSLES”

PROJECT “DEVELOPMENT OF FORESTRY SECTOR OF THE REPUBLIC OF BELARUS”
GEF/THE WORLD BANK
TF0A1173

Approved
First Deputy Minister of Forestry

______________ V.G. Shatravko

**REPORT №7**

under the Contract No. BFDP/GEF/SSS/16/23-32/18
dated May 29, 2018

on preparation of a booklet with a short description of the results

**Project Activity 3.1.3.1: “Implementation of specialized forest inventory, which takes into account requirements for adaptation to climate changes, biological diversity conservation, forest use sphere expansion”**

Executor

General Director
of RUE “Belgosles”

______________A.V. Tarkan

Minsk, 2020

*This report was prepared under the Forestry Development Project of the Republic of Belarus with the grant funding support of the Global Environment Facility (GEF).*



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**CONTENTS**

## 1. Publication of the printed matter

During the training workshops, the engineering workers of the expeditions made proposals for providing them with the printed matter that should contain the main final results of the project, and which can be applied in their everyday activity.

The work on the assignments of activity 3.1.3.1 resulted in preparation of the following work directions which should be observed in the step-by-step operations of the production process:

1. The technological instruction on the application of the technology of stereo-decoding during forest inventory work.
2. The technology of prompt/rapid detection of areas of dead, damaged and drying out forest plantations with the help of unmanned aerial vehicles.
3. The methodological guidelines for formation of permanent economic sites with the divisional method of forest inventory

Publication of the brochure “Implementation of specialized forest inventory which takes into account the requirements for adaptation to climate changes, biological diversity conservation, expansion of the forest use sphere” is accepted as the main way of informing the parties concerned and of conveying the working documentation to users.

The project “Development of the forest sector of the Republic of Belarus” envisages creation of conditions for increase in the efficiency of forestry management through improvement of the information systems and application of new approaches which influence the structure and condition of forests and through implementation of sustainable forest harvesting (use).

The goal of the completed assignments on the development of activity 3.1.3.1 “Implementation of specialized forest inventory which takes into account requirements for adaptation to climate changes, biological diversity conservation, expansion of the forest use sphere” can be achieved only when the specialized forest workers get to know the obtained results and implement the new approaches and developments directly in their professional activities. A no less important stage for creation of favorable conditions to improve the information systems is the search for the ways that would contribute to a more accessible and simple representation of the obtained information for its application.

The reporting materials of the stages are demanded and can be used in carrying out forest inventory activities only directly by the heads of the parties and the engineers-taxators. The reports on the assignments are compiled in accordance with the approved technological specifications and have a fragmented nature of information. The goal of the training workshops in the subsidiary forestry enterprises and expeditions was to give a general idea and to familiarize the engineering workers with the results of the work on the project. The results of the completed work are given in the form of technological instructions and methodological guidelines for the practical use of the engineering workers.

The 76-page brochure “Implementation of specialized forest inventory which takes into account requirements for adaptation to climate changes, biological diversity conservation, expansion of the forest use sphere” is printed in 200 copies, with its further distribution by structural units and departments:

- The RUE “Belgosles” – 110 copies, including: the 1-st Minsk forest inventory expedition – 55 copies, and the 2-nd Minsk forest inventory expedition – 55 copies;
- The RSFIUE “Gomellesproekt” – 50 copies;
- The RSUE “Vitebsklesproekt” – 30 copies;
- The Ministry of Forestry of the Republic of Belarus – 5 copies;
- The RUE “Bellesexport” – 5 copies.

The total expenses for the brochure content preparation, production of the original layout and printing edition amounted to 3000 USA dollars

Supplement 1. “The brochure “Implementation of specialized forest inventory which takes into account requirements for adaptation to climate changes, biological diversity conservation, expansion of the forest use sphere” gef

WORLD BANK GROUP

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# IMPLEMENTATION OF SPECIALIZED FOREST INVENTORY WHICH TAKES INTO ACCOUNT REQUIREMENTS FOR ADAPTATION TO CLIMATE CHANGES, BIOLOGICAL DIVERSITY CONSERVATION, EXPANSION OF THE FOREST USE SPHERE

Funded by Global Environment Facility (GEF)

MINISTRY OF FORESTRY OF THE REPUBLIC OF BELARUS

FOREST INVENTORY REPUBLICAN UNITARY ENTERPRISE
"BELGOSLES"

PROJECT "DEVELOPMENT OF FORESTRY SECTOR OF THE REPUBLIC OF BELARUS"
GEF/THE WORLD BANK
TF0A1173

**Component 3: Improvement of the information systems of the forestry sector and strengthening of its capacity**

**Project Activity 3.1.3.1: "Implementation of specialized forest inventory which takes into account requirements for adaptation to climate changes, biological diversity conservation, expansion of the forest use sphere"**

Minsk, 2020

**CONTENTS**

# 1. The technological instruction on the application of the technology of stereo-decoding during forest inventory work

## Introduction

Decoding of aerial photography materials during forest taxation is carried out in order to set borders of subcompartments, to determine characteristics of land categories covered with forest vegetation and taxation indicators of forest plantations.

The decoding way of forest taxation is based on stereoscopic contour and taxation analytical and measuring decoding of quantitative and qualitative characteristics of forest plantations and other land categories by their images in the materials of aerial photography of high resolution.

Decoding of digital aerial photography materials is carried out using specialized software-hardware facilities. The software package “PHOTOMOD” is used as the basic software for forest stereo-decoding.

The instruction provides for the sequence of work on the photogrammetric and radiometric processing of the data of the ADS 100 aerial photography in the software package PHOTOMOD, creation and editing of vector objects in the stereo mode, taking measurements in taxation subcompartments, construction and use of matrices of heights for measuring the heights of forest plantations.

Application of the developed technology of stereo-decoding applies to the objects for carrying out forest inventory without going to field forest-taxation work. First of all, use of this technology extends to the territories with radioactive pollution where long stay of man in the forest is prohibited.

# 1. Creation of the project "PHOTOMOD"

The ADS 100 data (oriented stereo-pairs of photography channels 0 and 19, processing level L 1, channel order BGRN) are loaded into the software package PHOTOMOD with the performance of absolute path correction and import of adjustment to the system. To perform this type of work, it's necessary to create a new project on the mounting table (figure 1.1).

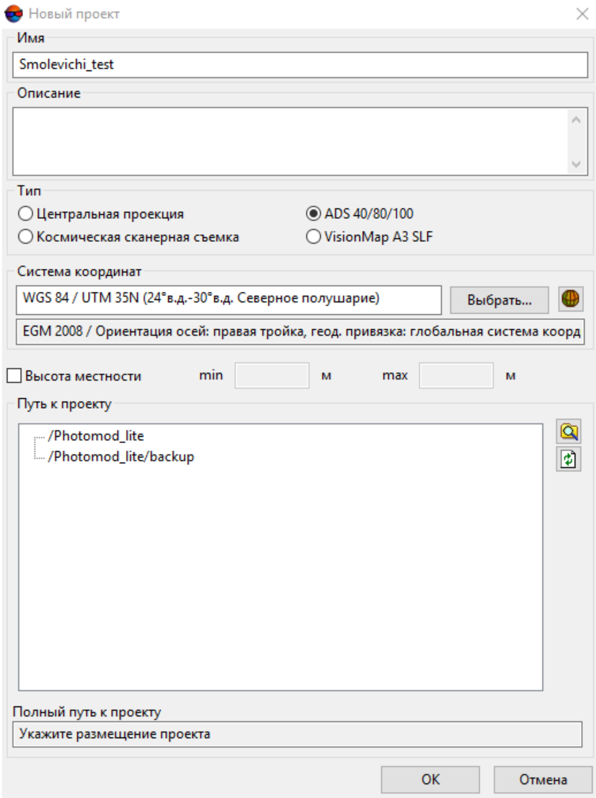



Figure 1.1 – Creation of a new project

*Create – New project*, a new project menu appears, set the project name (Smolevichi_test), in the field type ADS 40/80/100 – for the digital sensor data processing.

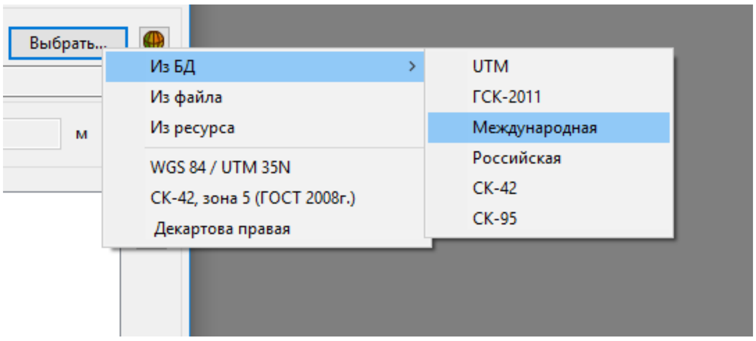
In the section *Coordinate system*, click the button *Select*. A list appears to select a coordinate system from the following sources:

- from the database;

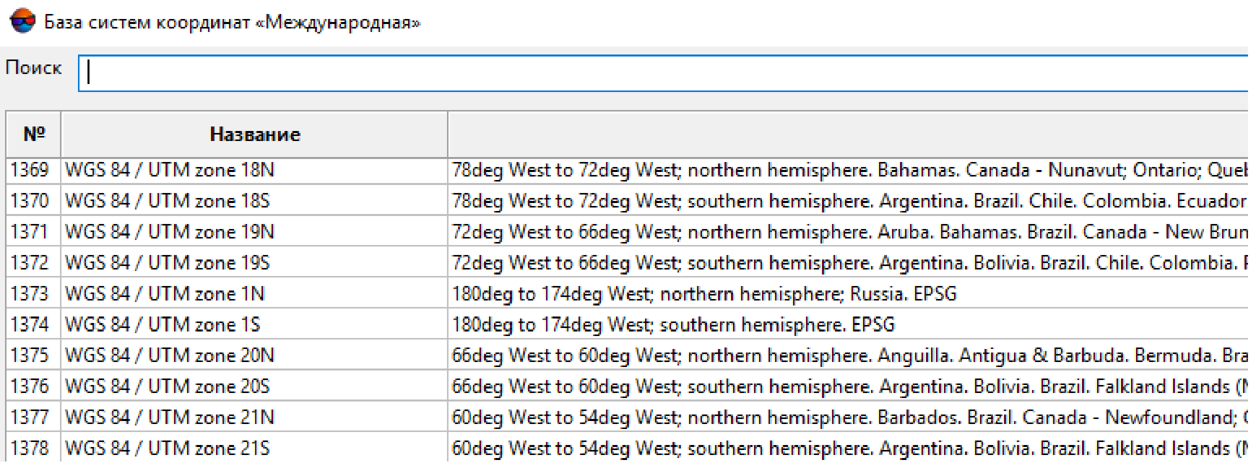
- from the files – to select a file of the coordinate system*.x-ref-system, placed outside the active profile resources:

- from the resources – to select the coordinate system of the active profile resources, for another project of the active profile.

Here, the coordinate system selection comes from the database.




Database – *International*, a list drops out (figure 1.2) to choose the necessary coordinate system. Here, it's WGS 84/UTM zone 35N


База систем координат «Международная»

Поиск

| № | Название | |
|---|---|---|
| 1369 | WGS 84 / UTM zone 18N | 78deg West to 72deg West; northern hemisphere. Bahamas. Canada - Nunavut; Ontario; Quel |
| 1370 | WGS 84 / UTM zone 18S | 78deg West to 72deg West; southern hemisphere. Argentina. Brazil. Chile. Colombia. Ecuador |
| 1371 | WGS 84 / UTM zone 19N | 72deg West to 66deg West; northern hemisphere. Aruba. Bahamas. Brazil. Canada - New Brun |
| 1372 | WGS 84 / UTM zone 19S | 72deg West to 66deg West; southern hemisphere. Argentina. Bolivia. Brazil. Chile. Colombia. I |
| 1373 | WGS 84 / UTM zone 1N | 180deg to 174deg West; northern hemisphere; Russia. EPSG |
| 1374 | WGS 84 / UTM zone 1S | 180deg to 174deg West; southern hemisphere. EPSG |
| 1375 | WGS 84 / UTM zone 20N | 66deg West to 60deg West; northern hemisphere. Anguilla. Antigua & Barbuda. Bermuda. Bra |
| 1376 | WGS 84 / UTM zone 20S | 66deg West to 60deg West; southern hemisphere. Argentina. Bolivia. Brazil. Falkland Islands (I |
| 1377 | WGS 84 / UTM zone 21N | 60deg West to 54deg West; northern hemisphere. Barbados. Brazil. Canada - Newfoundland; ( |
| 1378 | WGS 84 / UTM zone 21S | 60deg West to 54deg West; southern hemisphere. Argentina. Bolivia. Brazil. Falkland Islands (I |

Figure 1.2 – The base of the coordinate systems, "*International*"

The project may be created in any system of coordinates, but it's desirable to do it in the one where raster images are presented. Besides the system of coordinates (SK), it's necessary to set the geoid model: click and select *EGM2008*, which is pre-installed on the computer.

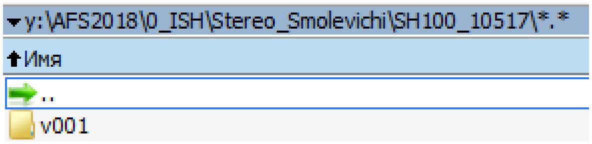
When working with SK 42, the geoid model installation and downloading are required; in SK WGS 84/UTM 35, it's possible to work without the geoid.

Then, set the terrain height checkbox and indicate, at least approximately, the elevation difference in the project images in the fields, max and min. In the territories of Belarus, the elevation difference is from 80 m. to 345 m. (in some places, it may reach 365 – 380 m.). The height data are used for refinement of the block installation and are taken into account when importing the exterior orientation elements, and when calculating the terrain pixel size (GSD). The elevation difference may be set in the project properties at any moment.

In the list *Project path*, select a folder in the active file resources for the project files. In the field *Full project path*, the project name and path are displayed. The service folders and configuration files are created in the selected project folder.

Click *OK* to complete the project creation. The program will offer to create the first route; agree, and the window *Block editor* appears.

**ADS data preparation**. To perform the absolute path correction of the files and their storage in a specified folder on a personal computer, the option *Service* > *ADS data preparation* is used (figure 1.3). The window indicates the location of the source data (L 1, passed by BelEAAPhGS) and the target folder where the prepared data will be stored. In the field *Placement of camera calibration data*, the folder with all the camera files is indicated.



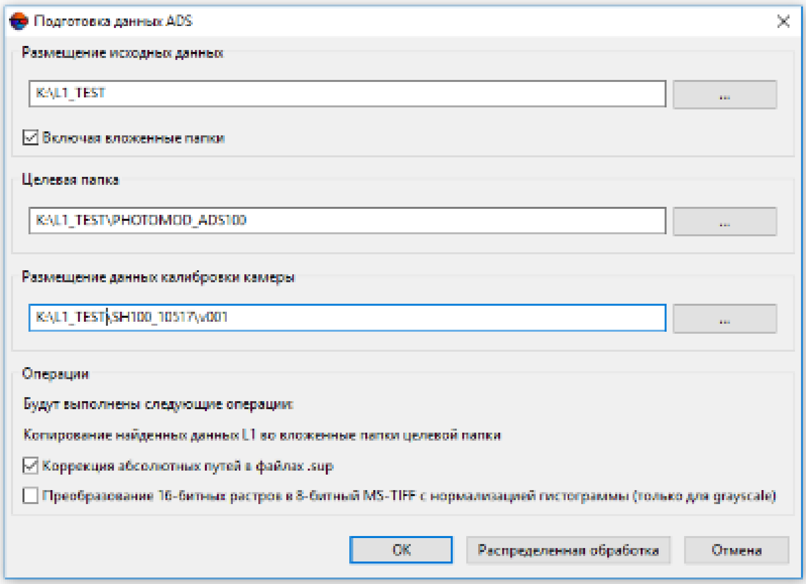
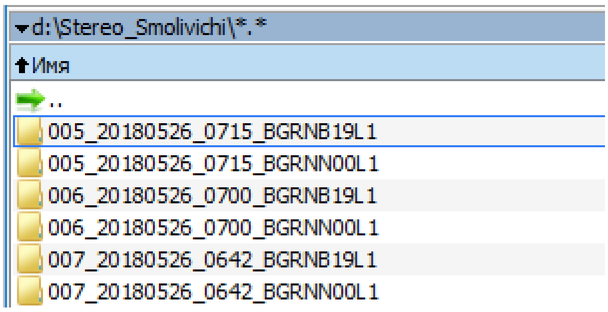
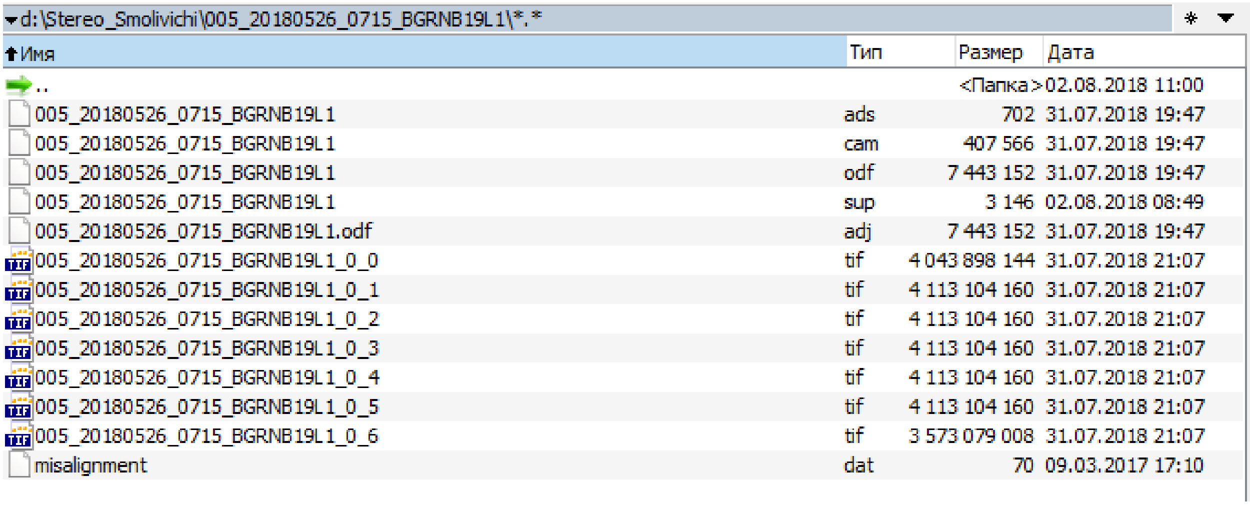




Figure 1.3 – The ADS data preparation

Conversion of 16-bit rasters to 8-bit rasters isn't performed, as it improves the image processing performance due to loss of quality. Click *OK* to start the processing; on its completion, the files will be arranged in folders in the output destination folder (as shown in the figure below).




To each of the given folders, we should add a camera file from the folder SH 100_10517 in accordance with the strip number and the photography angle (file name) and the file misalignment.dat, which is part of the delivery kit from the organization-performer of aerial photography (often copied from other projects). Thus, each folder should contain the following set of files (figure 1.4).



d:\Stereo_Smolivichi\005_20180526_0715_BGRNB19L1*.*

| Имя | Тип | Размер | Дата |
|---|---|---|---|
| .. | | <Папка> | 02.08.2018 11:00 |
| 005_20180526_0715_BGRNB19L1 | ads | 702 | 31.07.2018 19:47 |
| 005_20180526_0715_BGRNB19L1 | cam | 407 566 | 31.07.2018 19:47 |
| 005_20180526_0715_BGRNB19L1 | odf | 7 443 152 | 31.07.2018 19:47 |
| 005_20180526_0715_BGRNB19L1 | sup | 3 146 | 02.08.2018 08:49 |
| 005_20180526_0715_BGRNB19L1.odf | adj | 7 443 152 | 31.07.2018 19:47 |
| 005_20180526_0715_BGRNB19L1_0_0 | tif | 4 043 898 144 | 31.07.2018 21:07 |
| 005_20180526_0715_BGRNB19L1_0_1 | tif | 4 113 104 160 | 31.07.2018 21:07 |
| 005_20180526_0715_BGRNB19L1_0_2 | tif | 4 113 104 160 | 31.07.2018 21:07 |
| 005_20180526_0715_BGRNB19L1_0_3 | tif | 4 113 104 160 | 31.07.2018 21:07 |
| 005_20180526_0715_BGRNB19L1_0_4 | tif | 4 113 104 160 | 31.07.2018 21:07 |
| 005_20180526_0715_BGRNB19L1_0_5 | tif | 4 113 104 160 | 31.07.2018 21:07 |
| 005_20180526_0715_BGRNB19L1_0_6 | tif | 3 573 079 008 | 31.07.2018 21:07 |
| misalignment | dat | 70 | 09.03.2017 17:10 |

Figure 1.4 – A set of files for a stereo-project

After the project formation, the folder with the prepared ADS data may be deleted. Wherein, we should be sure that the raster files are stored in the PHOTOMOD internal resources, directory *Image*.

**Uploading images to the ADS project.** In the window *Block editor* (it appeared after a new project creation, figure 1.5), click the button to add the scanned images from the file; or *Block – Add images from files*.

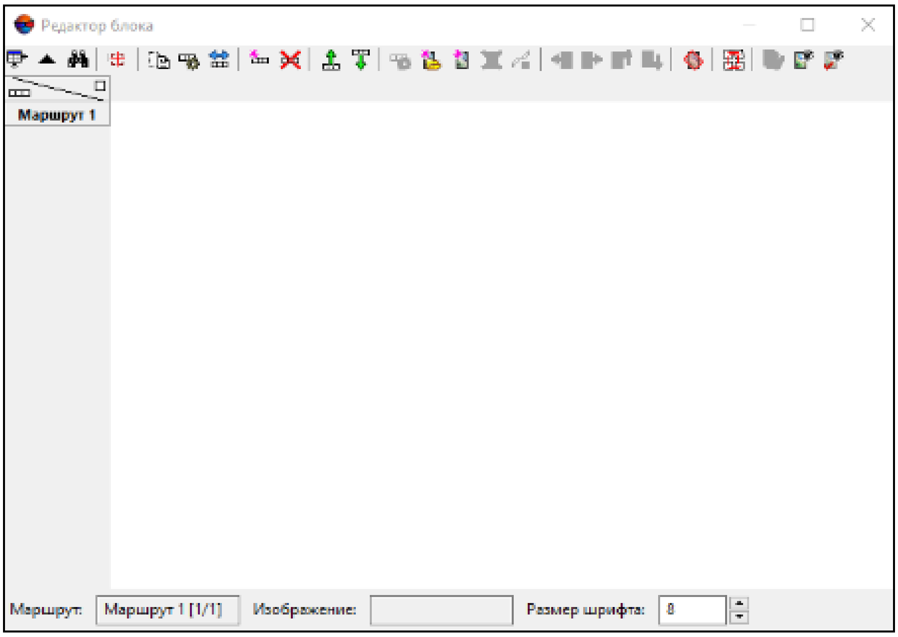



Figure 1.5 – The window "*Block editor*"

In the left part of the window *Add scanned images* (figure 1.6), select the folder with the prepared ADS data. In the right part of the window, start search from the current folder.

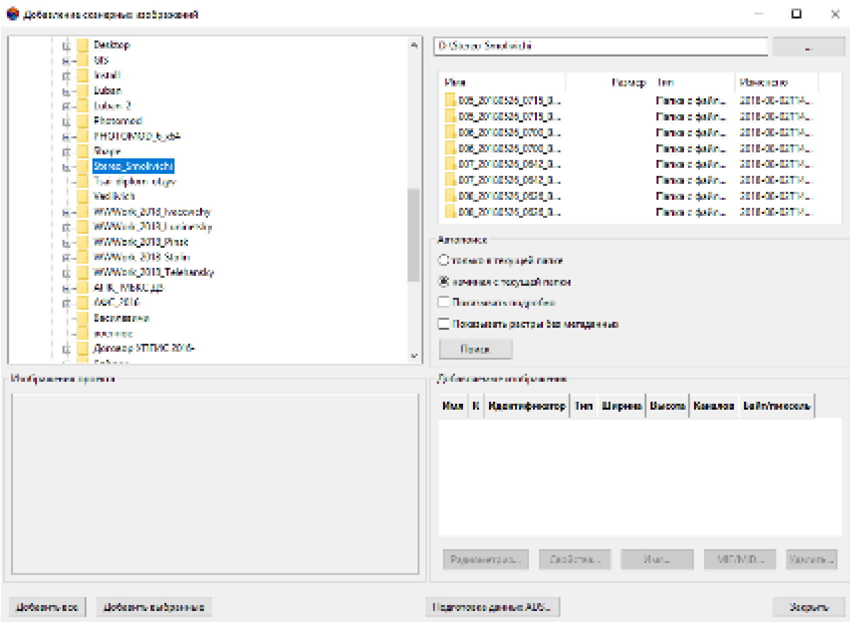


Figure 1.6 – The window “*Scanned image addition”*

The images “nadir” – “back” are added to the project for formation of stereo-pairs, with the button *Add the selected* or *Add all*, depending on the required set for the project under formation(figure 1.7)..

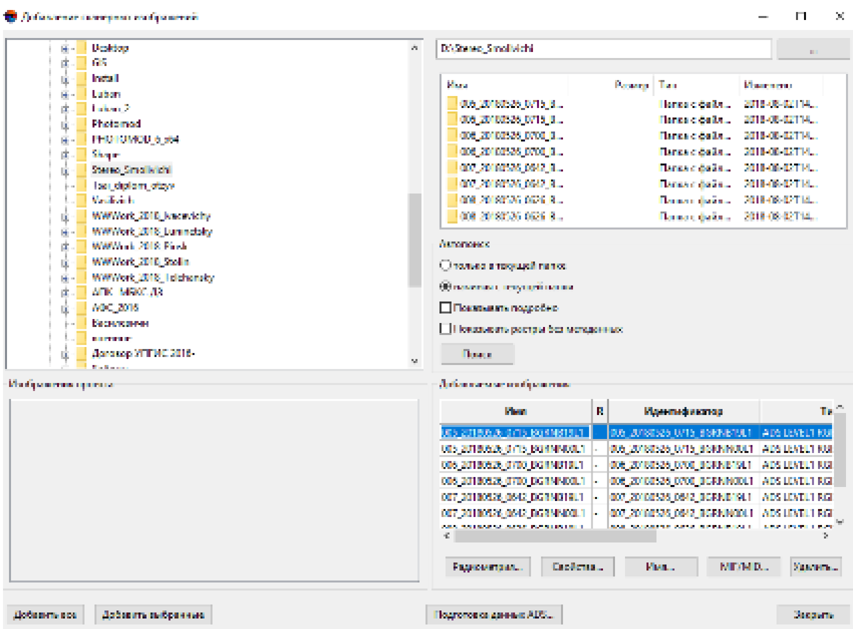


Figure 1.7 – Search of the image

On clicking the button *Add the selected/ Add all*, there appears the window *Parameters*, where everything is recommended to be left by default (figure 1.8).

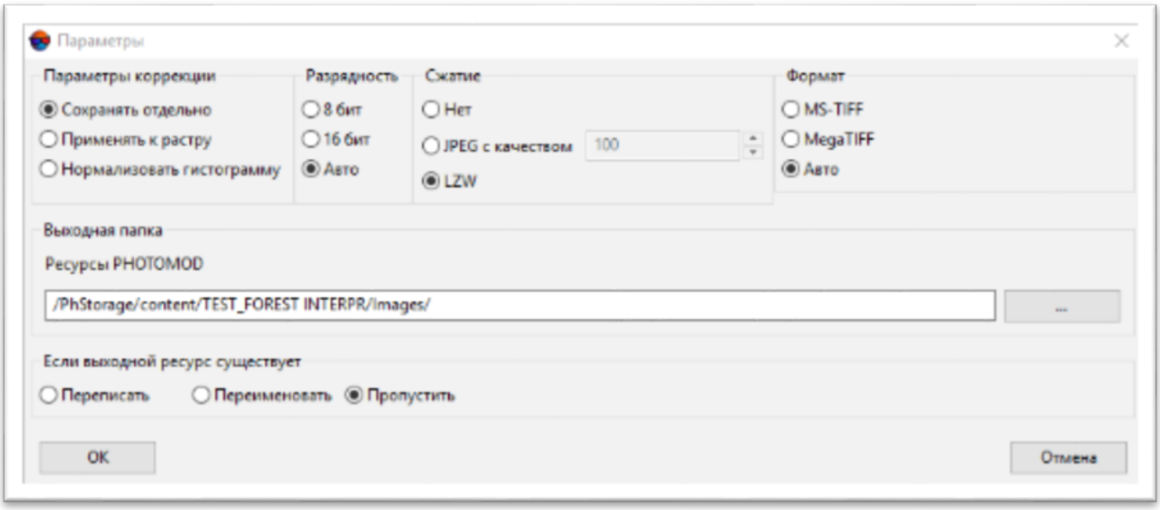



Figure 1.8 – The window “*Parameters*”

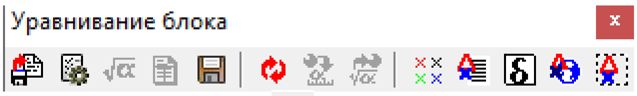
The converted images will be saved in the output folder in the profile resources, that’s why the folder with the prepared ADS data may be deleted (if it’s required only for the current project).

Click *OK* to start the image conversion and upload. The image upload process takes much time (10 hours and more) due to large sizes of the ADS images.

When uploading the images, a virtual folder for the data storage is selected.

**ADS project adjustment**. After the image uploading in the project, options for the import adjustment are selected. At this stage, the SC correct choice is controlled, the data adjustment option is disabled with the use of the DEM, the point measurement accuracy remains the default. For building mathematic image models for the uploaded (in the project) data, the following sequence of actions is required:

- Click the button , to display the panel *Block adjustment*.




- Click the button . The window *Parameters* opens (figure 1.9). Go to the tab *Snapshots*.

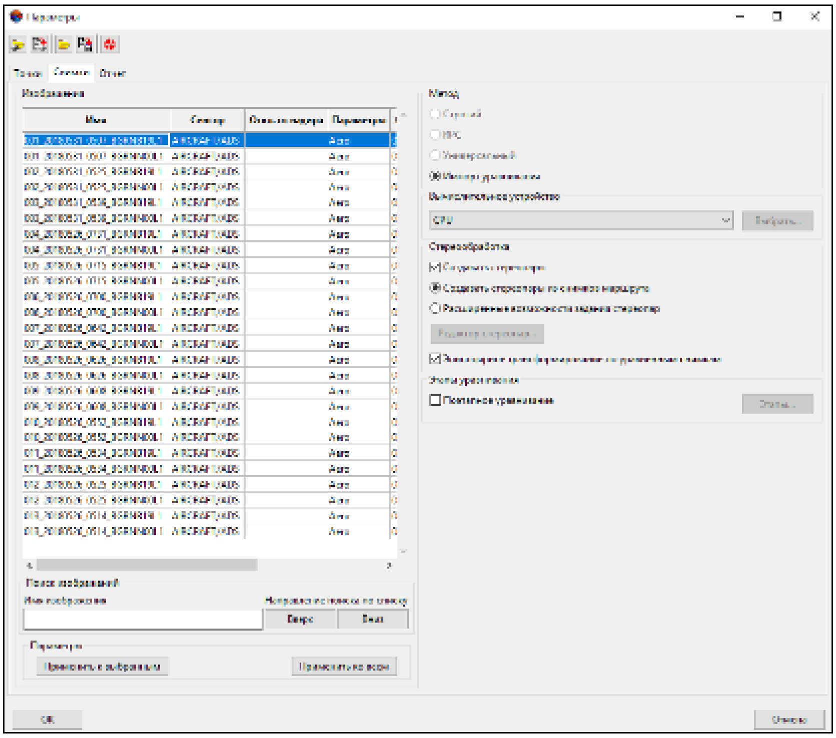


Figure 1.9 – The parameters of adjustment

When importing the adjustment on the tab *Snaphsots*, it's important to trace the options of stereo processing, as depicted in the figure above (graph *Method*, where *Import adjustment* should be active) and to complete the process using the button *Apply to all.*

Click  to perform the process of adjustment.

On completion the process, click  to save the adjustment results.

Thus, the project is adjusted. It should be noted, that the choice of the process of the project creation doesn't influence the results of the geodetic measurements (if the systems of coordinates and project heights, and the maximum heights of the forestry territory are correctly chosen).

The accuracy of the project creation is checked by the import of the control point catalogue, provided by the organization-performer of the aerial photography.

On completion the work, we get the data block consisting of horizontal scanning strips (with the width up to 6 km.) with overlapping not less than 20 %, that is enough for continuous decoding and vectorization of the objects. Now, it's possible to carry out the stereo processing of the photo images and to create the DEM and orthophotomaps.

It's also necessary to perform the block layout correction for the exterior orientation elements. *Block – Block layout – By exterior* (figure 1.10). After this operation, it's necessary to synchronize the project. *Project – Synchronize*. This should be done regularly on completion of each change.

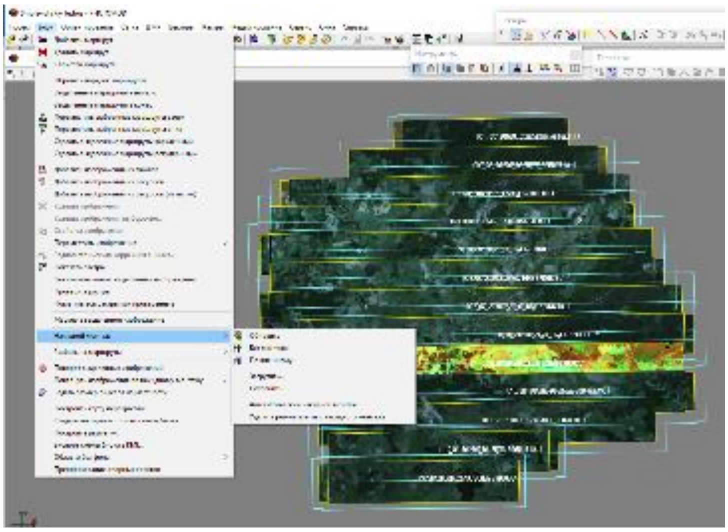


Figure 1.10 –The window “*Block layout*”

Further, it’s necessary to split the photo images into routes by their numbers. *Block- Split into routes – By image numbers* (figure 1.11). Then, synchronize the project for the changes to take effect.

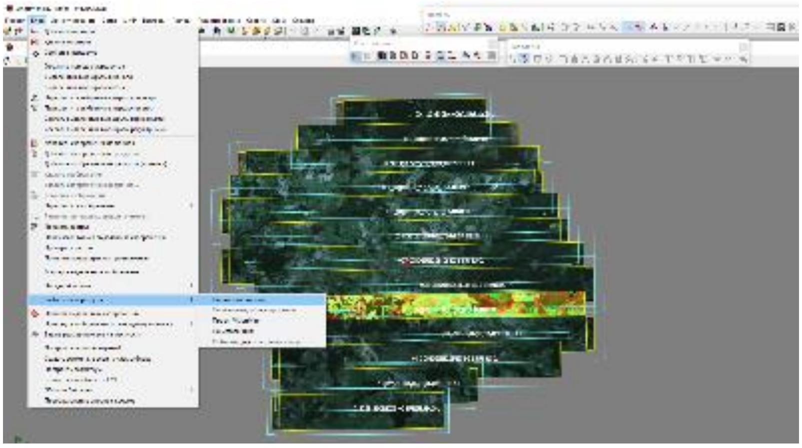


Figure 1.11 – Splitting by the photo image names

The final view of the mounting table should be like the one, presented in figure 1.12.

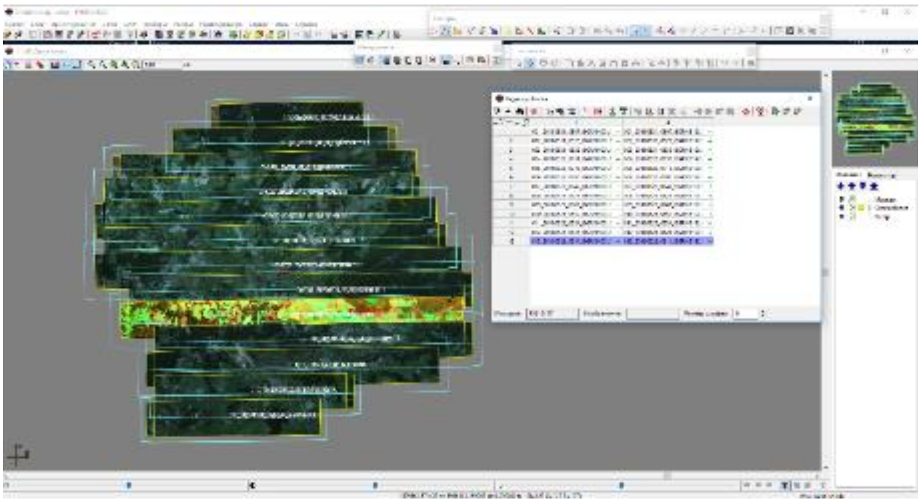


Figure 1.12 – The window *“Mounting table”*

Some work on decoding and photo image analysis can be carried out on the mounting table in the mono-vectorization mode. It's possible to enlarge the fragments or reduce the image with a magnifier. To clearly draw the image, perform *Rasters – Show rasters – Source only*. Synchronize the project.

The following sequence of actions is required to open a stereo pair. Select a stereo pair (click on the stereo pair of images), then *Windows – New 2D window* (stereo pair) or click the icon on the main panel. In the opened stereo pair, click for stereo view (the image should blur).

It should be noted, that the raster orientation *north – south* will change depending on a forward or reverse aircraft flight, so one stereo pair will be *north – south*, and the other *south – north* oriented. Thus, the image will be inverted (or at an angle) and all its superimposed rasters will be inverted too; this makes it difficult to decode.

In order to open the created project in the program Photomod, it's necessary to run the program from the desktop or the task bar , the window *Project management* appears; click the mouse to the desired project and click the button *Open*. If the window *Project manager* doesn't appear after the program download, click *Project – Open/Management*. (figure1.13).

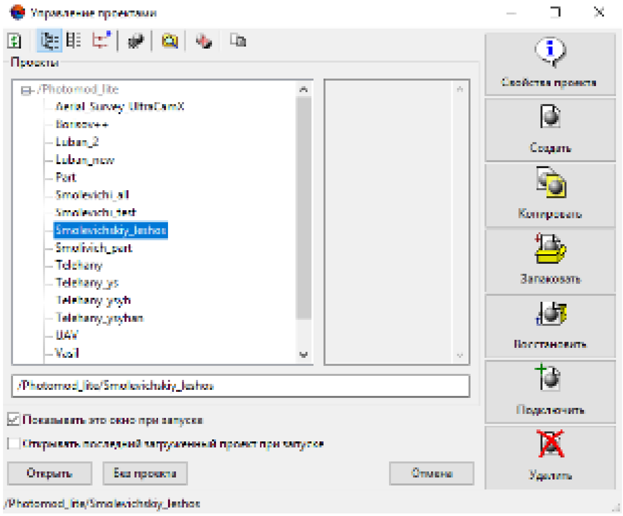



Figure 1.13 – The window "*Project management*"

The files of the processing level L 1 shouldn't be split into parts. In order to have the possibility to prepare a project, for example, for one forestry, it's necessary to contact the organization-performer of the aerial photography. We can create the project either simultaneously for all routes or for several routes. It's also possible to delete routes from the prepared project or to add the routes. The project should be obligatorily synchronized after each operation.

***Stereo analysis of the aero-space images in the program Photomod***

The stereo-analysis of aero-space remote photography images is performed in workstations equipped with special software-hardware facilities, including, stereo monitors and stereo glasses. The analysis of remote photography materials in the stereo mode is performed at different stages of decoding: during study and analysis of decoding features, contour and analytical decoding.

The sequence of actions for viewing images in the stereo mode is the following:

- open the existing project in the Photomod;
- open a stereo pair – in the box *Layout*, click to select a photo image;
- run *Open a new 2D window for the selected stereo pair* (or the keyboard shortcut *Ctr-Alt-W*);
- set the image scale with the scaling tools.

To change the longitudinal parallax on the selected image area, click the button *Parrallax fixed mode* on the 2D-window panel (changes are performed with the mouse wheel).

The stereo image adjustment for better stereo effect:

- when working in the stereo mode, there arises a task of the stereo image depth adjustment to achieve the best stereo effect in the desired area of the object under analysis. This task is especially vital when working with "deep" images, i.e. images with a large variation of longitudinal (horizontal) parallaxes in the stereo surveillance.

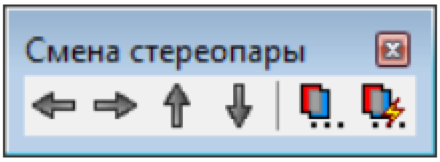
For the stereo effect adjustment, set the editing marker to the area of interest, project it to the surface of the relief or the object. Then, click the key *F 2* or the button *2D-window*.

The program converts the stereo images so that the zero values of the longitudinal parallax would be in the marker point, and the best stereo effect – in the vicinity of this point or its "depth".

To restore the base stereo effect "depth", click the key *F 3* or the button in the 2D-window.

To change the stereo mode phase (i.e. to switch between the left and the right photo images), click the button *F 11* or the button in the 2D-window.

Besides, to change the stereo image "depth", use the keyboard shortcut *Shift-PgUp/PgDn* or the *Shift*-wheel. Before starting work in the stereo mode, it's important to make sure that the required stereo pair is selected, the stereo mode is on, the fixed parallax is on, the stereo viewing phase is correctly selected (the left-right or the right-left photo image) .




To move between the adjacent stereo pairs, the tools of the panel *Stereo pair change* are used. The panel is activated in the menu *Window – Toolbars*.

For manual stereo pair change, it's necessary (by the photo image number and the notch angle) to:

- select *Selection of a stereo pair for transition* in the window *Stereo pair change;*
- open the tab *Parametric search* in the opened window *Stereo pair selection;*
– select the desired photo image and click *OK*.

## 2. Radiometric correction of images

Radiometric correction of synthesized photo images is chosen at the preliminary stage or is possible in the current project. Radiometric correction of images implies improvement of their visual characteristics for purposes of optimal use to obtain the desired results (for example, forest taxation decoding, fire monitoring, forest condition assessment). The functions of radiometric correction in the program Photomod include determination of composition and sequence of channels and auto-levels; adjustment of brightness, contrast and gamma-correction; determination of color balance; geometric transformations. The main task of radiometric correction of aerial photography materials for forest decoding is formation of "pseudo-color" images (images in false colors), suitable for color separation of wood species.

To perform the procedure of radiometric correction of the ERS materials (stereo pairs, separate images), run the command *Rasters/Image Wizard*. In the opened dialog window, select a photo image and click *Radiometric correction* .

In the dialog *Perform auto-levels*, select *No*. Enlarge a part of the photo image in a specific place (figure 2.1).

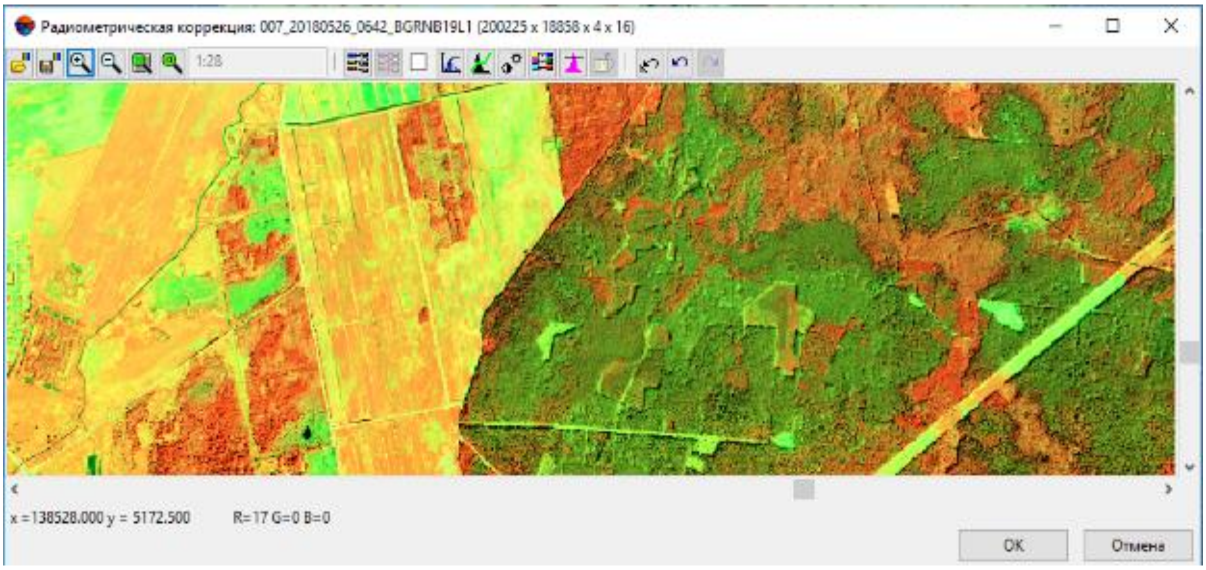



Figure 2.1 – The window “*Radiometric correction*”

The image in aero-space photography materials is usually formed from several spectral channels. Their number depends on the photography equipment and the camera features. Photo images with four channels (red, green, blue and near infrared) are, as a rule, used for forest-accounting tasks. Differences between deciduous and coniferous trees (due to differences in their coefficients of spectral brightness) are better noticeable in an infrared channel. That’s why, when forming “pseudo-color” images (traditionally used in forestry), a red channel is replaced by an infrared channel, green – by red, blue – by green.

In order to get a color spectrum zone image (familiar to forestry specialists) with vivid color separation of coniferous and deciduous species, it’s necessary to adjust the histograms of each channel separately. When adjusting the histograms of channels (for the purpose of optimization of color differences between wood species), it’s necessary to make use of the taxation characteristics of the available reference base -- the training sample, containing the taxated-decoded trial sites and subcompartments with selective-measuring (selective-enumerating) taxation, which are laid on the basis of the compiled occurrence tables of forest plantations and other categories of lands.

The adjustment of channel histograms is performed in the following way:

– enter the dialog window *Curves*  (figure 2.2)
- uncheck *For all* (set by default) and tick *View*;
- select the desired channel from the list (*Red, Blue, Green*);
- adjust the chosen channel histogram;
-repeat these steps for the other channels.

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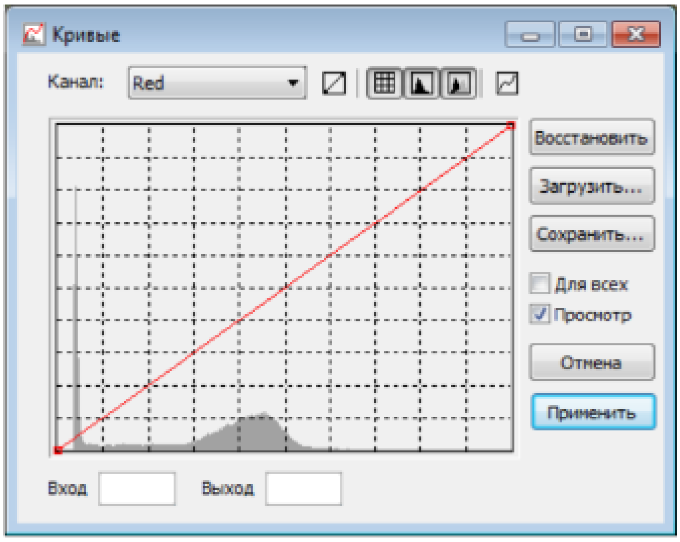


Figure 2.2 – The dialog window “*Curves”*

The histogram adjustment consists in the change of the curve shape with the left mouse button (click *Add the curve pivot points* or *Change the curve shape* by moving the points); the adjustment results are assessed visually by the changed image. Dark grey (in the window *Curves*) indicates the original chart/diagram, light grey – the corrected one (figure 2.3).

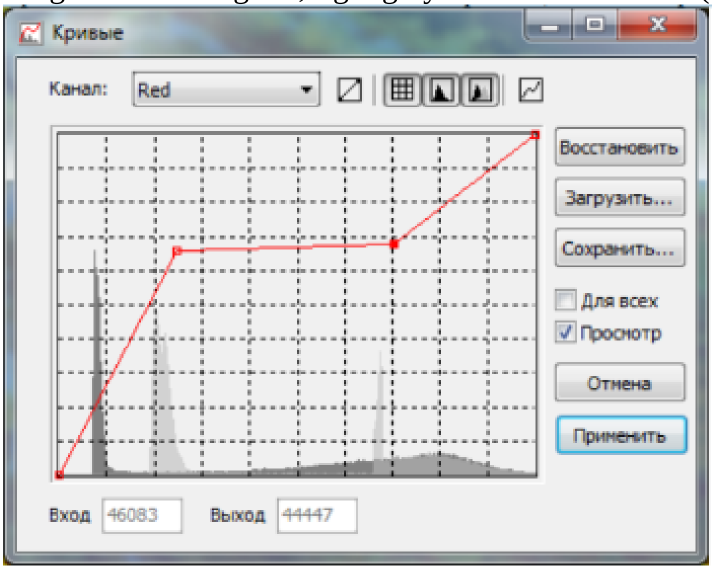


Figure 2.3 – A corrected histogram

The histogram “cutting” right and left is performed by the shift of the extreme points of the curve to the center so as to get the desired color tones (wherein, the vertical position of the points should be saved). The color channel saturation is adjusted by adding points to the curve (figure 2.4).

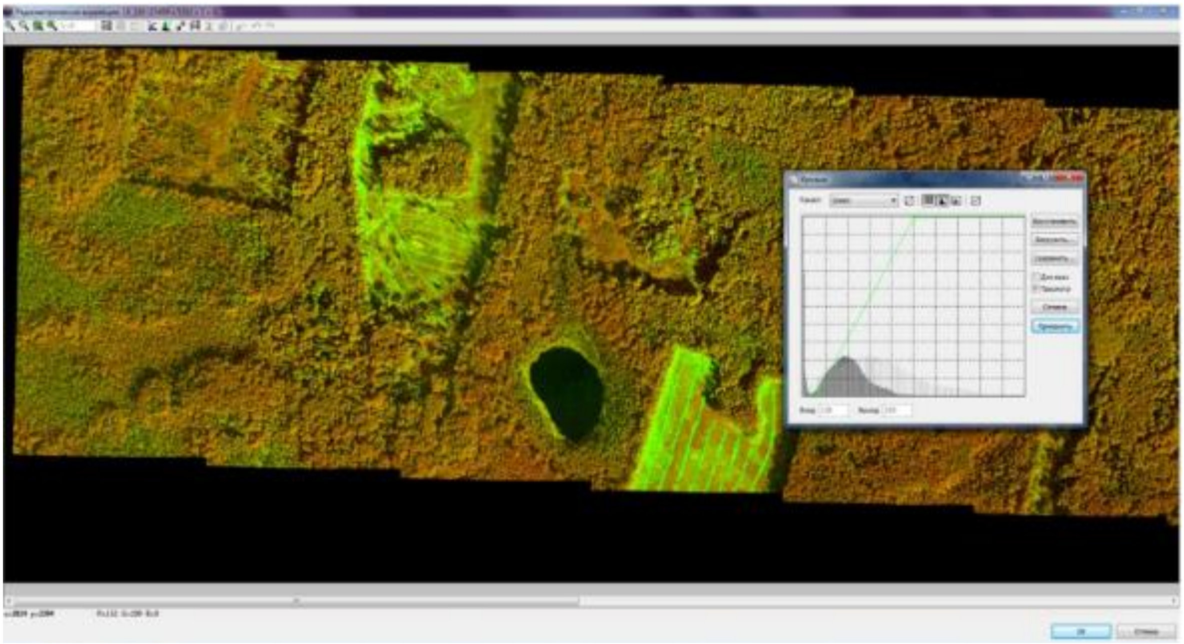

Figure 2.4 – Adjustment of the green channel

For the formation of “pseudo-color” images

- select the blue channel (*Blue*), reduce the share of the channel participation in the formation of the spectrum zone image (figure 2.5);

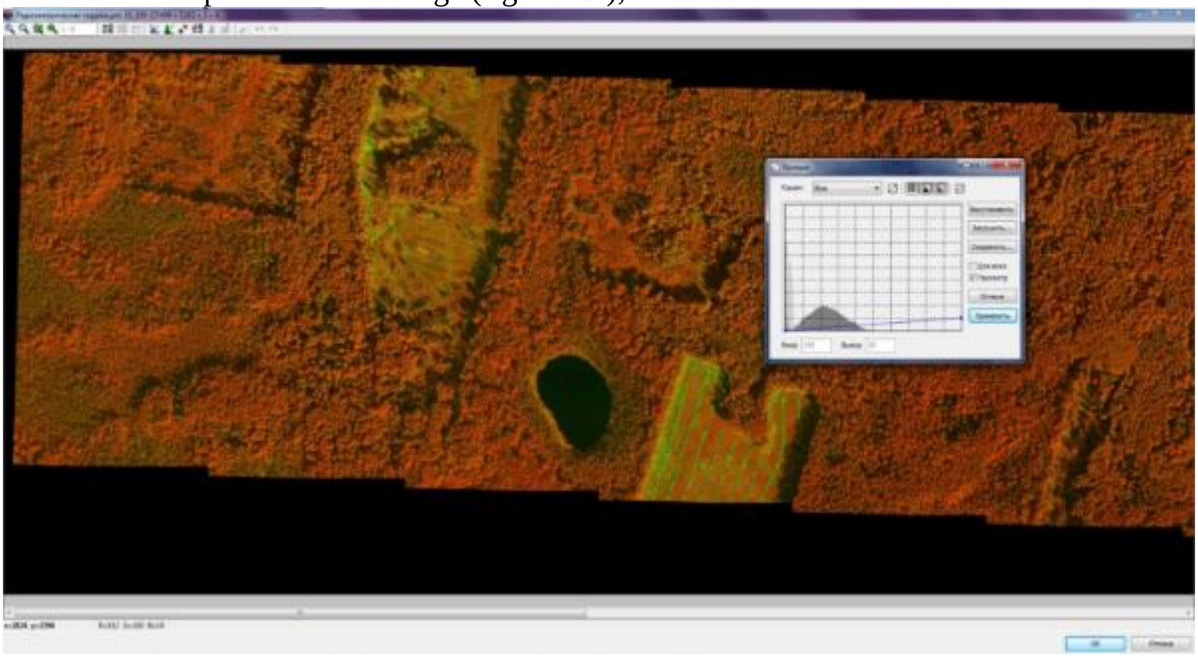

Figure 2.5 – Adjustment of the blue channel

- select the green channel (*Green*), adjust its histogram so that to clearly trace (in the images) the difference between the deciduous (yellow – orange color) and coniferous (light-green – dark-green color) species;
- if necessary, adjust the histogram for the red channel (*Red*) (figure 2.6).

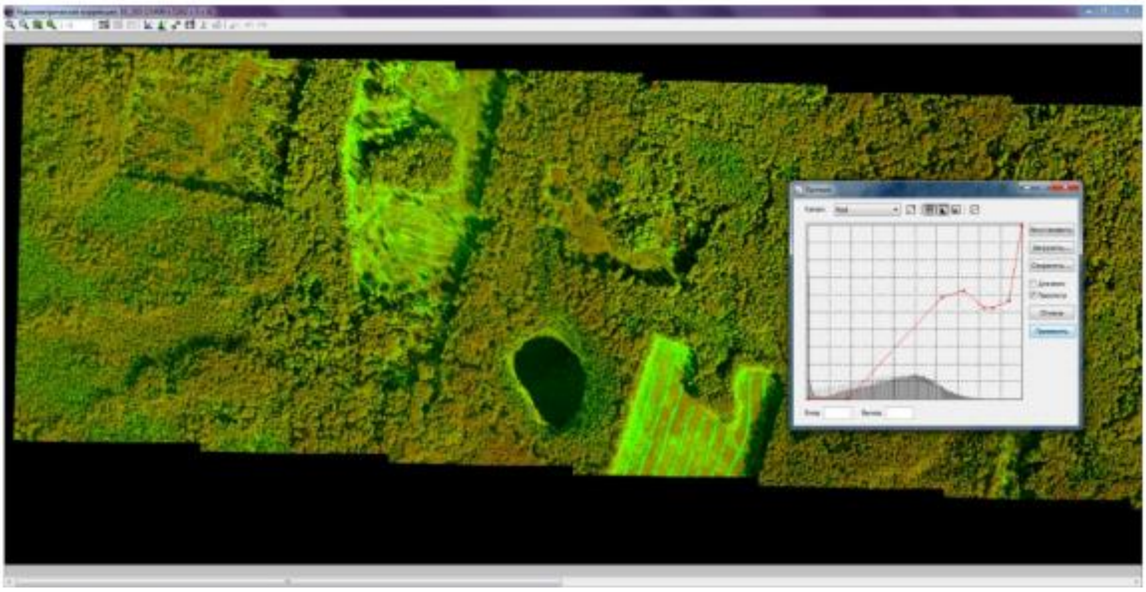

Figure 2.6 – Adjustment of the red channel

When choosing a working option, focus on the display option which maximally emphasizes the difference of wood species. Equally important is the type of decoding materials familiar for processing.

A different channel combination gives a different level of brightness and color rendering. The combination should be chosen in the way so that the main channel is infrared, because differentiation of forest plantations is traced exactly in this range.

After selection of the main combination of colors, it's possible to make the image more contrast, brighter and sharper; to apply a histogram or sharpening filters. Such settings are selected for a group of images related to blocks, different in photography time, individually. If necessary, once created combinations can be saved to a file and re-used by the file import to any project.

Due to specific peculiarities of spectral characteristics of each photography material (flight), the algorithm of change of image histograms (visual enhancement of the original images) for different photography materials will be individual.

In order to apply the parameters of radiometric correction for a group of images, it's necessary to:

- click *Save radiometric correction parameters* (saving of radiometric parameters, set for one image);
- select a group of photo images to distribute the results to them;
- load the radiometric parameters for the selected photo images from the file;
- exit *Image Wizard*, apply the changes.

## 3. Decoding of the remote sensing data (aero- and space photography materials)

### 3.1. Study and analysis of the decoding features

During contour and taxation (analytical and measuring) decoding, for determination of the qualitative indicators of forest plantations (composition, average height of a tier and forest elements, age and average diameter of forest elements, density, bonitet classes, groups of forest types etc.), categories of lands, not covered with forest vegetation, forest and non-forest lands, there are used the following decoding features:

- photometric, i.e. colors in color spectrum zone images, reflecting the differences in the spectral brightness of forest objects;

- morphological (structural), reflecting the morphology of objects under decoding, i.e. shapes and sizes of crowns, gaps between crowns, plantation canopy structure, as well as, the geometric and structural features of forest and non-forest categories of lands, not covered with forest vegetation;

- landscape, reflecting the regularities of landscape element distribution, types of growing conditions and predominant species, depending on the landscape geo-morphological structure.

Forest decoding is a complex process of remote object recognition. Measuring methods, regularities of forest plantation structure, biological features of wood species under decoding are used as the decoding features for determination of the indicators of forest plantations and other land categories.

Table 3.1 presents the list of objects under decoding, ways and methods of their determination.

Table 3.1 – The list of taxation indicators, feature classes, ways of determination of taxation indicators and methods of their decoding

| | | | |
|---|---|---|---|
| 1 | Category of lands | Photometric and morphological | Analytical decoding |
| 2 | Predominant species | Photometric, morphological and landscape | Analytical and measuring decoding |
| 3 | Plantation composition | Photometric, morphological and landscape | Analytical and measuring decoding |
| 4 | Age (class or group) | Morphological and photometric | Analytical decoding with the use of relationships |
| 5 | Forest type (type of forest-growing conditions) | Landscape, morphological and photometric | Analytical decoding |
| 6 | Bonitet class | Landscape, morphological, relationships with other indicators | Analytical and measuring decoding with the use of relationships |
| 7 | Average height (of a tier, of a forest element) | Measuring methods, eye assessment, relationships with other indicators | Measuring and analytical decoding with the use of relationships |
| 8 | Average diameter of forest elements | Relationships with other indicators | Measuring decoding with the use of relationships |
| 9 | Canopy closeness | Measuring methods, eye assessment | Measuring and analytical decoding |
| 10 | Diameter of crown projection | Measuring methods, eye assessment | Measuring and analytical decoding |
| 11 | Number of crown projections | Measuring methods | Measuring decoding |
| 12 | Relative density | Relationships with closeness, eye assessment | Measuring decoding with the use of relationships, analytical decoding |
| 13 | Stock/reserve per 1 ha. | Relationships with other indicators | Measuring and analytical decoding with the use of relationships; reference tables |

On the basis of the photometric, morphological and landscape features, there are determined the following main subcompartment taxation indicators: land category, predominant species, plantation composition, age (class or group), type of forest-growing conditions. The importance of the above-mentioned decoding features is principal for the final result, so their study (analysis), correct choice and sequence of use determine the efficiency of their application and the quality of decoding as a whole.

The analysis of the photometric and morphological features of decoding is carried out in the ground and cameral conditions in taxation-decoding trial sites and subcompartments by selective measuring-enumerating taxation (these areas should be accurately identified and put on the aero-space photos). The main task of the ground analysis is the formation of the decoding features that ensure determination of the subcompartment taxation characteristics of forests with regulatory/normative accuracy. For analysis, there are selected 2 – 3 trial sites and 2 – 6 subcompartments by selective measuring-enumerating taxation of each predominant species, characterizing the main age groups presented in the object under study.

*Color*. It’s determined (by a decoder) visually in an analytical way, or automatically. During automatic detection, it’s necessary to point the mouse cursor to the lighted part of the tree crown, and click the left button (similar to the features of gap colors). The program compares the pixel color in the cursor position with the color guide, generated earlier, and chooses its closest color gradation.

*Crown projection in the plan*. It’s determined in an analytical way using the classification of tree crown projections in the plan.

*Falling shadow*. It’s a tree shadow falling on the ground and clearly describing/depicting the shape of a separate tree crown. It’s noticeable only in low-density plantations or on the borderline of the subcompartment with open space.

*Tree crown bulge*. It’s determined in an analytical way under stereoscopic viewing (in the program Photomod StereoMeasure).

*Crown projection size*. Holding down the right mouse button, the length horizontal crown projection (from north to south, and from west to east) is measured, the average value is calculated and fixed in the table.

*Shape of gaps*. The characteristic shape of gaps between crowns of adjacent trees next to the tree under study is determined in an analytical way.

*Size of gaps*. Gaps between adjacent trees are determined in the way similar to the crown projection sizes – the average value is calculated by several measurements and fixed in the table.

*Viewability/Visibility in depth*. It’s determined in an analytical way under stereoscopic viewing. Stereoscopic depth viewability of the plantation crown in the area of the tree under study is analyzed. The visibility is considered good, when the gaps between the adjacent trees are large, and the ground surface is vividly seen. The visibility is satisfactory – some crowns of the adjacent trees are closed, but there are places with the visible ground surface. Dense canopy – the major part of crowns of the adjacent trees are closed, there are practically no gaps between them, the ground surface isn’t visible.

*Color of gaps*. The process is similar to the process of determination of the tree crown color.

*Own shadow*. It’s a shadow located on the crown of the tree under measurement. It is’ determined in an analytical way.

In flat conditions, when studying landscape decoding features, much importance is given to a comprehensive analysis of distribution (location) of types of forest-growing conditions in the general drainage system. This task is most effectively solved by assessment (on the materials of the aero- and space photography) of the drawing and density of the hydrographic network as the most important indicators of the soil-ground (forest-growing) conditions.

In the cameral period, forest type schemes and tables of landscape decoding features are compiled for each separate landscape (on the materials of the landscape-typological studies).

As a result of studying the landscape decoding features of each landscape, the final table of landscape decoding features is compiled. This table shows the following regularities (patterns):

- occurrence of types of forest-growing conditions by the relief elements in the context of bonitet classes;
- occurrence of forest-forming species and their distribution by the relief elements;
- confinement of types of forest-growing conditions to various parts of slopes with different exposure and steepness (by the forest-forming species);
- occurrence of forest-forming species by the altitude gradation in the context of types of forest-growing conditions.

During forest-taxation decoding based on the analysis of various landscape elements, there is found some additional information arising from the properties and characteristics of the soil-typological categories for establishment/demarcation of the borders (contours) of taxation subcompartments and determination of some taxation indicators.

During subcompartment forest taxation by a decoding way on the ERS materials with the spatial resolution of 0.3 – 0.6 m., the use of landscape features is an additional way of receiving the detailed taxation characteristics of a subcompartment (determination of the predominant species, composition, type of forest-growing conditions, bonitet class). In such cases, there are analyzed the following features: confinement of types of forest-growing conditions, of bonitet classes, of predominant and constituent species to various forms of elements of the relief and hydrography, altidute, slope exposure and steepness.

The required information for these purposes may be received on the basis of the available ground taxation data or by a joint analysis of the topographic maps, forest plantation plans and taxation descriptions of the latest forest inventory.

The landscape decoding features are used during contour and analytical decoding – in the process of the analysis of the plantation canopy in the stereo mode. Wherein, large generalized subcompartments with clearly distinguishable natural borders are analyzed using the photometric, morphological and landscape features of decoding; this serves as the basis for drawing borders between subcompartments.

The use of the landscape features increases the reliability of determining the bonitet classes and types of forest-growing conditions and, consequently, other related taxation indicators.

### 3.2. Contour decoding

Contour decoding – establishment of borders of subcompartments – is always performed in the stereo mode. It should be remembered that contour decoding is inseparable from taxation decoding, as in order to correctly establish the borders of subcompartments the executor should preliminary evaluate/assess the taxation characteristics of each of them (at first, approximately). The criteria for demarcating subcompartments are the thresholds of differences (established by the forest inventory instruction) in the composition, height, shape and sizes of crowns, canopy closeness, growing conditions and other features of plantations under decoding. During decoding, these plantation characteristics are initially analyzed and evaluated by the eye examination (during contour decoding) and serve as the basis for drawing borders of subcompartments. The analysis of stereo images during contour decoding should be made in the scale of the issued forest maps (forest inventory tablets). This important point of contour decoding allows the decoder not to make groundless splitting (division) of forest-taxation subcompartments.

The classic sequence of actions (stages) during contour decoding is the following:

- general overview of the area;
- selection of the topographic objects;
- selection of the generalized taxation subcompartments;
- detailing of the taxation subcompartments.

At first, the stereo model of the whole selected quarter is analyzed so as to study the character of the relief and hydrography, their constructions and geomorphological features. The general terrain slope, the direction of the watercourses and lines of watersheds are determined. The general nature of the forest area, representativeness of various categories, forest plantation diversities are revealed. After evaluating the representativeness of various area categories in the quarter, decoding of the topographic objects is performed. The poorly-visible roads and brooks are drawn. The non-forest areas (haymaking and plowing areas, swamps, farms) are marked. The uncovered forest areas (clearings, wastelands, cuttings, burnt-out areas) are demarcated. There may be marked some other categories of forest areas with well-visible borders, e.g. forest cultures, young stands among mature forests, and others The selection /demarcation of all the categories of the areas is carried out with proper detailing, depending on the taxation category (correspondingly, on the average, minimum and maximum area of the forest-taxation subcompartment).

The third stage of contour decoding consists in dividing the quarter into large forest sites – generalized subcompartments, as a rule, combining several taxation subcompartments with close taxation characteristics. After selecting the large generalized subcompartments, having objective natural borders, there comes the last stage of contour decoding – detailing of taxation subcompartments. The detailing of taxation subcompartments implies division of generalized subcompartments into maximally uniform/homogeneous in taxation value sites with the area meeting the requirements of the forest inventory instruction.

The preparation for contour decoding of aero- and space photography materials in the Photomod consists in the following:

- receiving a prepared project in the Photomod with the photography materials;
- loading the required raster and vector layers (borders of forestries and quarter clearings, protective forest categories, hydrography, roads) into the project;
- formation of a new vector layer (layers) to save the results of contour decoding.

In order to optimize the work on contour decoding, the following sequence of actions is recommended (on the example of a small site):

Crop the available vector ( LIS Smolevichsky forestry) schematically in the ArcGis, save the desired vector area as a separate shape-file, and export to the Photomod. *Vectors – Import – shp* (figure 3.1), and then *Save as* in the Photomod structure.

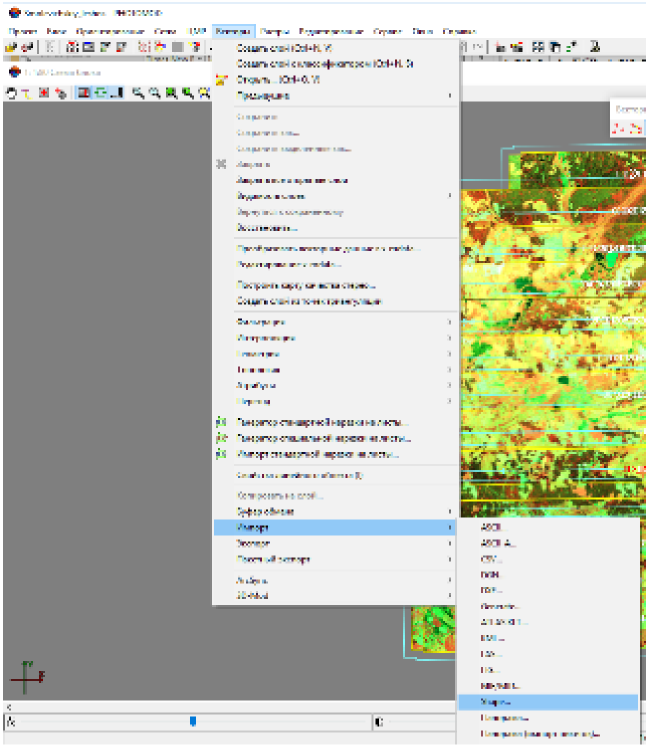

Figure 3.1 – Import of the shp-file

When opening a stereo pair *(Windows – new 2D window*) and enlarging the image, it's seen that the LIS contour doesn't match the image situation. It happens because the vector lies at the wrong height. Besides, as seen in figure 3.2, the stereo pair flits depending on the direction of the flight, so it's necessary to work with the inverted vector. This situation cannot be corrected.

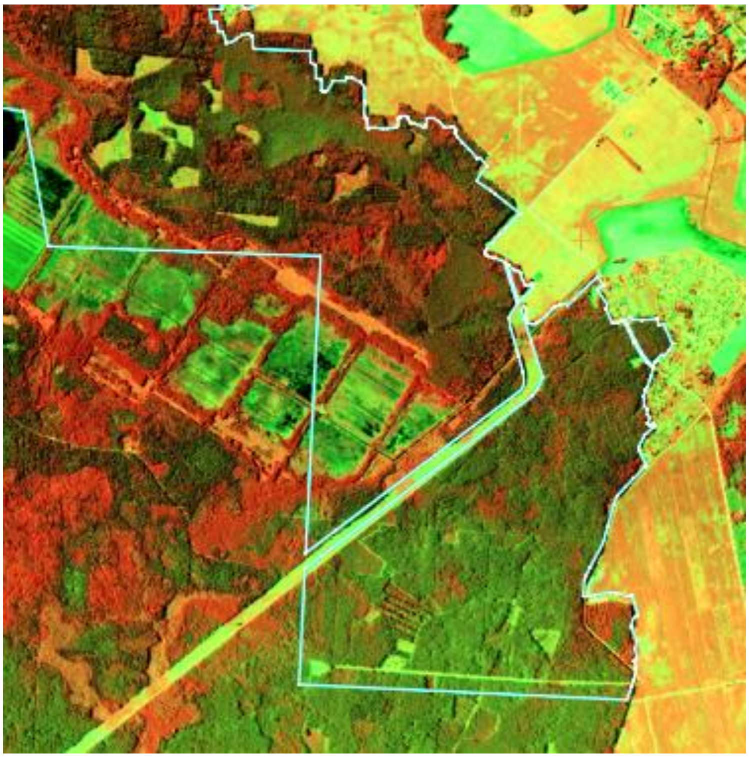

Figure 3.2 – An imported vector

So that the vector lies according to the situation, you should "plant" the LIS vector on the average tree height. Define the tree heights in several places with the spacebar, set the cursor to the average height. Then, select all the objects and raise them (with the key *K*) to the height of the marker. Now, the contour matches the situation in the picture (figure 3.3).

Figure 3.3 – A vector "planted" by the height

Quarters, subcompartments and other vector objects can be loaded in this way too. It should be noted that the territory height of each stereo pair differs a little, so when opening each stereo pair, it's necessary to "replant" the vector to the required height. It's possible to immediately project the vector to the matrix of heights, if it's available.

The available LIS layer is the main editable layer. Quarters are built on the basis of the LIS layer by the polygon line breakdown method. Draw polylines in the editable layer (cut off the LIS layers), using the hotkeys *SHIFT + V* (attraction to the vertex), *SHIFT + L* (attraction to the line). If necessary, use the 2D and 3D snapping, but if the old quarters are poorly drawn, the lines will only interfere. *Vectors – Open polyline input mode*. In order to cut the polygon with a polyline, select the polyline and perform the following sequence *Vectors – Topology – Cut polygons (polylines).* If there are unnecessary polygons, *Delete*. That is the procedure of cutting the LIS into quarters. This operation is performed in the stereo mode. The result (in figure 3.4) is vividly seen in the plane.

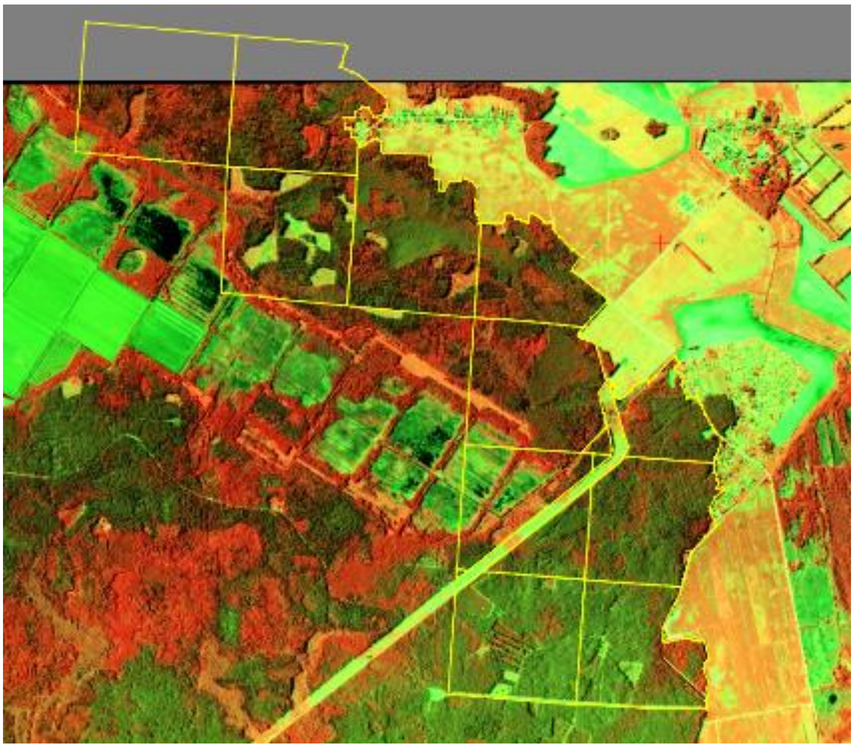

Figure 3.4 – Quarters, built in the Photomod window

**Input of the attribute information.** After creating vector objects, it's necessary to set their attributes. Entering (input of) the attribute (address) information for the vector objects is performed in the following sequence:

- selection of a vector object;
- selection of the key *Object attributes*  of the panel *Vectors* (figure 3.5);
- entering (input of) the number of the quarter and subcompartment into the attribute fields, generated earlier.

The quarter number should be entered automatically for all the vector objects:

- select all the layer objects related to one quarter;
- add the attribute *SQ* (area) and *Kv* (quarter number), if necessary, add the numbers of the forestry and the forest enterprise
- enter the quarter number in the paragraph *Default value*, click *OK*.

There exists a possibility of automatic calculation and recording (in the attribute table) of the subcompartment/object area using the tool *Vectors→ Attributes → Automatically filled attributes of the layer*.

Thus, the area can be set automatically, each quarter number should be set manually..

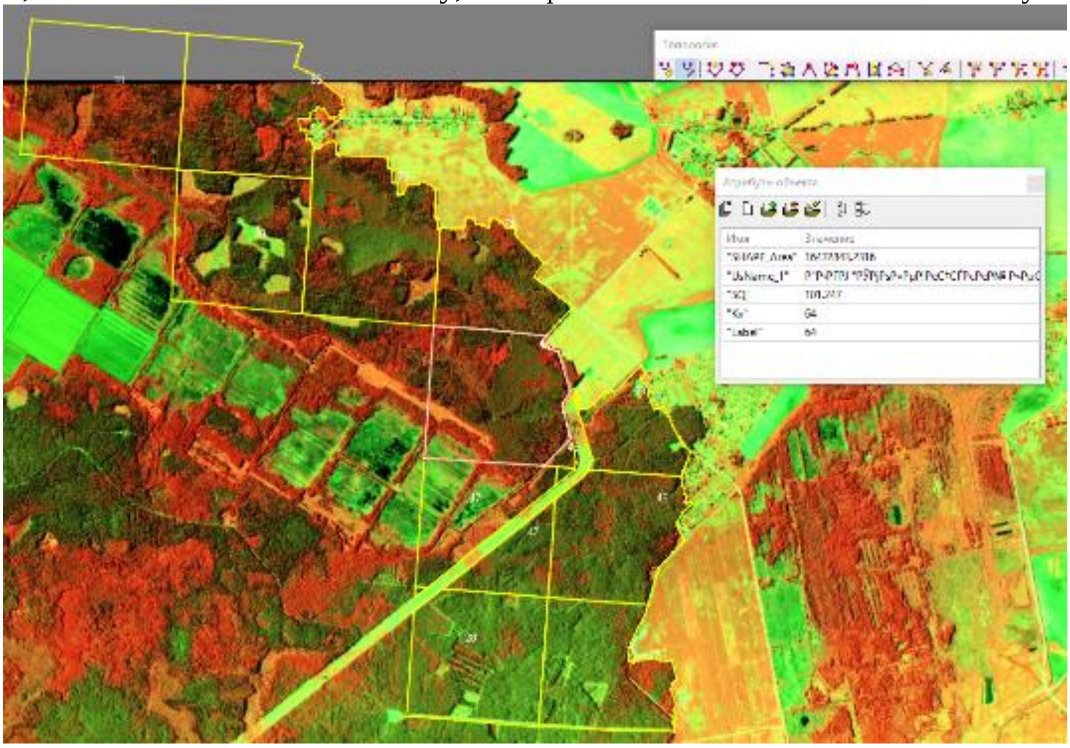

Figure 3.5 – Attributes of objects in the Photomod Window

The system provides the possibility of creating signatures of the vector objects both from the attribute values and code table fields, and in the form of coordinates.

In order to create signatures to the vector objects, perform the following actions:

1. Select *Vectors* > *Attributes* > *Create signatures*. The window *Create signatures* opens.
2. Select one of the signature creation options.
3. Click *OK*. The signatures to the selected objects are displayed in the 2D window.

After entering all the attributes of the layer, the following error checking is performed (the function is available only for the software package “PHOTOMOD” StereMeasure version):

- blank attribute values (missing values of numbers of quarters and subcompartments);
- mismatch of the attribute values to the specified type;
- presence of a duplicate specified set of attribute values within the vector layer.

It’s necessary to execute (in the 2D menu) the command *Vectors/Attributes/Check layer semantics*. In the window *Semantics check*, using the key , add the attributes («quarter №», «subcompartment №»). Select the criterion to check, launch the control, correct the errors.

The subcompartment decoding can be carried out by two methods: by polylines and by cutting the available polygon (similar to the quarter decoding).

The overall picture of the territory is clearly visible in the stereo mode; the nature of the relief can be assessed. But, when you zoom in, the image blurs, and it’s more difficult to demarcate the border. So it’s possible to correctly assess the situation, in order to correctly demarcate the borders of subcompartments.

When decoding subcompartments by the method of cutting (dividing) the training grounds (polygons), it’s recommended to decode each quarter in a separate file. Otherwise, it’s possible to randomly adjoin a sucompartment from the adjacent quarter. The given method has several disadvantages. Firstly, decoding is to start from the edge of the quarter, and that contradicts the instruction to start with selection of the most easily demarcated sites. Secondly, only adjacent sites are easily cut (divided), the program is unpredictable in reference to the sites located in the middle. There are cases, when cutting the sites, that one site is cut (divided) and the adjacent sites are merged. This process hasn't been investigated properly yet, but it proves, that it's necessary to check the layer for the topology errors in the ArcGis, since it's possible to find an error in the Photomod, but it's difficult to correct it.

When cutting the polygon by polylines in the stereo window, there will appear an effect that the quarter border moves. This is only in stereo; on the plane the border doesn't shift. This can be seen when viewing the contours on the plane. Figure 3.6 presents quarter 78, decoded by cutting into polygons.

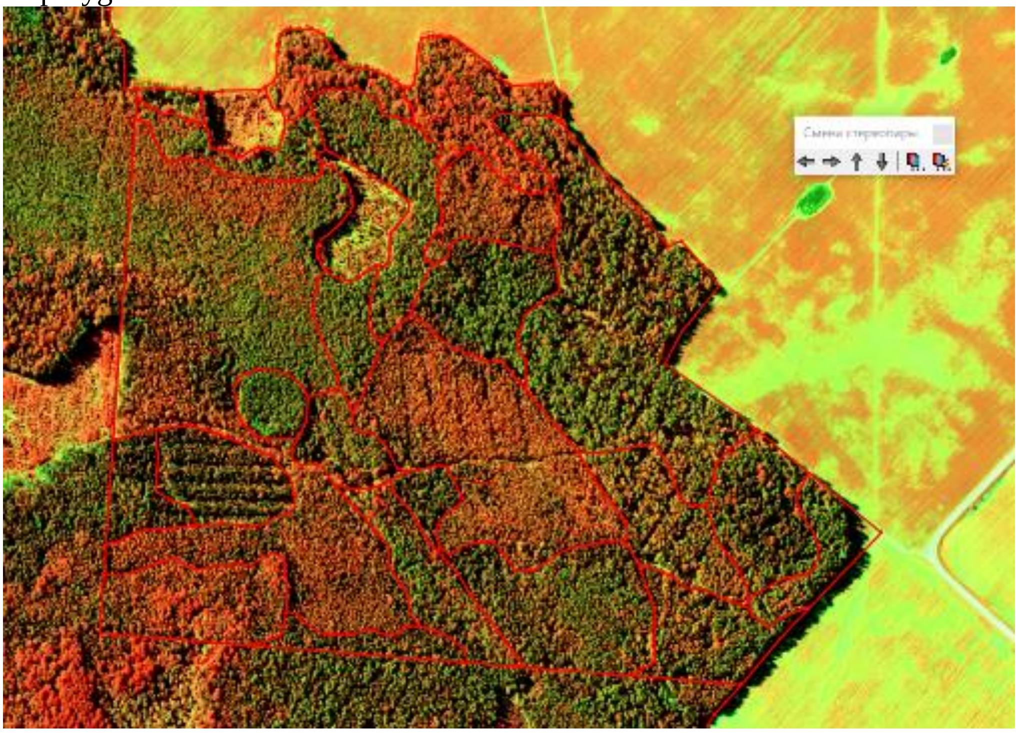

Figure 3.6 – A decoded quarter in the stereo mode

The method of polylines is proposed as an alternative method for dividing quarters into subcompartments. When drawing polylines, it's necessary to ensure that the ends go out of the contour; but they shouldn't intersect as seen in figure 3.7 (otherwise, extra polygons are formed). It's recommended to use *SHIFT+V* for attraction to the vertex so as the contour curvature should be smoother. The keyboard shortcut works only for the layer under editing; and if it's necessary to be attracted to the LIS, the 2D snapping should be used.

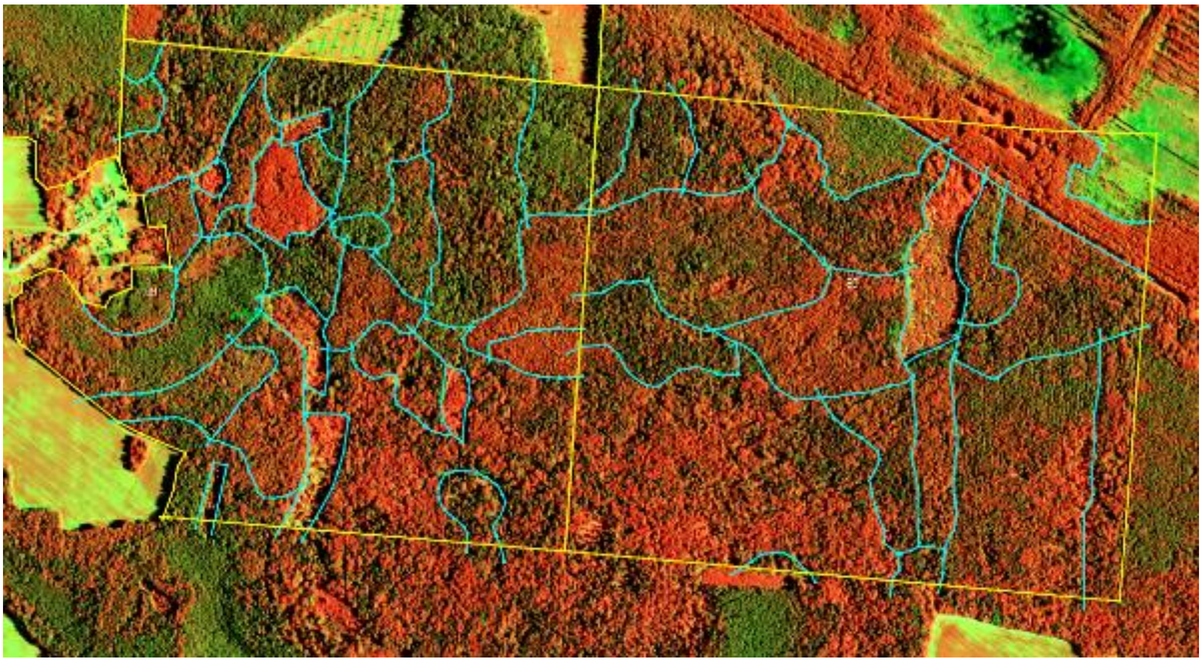

Figure 3.7 – Decoding by the method of polylines (quarters 89 and 90, the Klenninskoye subforestry)

When vectorizing the borders of forest-taxation subcompartments in the stereo mode, it’s recommended to adhere to the following rules:

- perform the digitization (vectorization) at the average height of the subcompartment first tier (if necessary, adjust the marker position in height with the mouse wheel);
- set the optimal number of polyline (polygon) vertices to make the subcompartment borders smooth without sharp turns; it’s undesirable to add the vertices too often (it will lead to the decoder’s fatigue and will be labor consuming) or too rarely (it may lead to creation of “saw-like” borders uncharacteristic of natural objects);
- perform the adjoining of common vertices for adjacent polygons (when creating a new polygon, adjoin the vertices to the adjacent polygon using the function of snapping);
- don’t create too small in area subcompartments (the minimum subcompartment area is 0.1 ha., depending on the inventory category);
- select the scale convenient for vectorization taking into account the scale of the output cartographic materials; it will help to avoid creating small subcompartments and subcompartments with narrow elongated borders (that’s typical of contour decoding with high magnification);

Figures 3.8 and 3.9 present the results of decoding quarter 64 of the Klenninskoye subforestry of the SFI “Smolevichsky forestry” and the overall view of the decoded subcompartments.

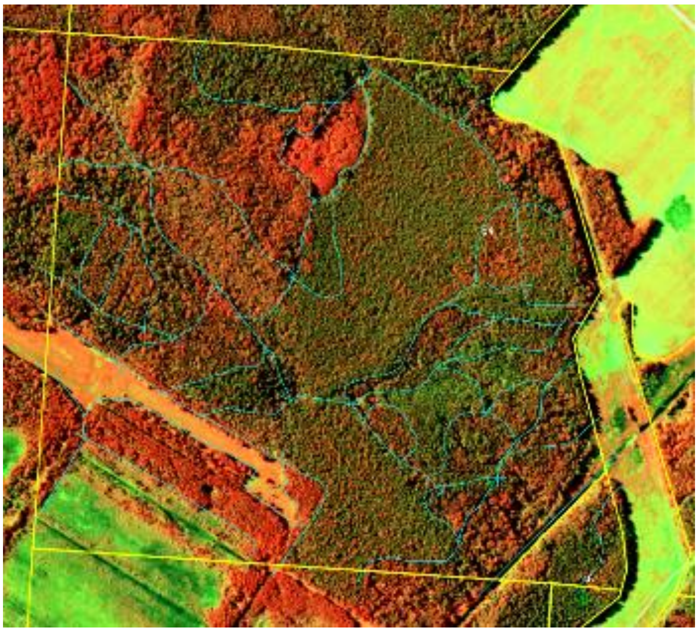

Figure 3.8 – A quarter, decoded by the method of polylines

Figure 3.9. – The quarters of the Klenninkskoye subforestry, decoded in the stereo mode

**3.3. Measuring decoding**

The analytical way of decoding implies the eye determination of the composition, age class and forest type of the plantation on the basis of the previously studied decoding attributes. The relative density is determined on the basis of the eye evaluation of the canopy closeness and the established dependencies of the canopy closeness with the density, the tree species and the plantation height. Using the software package PHOTOMOD StereoMeasure tools, there are measured such taxation indicators as: height of the plantation canopy or of the forest element, crown diameter, degree of the canopy closeness, number of the trees.

The methodological sequence of actions during taxation decoding in the software package PHOTOMOD is as follows:

- Preparation of the object project for decoding in the Photomod.

- Determination of the forest type (forest-growing conditions) and bonitet class.
- Determination of the plantation composition formula.
- Determination of the average heights of a forest tier and of forest elements.
- Determination of the average diameters of forest elements.
- Determination of the age.
- Determination of the relative density.
- Determination of the stock/reserve per 1 ha.

The sequence of the decoding taxation indicators depends on the specific conditions. The first one for decoding is the indicator which is decoded most confidently.

**Determination of the forest plantation composition**.

Determination of the composition formula using circular plots/platforms is carried out in the following way:

- inside the circular plot/platform, count the number of visible horizontal projections of the tree crowns for each species;
- measure the average diameter of the crowns and the height of trees for each species;
- determine the average trunk diameter at chest height (on the basis of the established relationships);
- determine the average area of the cross section of one tree for each species (according to the circle area formula);
- multiply the average cross section area by the number of trees for each species;
- determine the sum of the average areas of the cross section for each tree species and establish a preliminary composition formula;
- taking into account corrections for the invisible (in the aerial photography images) horizontal tree crown projections, determine the final composition formula (the percent of the visible and of the invisible tree crown images may be determined according to the data of the trial areas laid in the given region).

A circular plot/platform is an object of a standard geometric shape; its creation requires the following sequence of actions. *Windows*> *Toolbar* > *CAD objects* or set the parameter *Editing* > *Object input mode* > *CAD objects* The window *CAD objects* opens to select one of the toolbar buttons (figure 3.10). Then, press *Insert* to start the object creation. The parameters and size of the object are set by juggling the mouse and pressing *Insert*. Upon the completion of the object creation, it's necessary to press *Enter;* to cancel the object creation – *ESC*.

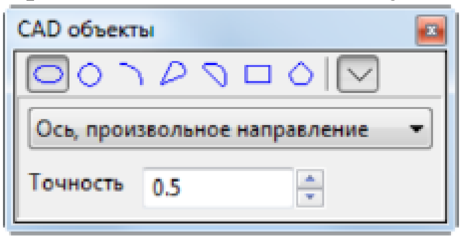


Figure 3.10 – The window "*CAD objects"*

Under stereo-decoding conditions, it's possible to count the number of trees for each species; wherein, it should be done not with a large scale because the image starts to blur. It's easier to count the number of trees in subcompartments with 1 – 2 tree species presented. If there are more tree species, it's practically impossible to differentiate species among the broad-leaved trees (figure 3.11).

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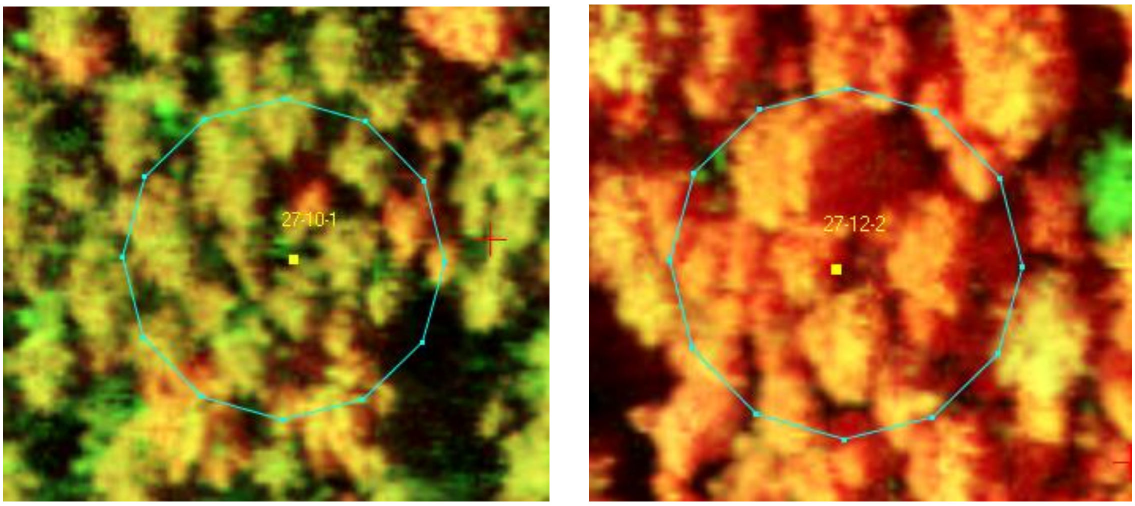


Figure 3.11 – Determination of the forest plantation composition by the method of circular plots/platforms

**Determination of the average height of the forest element and the tier**

The heights of forest elements (an average tree tier of a forest plantation) are determined by measurement of the point elevations in the stereo mode. In small in area subcompartments, there are measured 4 – 5 trees with the average height value, two trees with the minimum and two trees with the maximum height values. In subcompartments of a large area or of a complex configuration, measurements of the tree heights are made in various parts of the subcompartment. The measurement results are summed up and averaged for each tree species.

The technical difficulty, when measuring tree heights in the stereo mode, is the right choice of the base and the top of the tree. The accuracy of determining the tree height depends on the accuracy of measuring the heights of the base and the top of the tree.

When determining the bottom point of the tree base, it's required to take into account the height of the grass cover, the under-forest and the undergrowth, and put the appropriate amendments into the measurement results. The tree top in a photo image is often located on the borderline of its own shadow and the lighted part of the tree crown.

The second difficulty consists in the situation that in the laid point there may not be any clearly visible tree top where the correlation coefficient is low. Besides, with increase of the scale, the image in stereo starts to blur, Thus, sometimes, it's more efficient to measure the height of an adjacent tree which misses the circular plot but is clearly visible.

The sequence of actions for a semi-automatic measurement of tree heights in the program Photomod StereoMeasure is the following:

- open the window *Measurements* on the 2D-window panel (figure 3.12)

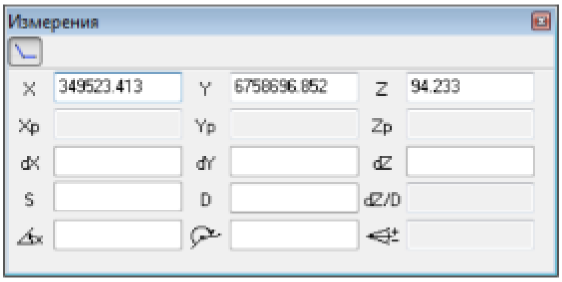


Figure 3.12 – The window "*Measurements*"

– - select a tree for determining the height;

- select the place to determine the height at the ground level (a clearly visible site of the ground, free of vegetation next to the tree);

- set a convenient viewing angle (scale);

- using the mouse wheel, lower the marker to the bottom of the reference point (the height of the lower point and the marker height should coincide visually) and fix it with the right mouse button or the key *Insert*;

-“raise” the marker to the height of the tree or tree groups using the mouse wheel or pressing the spacebar to automatically snap.

The tree height will correspond to the value **dZ** in the dialog window “*Measurements*”.

The result of the height measurements can be seen in figure 3.14.

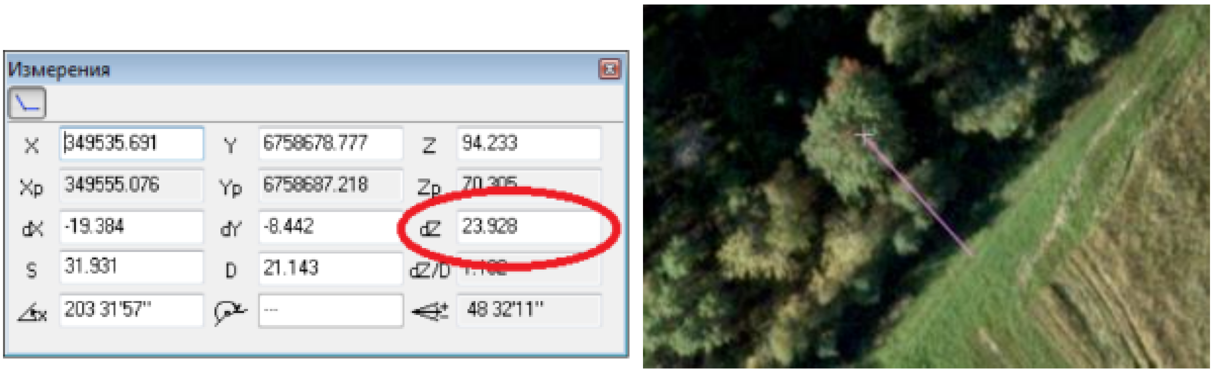



Figure 3.14 – Measurement of the height in the stereo mode

However, it isn’t always possible to find a tree at the edge of the forest; then, it’s necessary to measure the height of the ground’s surface separately and to keep the tree height in mind.

Measurements of the tree heights (subcompartments) can be made in manual and semi-automatic modes, and the values are entered in the attribute *Height* in the automatic mode.

The DEM with accuracy 0.5m is imported for semi-automatic measurements. The relief matrix can be created directly in the project for the operator convenience. The procedure of creating/constructing matrices of terrain and relief will be dwelt upon in the next section of the text..

The objects (subcompartment borders; a point determining the polygon height) are raised to the average tree top heights *H_top* and through the option *Vectors* > *Attributes* > *Write the height of the object above the matrix in the attribute*, the relative height of the forest canopy (*Height*) above the ground surface (*H_ground*)e is entered.

The software PHOTOMOD also provides the possibility of automatic creation of the digital terrain matrix (DTM) containing the heights of trees, houses and infrastructure objects, and the digital elevation matrix (DEM) describing only the level of the ground surface. The arithmetic difference between the DTM and the DEM is interpreted as the forest height used for the quantitative evaluation of the tree stand taxation characteristics.

**Determination of the average diameters of the tree stands of forest elements.**

The average diameter of the tree stands of forest elements cannot be directly measured. For its determination, it’s necessary to determine (by measuring) the average height and the average diameter of the crown and, according to the corresponding graph, table or equation, to determine the average diameter at chest height. The dependent variable in the equations is the average crown diameter, the independent variables are the taxation-decoding indicators, determined during natural measurements in the trial areas (average height, average crown diameter, crown closeness) or subcompartments by selective, measuring or enumerating taxation.

For the measurement of the average crown diameter in the Photomod, it’s necessary:

- open the window *Measurements* on the panel of the 2D-window;
- place the marker on the crown edge;

- fix the marker position, pressing the key *Insert* or the right mouse button;
- place the marker (using the left mouse button) on the opposite end of the crown.

The diameter of the horizontal projection of the tree crown will correspond to value *D* in the dialog window *Measurements*. The measurement of the tree crown diameter is performed in two directions – from north to south and from west to east. The results are summed up, averaged and entered into the table of the object attributes (figures 3.15 and 3.16). For measuring the crown diameters, it's necessary to select trees with clearly visible crown projections, close in height to the average. The crown diameters can be measured both in the stereo mode and in the horizontal plane

.

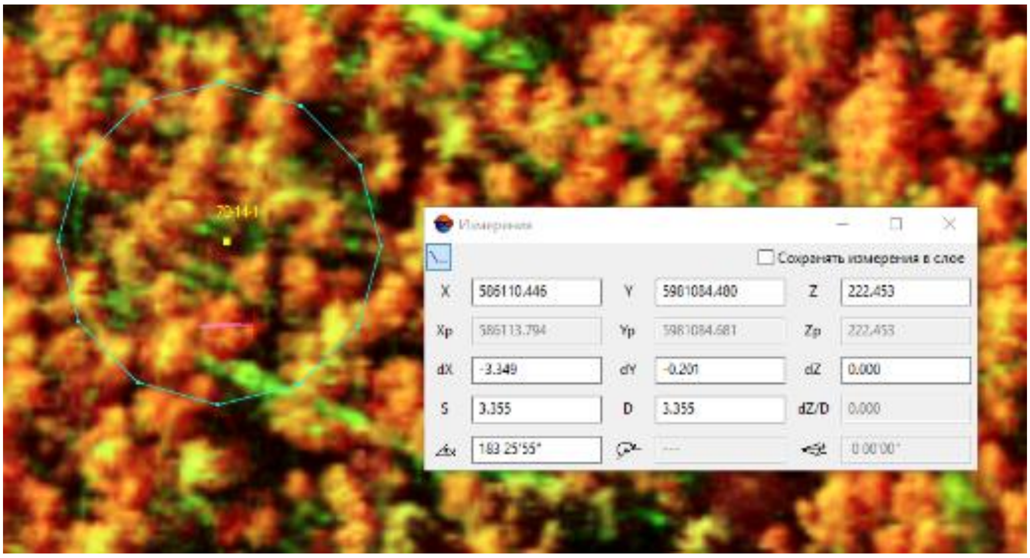



Figure 3.15 – Measurement of the crown diameter in the stereo mode

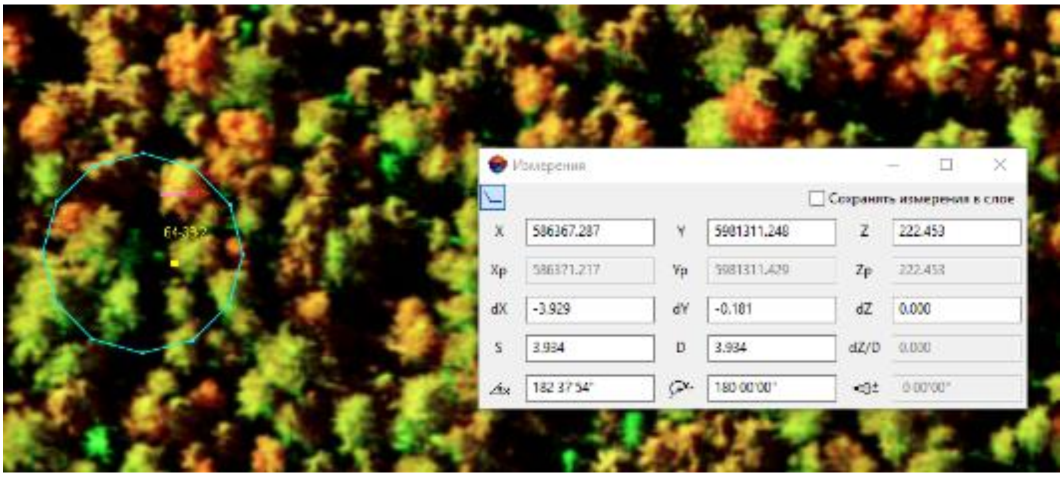



Figure 3.16 – Measurement of the crown diameter in the stereo mode

However, the measurement of the width is possible only when tree crowns are well-distinguishable. In figure 3.17, we see merged tree crowns, so it's practically impossible to measure the tree crown diameters in this place. So, in order to measure the crown diameters, it's necessary to select trees with clearly visible crown projections, close to the average in height.

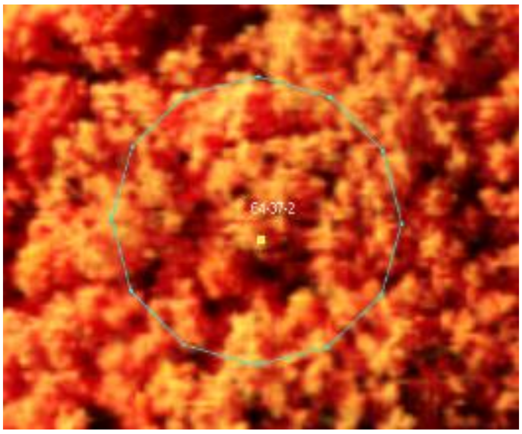




Figure 3.17 – An example of determining the crown diameter

When determining the average diameters of the tree stands of forest elements on the basis of the established dependencies on the average crown diameters, it's necessary to measure the crowns of 6 – 10 trees, to calculate the arithmetic value and to find (according to the graph) the corresponding value of the average diameter at chest height (figure 3.18).

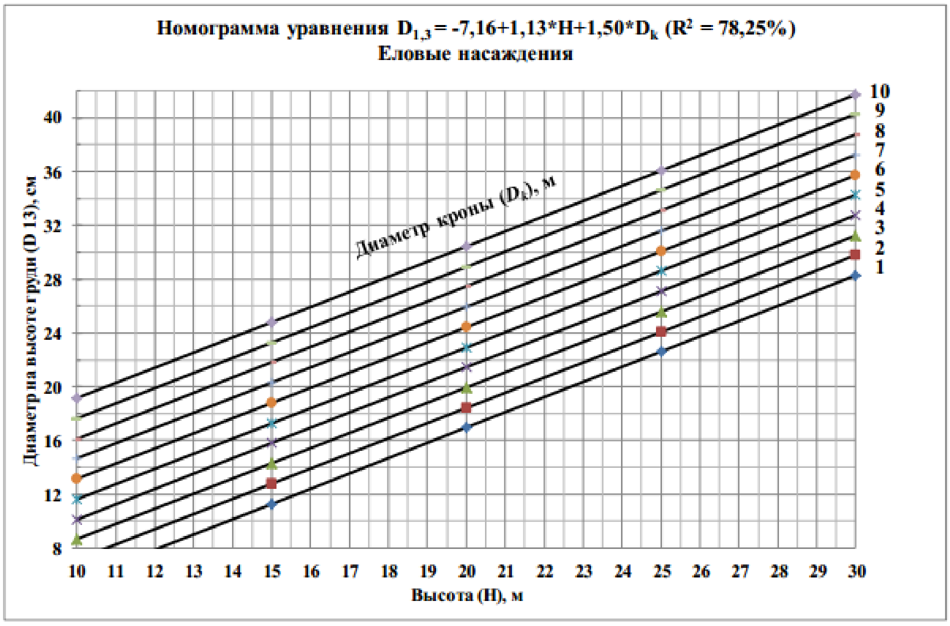




Figure 3.18 – A table of the relationships of the crown diameters and the tree heights, for coniferous plantations

**Determination of the relative density (closeness) of the canopy**. It's important to know that the density of plantations with the presence of large rounded and blunt crown projections in the canopy appears to be higher in a photo image than actually (e.g. in deciduous plantations). The presence of spiky crowns in the canopy (e.g. in spruce plantations) creates an opposite effect of a lower density.

In the program Photomod StereoMeasure, the module for determining the canopy closeness was implemented. The value of the canopy closeness allows to determine the relative plantation density through the established relationships.

The measuring way of determining the relative density in the program Photomod StereoMeasure is the following:

- open a stereo pair with the forest under analysis; select *Grid* > *Create;*
- select *Grid* > *Properties* and set the grid pitch based on the image resolution;

- press and hold *Shift* to draw a rectangular grid on the area of the forest. The grid should extend beyond the boundaries of the forest (figure 3.19);

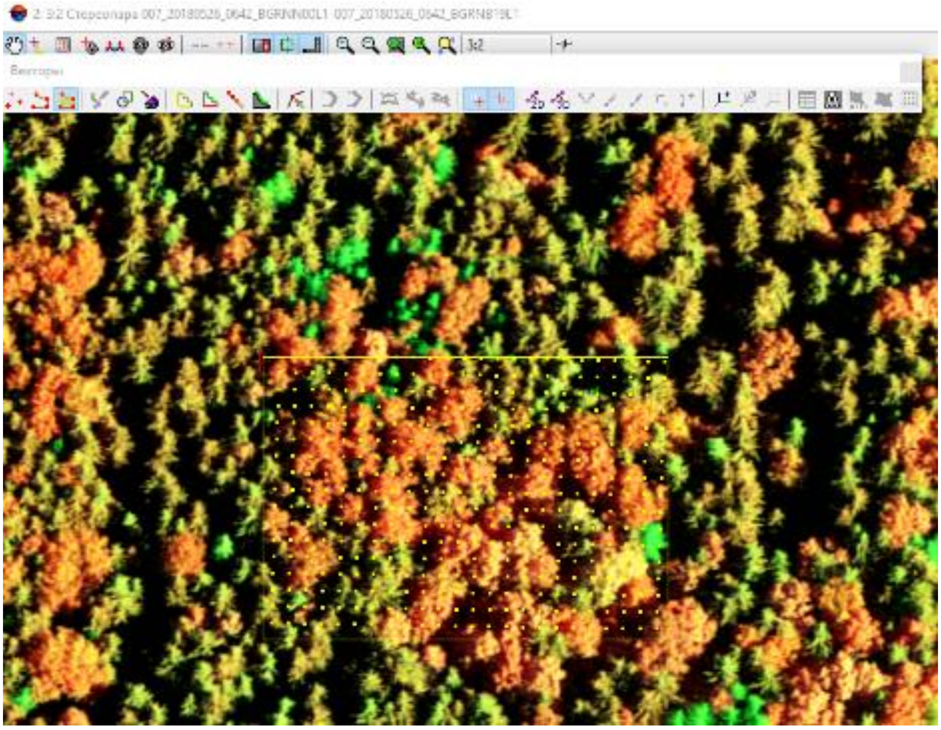


Figure 3.19 – Creation of a grid

- select *Vectors* > *Create a layer* to create a vector layer without the classifier;
- create the polygon so that its boundaries coincide with the forest boundaries;
- select *Grid* > *Create borders from vectors*; as a result, the grid contour is limited to the created polygon (figure 3.20);

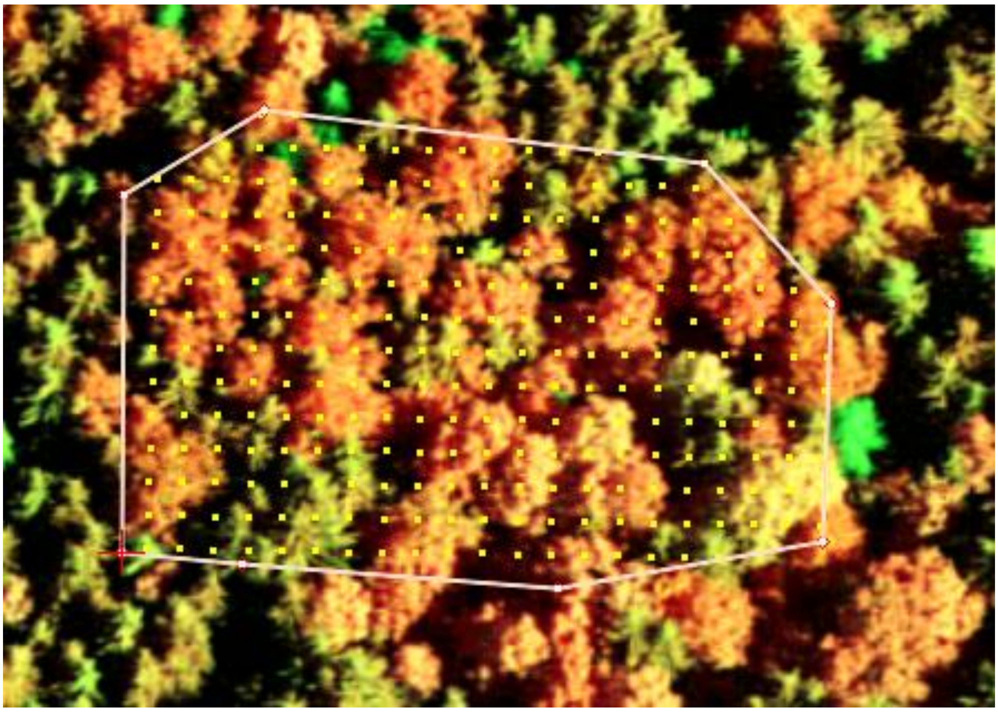


Figure 3.20 – Grid borders, created from vectors

- make active the layer *Grid* in the window *Layer manager*;

- select *DEM* > *Pickets* > *Profiling mode* > *Enable* or click the button on the additional toolbar *Profiling mode*; the marker then is positioned in the first grid node;

- if the grid node hits the tree crown, press *Enter* to create a point in this node. Press *Delete* to skip the grid node. The transition to the next node of the grid occurs automatically. To return to the previous grid node, press *Backspace*;

- on passing all the grid nodes, the message appears *Bypass completed*.

The system also provides the possibility to put points manually on the grid within the polygon without using the profiling mode. But, it's necessary to observe the accuracy of picket positioning in the plan relative to the grid nodes within one third of the distance between the grid nodes.

- Make active the layer *Vectors* in the window *Layer manager*.

- Select *Vectors* > *Attributes* > *Calculate the canopy closeness* or click the button on the additional toolbar *Vectors.*

For calculating the closeness, select *Counting pallet nodes – On tree crowns*. For calculating the value of the reverse closeness, select *Counting pallet nodes* > *Between tree crowns*. With the high density of trees, it's more optimal to put points between the tree crowns. In this case, select *Between tree crowns* to calculate the closeness value (figure 3.21).

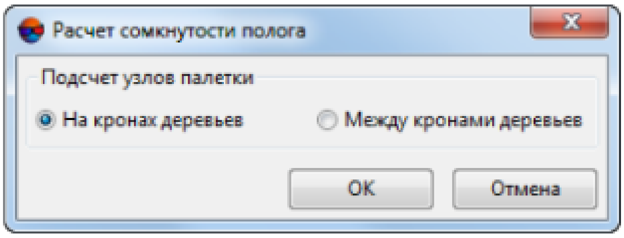



Figure 3.21 – The window "*Canopy closeness calculation*"

Click *OK*. The message with the calculation results is issued. These results cannot be saved, it's only possible to take a screenshot (figure 3.22).

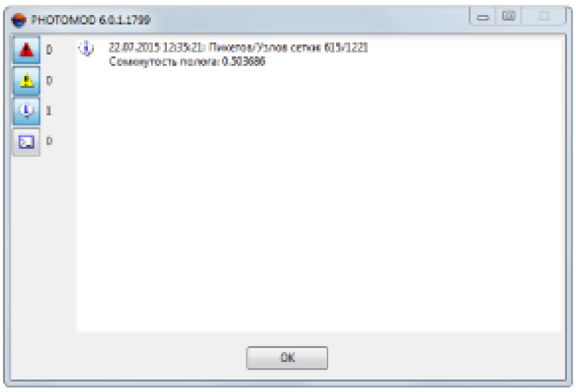



Figure 3.22 – A result of the canopy closeness calculation

The difficulty is that the tree tops aren't visible in all places; thus, it's necessary to move the grid so as each item of the grid maximally matches a tree top (figure 3.23).

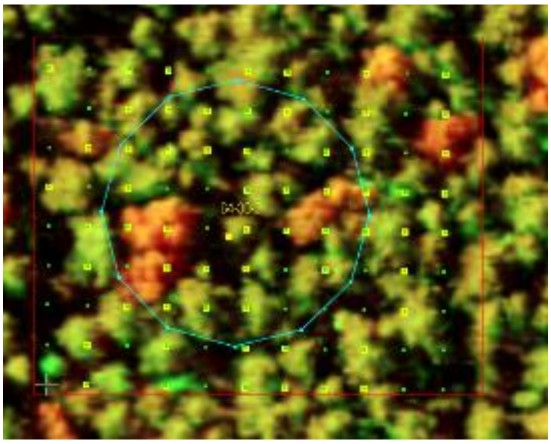


Figure 3.23 - A fragment of the grid

The plantation density is determined by the value of the degree of closeness (using equations, graphs and nomograms). The established multiple relationships between the taxation and decoding indicators can also be used for determination of the plantation density (figure 3.24).

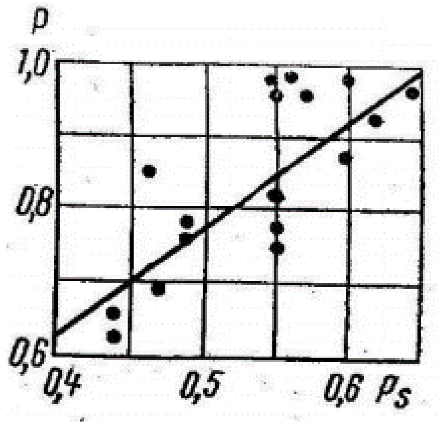



Figure 3.24 - Dependency between the canopy density and closeness in pine plantations, at the age of 70 – 130.

**Determination of the plantation stock (reserve).** The stock (reserve) of forest plantations is determined:

- according to the standard tables by the predominant species, tier height and relative density (figure 3.25);
- according to the established multiple relationships between the taxation and decoding indicators.

**4.1. Суммы площадей сечений (G) при полноте 1.0,**
**видовые числа (F), видовые высоты (HF)**
**и запасы (M) древостоев по относительным полнотам**

| Н, м | G, м² | F | HF | Запасы (м³) по относительным полнотам | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1,0 | 0,9 | 0,8 | 0,7 | 0,6 | 0,5 | 0,4 | 0,3 |
| | | | | СОСНА | | | | | | | |
| 3 | 10,3 | 0,906 | 2,72 | 28 | 25 | 22 | 20 | 17 | 14 | 11 | 8 |
| 4 | 15 | 0,767 | 3,07 | 46 | 41 | 37 | 32 | 28 | 23 | 18 | 14 |
| 5 | 19,2 | 0,667 | 3,33 | 64 | 58 | 51 | 45 | 38 | 32 | 26 | 19 |
| 6 | 22,1 | 0,633 | 3,80 | 84 | 76 | 67 | 59 | 50 | 42 | 34 | 25 |
| 7 | 23 | 0,627 | 4,39 | 101 | 91 | 81 | 71 | 61 | 51 | 40 | 30 |
| 8 | 23,9 | 0,617 | 4,94 | 118 | 106 | 94 | 83 | 71 | 59 | 47 | 35 |
| 9 | 25,5 | 0,593 | 5,33 | 136 | 122 | 109 | 95 | 82 | 68 | 54 | 41 |
| 10 | 27,1 | 0,572 | 5,72 | 155 | 140 | 124 | 109 | 93 | 78 | 62 | 47 |
| 11 | 28 | 0,562 | 6,18 | 173 | 156 | 138 | 121 | 104 | 87 | 69 | 52 |
| 12 | 29 | 0,552 | 6,62 | 192 | 173 | 154 | 134 | 115 | 96 | 77 | 58 |
| 13 | 29,9 | 0,540 | 7,02 | 210 | 189 | 168 | 147 | 126 | 105 | 84 | 63 |
| 14 | 30,7 | 0,530 | 7,43 | 228 | 205 | 182 | 160 | 137 | 114 | 91 | 68 |
| 15 | 31,5 | 0,521 | 7,81 | 246 | 221 | 197 | 172 | 148 | 123 | 98 | 74 |
| 16 | 32,2 | 0,495 | 7,92 | 255 | 230 | 204 | 179 | 153 | 128 | 102 | 77 |
| 17 | 32,9 | 0,504 | 8,57 | 282 | 254 | 226 | 197 | 169 | 141 | 113 | 85 |
| 18 | 33,6 | 0,498 | 8,96 | 301 | 271 | 241 | 211 | 181 | 151 | 120 | 90 |
| 19 | 34,3 | 0,491 | 9,33 | 320 | 288 | 256 | 224 | 192 | 160 | 128 | 96 |
| 20 | 35 | 0,484 | 9,69 | 339 | 305 | 271 | 237 | 203 | 170 | 136 | 102 |
| 21 | 35,7 | 0,478 | 10,03 | 358 | 322 | 286 | 251 | 215 | 179 | 143 | 107 |
| 22 | 36,3 | 0,472 | 10,39 | 377 | 339 | 302 | 264 | 226 | 189 | 151 | 113 |
| 23 | 36,9 | 0,467 | 10,73 | 396 | 356 | 317 | 277 | 238 | 198 | 158 | 119 |
| 24 | 37,5 | 0,461 | 11,07 | 415 | 374 | 332 | 291 | 249 | 208 | 166 | 125 |
| 25 | 38,1 | 0,457 | 11,42 | 435 | 392 | 348 | 305 | 261 | 218 | 174 | 131 |
| 26 | 38,6 | 0,453 | 11,79 | 455 | 410 | 364 | 319 | 273 | 228 | 182 | 137 |
| 27 | 39,2 | 0,449 | 12,12 | 475 | 428 | 380 | 333 | 285 | 238 | 190 | 143 |
| 28 | 39,6 | 0,446 | 12,50 | 495 | 446 | 396 | 347 | 297 | 248 | 198 | 149 |
| 29 | 40,1 | 0,447 | 12,97 | 520 | 468 | 416 | 364 | 312 | 260 | 208 | 156 |
| 30 | 40,6 | 0,443 | 13,30 | 540 | 486 | 432 | 378 | 324 | 270 | 216 | 162 |
| 31 | 41 | 0,441 | 13,66 | 560 | 504 | 448 | 392 | 336 | 280 | 224 | 168 |
| 32 | 41,4 | 0,438 | 14,01 | 580 | 522 | 464 | 406 | 348 | 290 | 232 | 174 |
| 33 | 41,7 | 0,436 | 14,39 | 600 | 540 | 480 | 420 | 360 | 300 | 240 | 180 |
| 34 | 42 | 0,434 | 14,76 | 620 | 558 | 496 | 434 | 372 | 310 | 248 | 186 |
| 35 | 42,2 | 0,433 | 15,17 | 640 | 576 | 512 | 448 | 384 | 320 | 256 | 192 |

Figure 3.25 – Relationships between the relative densities and heights of trees

*Notes to fig.3.25*: 4.1. Sums of cross-sectional areas (G) with density 1.0,
species numbers (F), species heights (HF)
and tree stand stock (M) by relative densities

An example of determining the stock/reserve per 1 ha. according to the standard tables for pine plantations with the average tier height 24m. and the relative density 0.7 (figure 3.26).

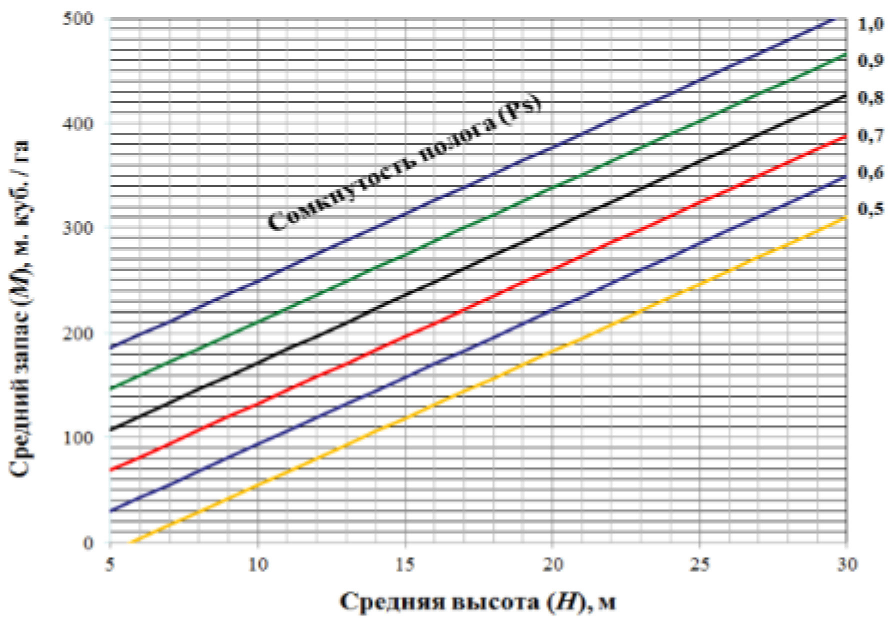



Figure 3.26 – An example of a nomogram of the regression dependency of the average stock and the average height

**Determination of the age class.** The tree stand age isn't directly depicted in remote sensing materials, but it determines the silvicultural condition of trees and the structure of the tree stand canopy. During decoding, a set of direct and indirect features/attributes are used for determining the age.

With the increase of the tree stand age, sizes of its tree crown projections increase; their color gets darker and the gaps between the tree crowns become larger. With age, the crown shape changes too - the relative tree crown length along the trunk decreases, the crown shape changes from conical (proper for younger trees) to obovate in mature and over-mature trees. Young and, especially, middle-age tree stands are characterized by a slight height differentiation. The difference in tree heights is more vividly seen in tree stands of older age.

The degree of the crown distinguishability is one more important feature when determining the age by the photo images. It should be noted, that the degree of crown distinguishability depends both on their sizes and (to a greater degree) on their crown density. The character of the crown shape changes with age depends on the region.

*The direct decoding features*/attributes for the age determination are the following:

- sizes of crown projections;
- image color of crown projections;
- sizes of gaps between tree crowns;
- crown shapes;
- relative crown length along the trunk;
- different tree heights;
- crown density;
- density of own and falling shadows.

*The indirect decoding features*/attributes foe the age determination are the following:

- confinement of a forest plantation to the landscape elements;
- types of forest-growing conditions, forest types and bonitet classes.

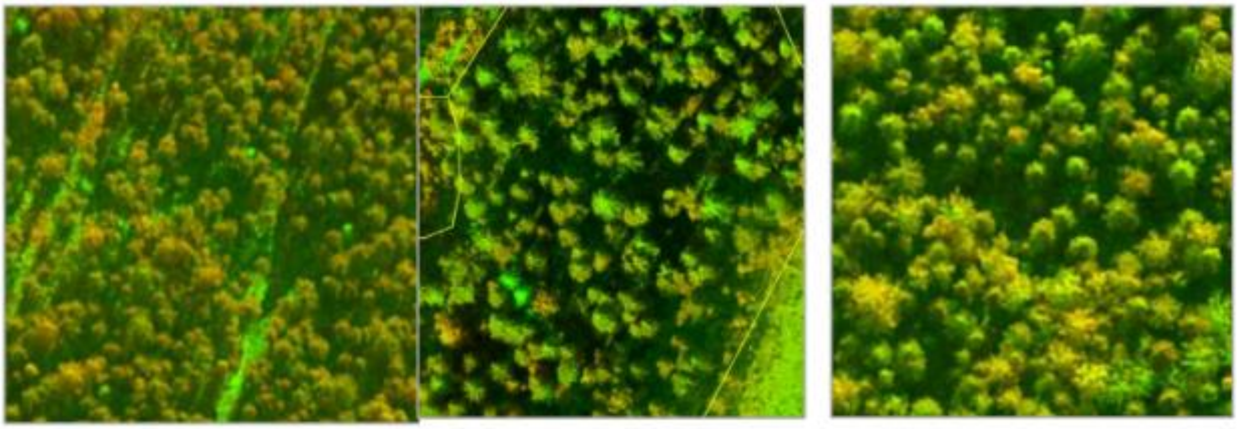
During decoding, determination of age classes may be carried out taking into account the following features/attributes:

Age classes 1 -2. The crowns of separate trees are non-distinguishable, but the canopy surface differs from uncovered forest areas by some elevation in relation to roads or clearings. The light color tone of the canopy image prevails. At the sides of young stands, there may be visible some narrow stripes of shadow. By the end of age class 2, some small gaps of the dark color tone may appear in the images.

Age class 3. Small tree crowns are visible, the gaps between the crowns are small and of the dark color tone. The crown projections are isolated from each other and are depicted as a dense grid of points.

Age class 4. The crowns and gaps between them are clearly visible. Different tree heights become noticeable. The canopy viewability is good – up to half the heights of the tree stand. In deciduous stands, there appear gaps in the canopy.

Some examples of the images of spruce plantations of various age in the aerial photography materials are given below (figure 3.27).



а б в

Figure 3.27 – An image example of spruce plantations in the aerial photography materials

а – plantations at the age of 70;
б – plantations at the age of 90;
в – plantations at the age of 120.

When determining the age, besides the direct and indirect decoding features, there may be used the established relationships (preferably multiple ones) between the taxation and decoding indicators. For example, the dependency between the height, the crown diameter, the tree trunk diameter and the age in pine tree stands (figure 3.28).

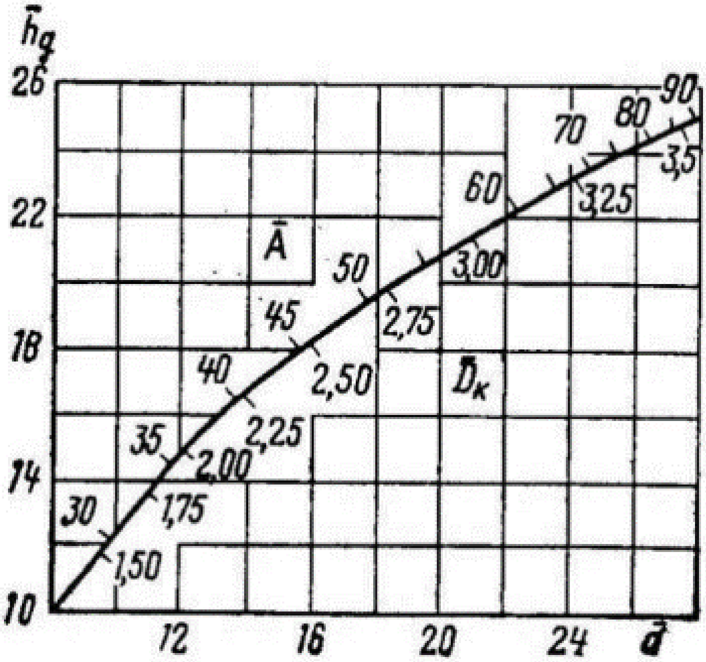



Figure 3.28 – Dependency between the height, the crown diameter the trunk diameter and the age in pine tree stands

**4. The database structure (the classifier).**

The existing methods of the forest cover analysis are used for compiling the database structure. Creation of the classifier is based on the method of the analysis of the decoding features of objects; its essence lies in identification/revealing, correlation and generalization of the values of the object features (attributes).

The classifier is a set of standard attributes used for thematic classification of objects. All vector objects that are created in a layer with the classifier, are attached to one of the classifier entries. The software PHOTOMOD provides the opportunity of creation, editing, import and export of the classifier (in the window *Classifier)*. The classifier is a tool of systematization of vector objects. Work with the classifier allows, for example, to select all the objects of one code, to delete them, as well as, to display various classes of objects in different colors.

The classifier is created for display of objects in symbols: layers of data and their attributes, fillable according to the requirements for forest inventory information management.

Table 4.1 presents the main layers and attributes of the data which are required when carrying out stereo-decoding.

Table 4.1− The database structure

| № | Database layer | Database type | Layer description | Main attributes |
|---|---|---|---|---|
| 1 | Border of a quarter Kvartal_polygon | Polygon | Border of a forest quarter | Area |
| | | | | Forestry number Num_lesn |
| | | | | Quarter number Num_kv |
| 2 | Border of a subcompartmen Vydel_ polygon | Polygon | Border of a subcompartment | Area |
| | | | | Subforestry number Num_lesn |
| | | | | Quarter number Num_kv |
| | | | | Geodesic ground height H_ground |
| | | | | Geodesic tree top height H_top |
| | | | | Tree height Height |
| 3 | Hydrography | Polygons (boggy) polylines (rivers) | Small rivers, brooks, boggy areas | Object reference geometry is specified in the field |
| 4 | Road network | Polylines | Forest and country roads,, paths | Object reference geometry is specified in the field |

The database structure is a direct part of the project PHOTOMOD and is saved when archiving the project. The use and editing of the classifier and objects are available both on the mounting table and in the mode of a stereo pair of photo images. The classifier conversion to the file is carried out with extension of *RSC. The classifier is a structure, mutually agreed with the GIS applications through the exchange of the data which have the file *DBF: *Windows > List of objects> Save as file *DBF*. For a successful exchange with other software products, the data (layers, codes, attributes and their values) encoding compliance is required in Latin letters, since Cyrillic isn’t always correctly displayed on import-export tables.

The database structure (data layers with attributes) can be automatically embedded in a new or an existing classifier from the exchange formats ArcGIS *SHP and AutoCad *DXF, with the presence of the file *DBF.

A step-by-step description of the classifier creation and editing is given below.

*Step 1*. The layers (data class), sublayers (data subclasses), codes of objects. The structure of the database of stereoscopic decoding is created on the mounting table in the tab: *Vectors> Create a layer with a classifier* (figure 4.1).

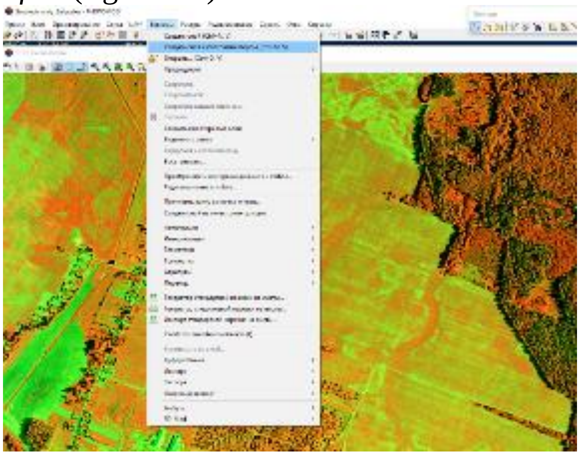


Figure 4.1 – Creation of the database structure

Through the tab *Windows > Toolbar > Vectors* (object geometry editing), open the icon *Show/Hide the classifier window* (figure 4.2)

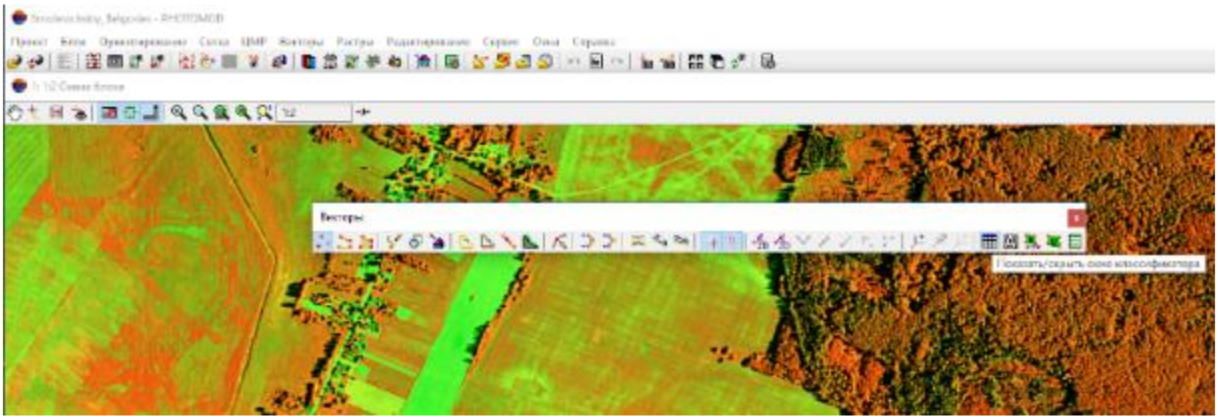


Figure 4.2 - The window "*Classifier*"

The desired class of objects (FOREST) is added (with the icon) in the left window *Add a layer* (figure 4.3).

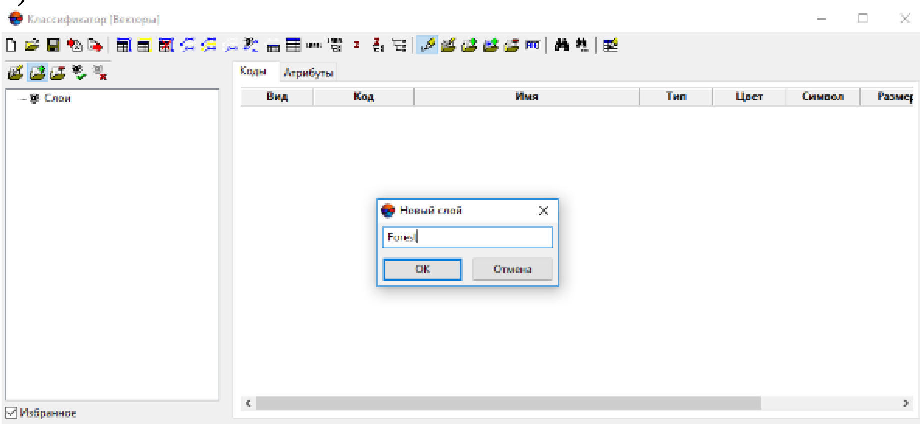



Figure 4.3 – Addition of a classifier layer

On the top right of the panel, with the icon *Add an object*, set its attributes – code (0001), code name (FOREST), type of an object (P – point, L – line, C – (circle) – Polygon). The line color and thickness are set for the user's convenience (figure 4.4).

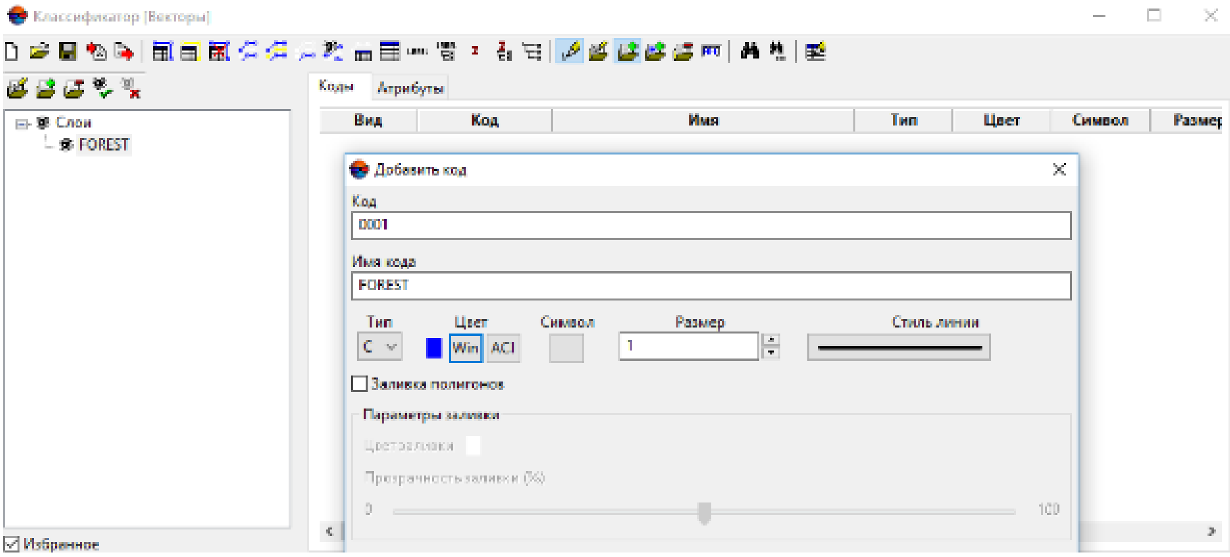



Figure 4.4 – Editing of a classifier code

*Step 2* The attributes of objects. In the tab *Attributes*, create the attributes of the object FOREST: :CODE NAME - choose the attribute type (text – a character string, integer – a list of values, float –numerical), the size, available only for editing the text type and description for export (figure 4.5).

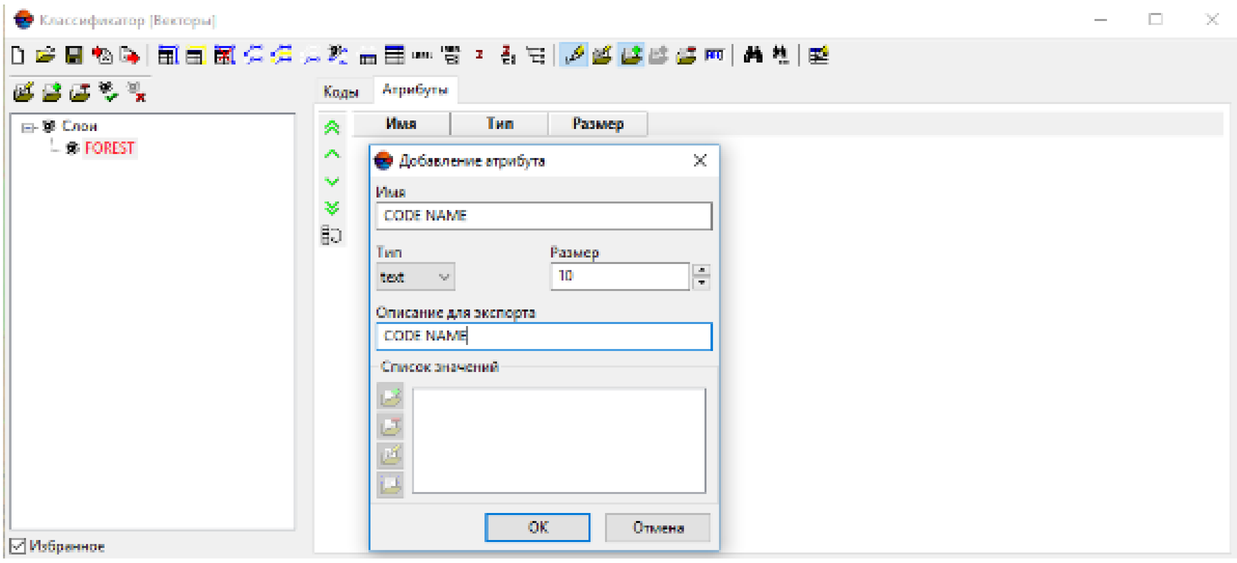



Figure 4.5 – Addition of an object attribute

*Step 3*. The import of the database from external sources. The import objects with their attributes and values from the file *SHP are automatically placed in the root directory *Classifier layers*. The names and types of attributes are displayed in the tab *Attributes*. Any object is selected on the mounting table and, with the icon *A*, the presence of the object attribute values is checked in the tab *Vectors* (figure 4.6).

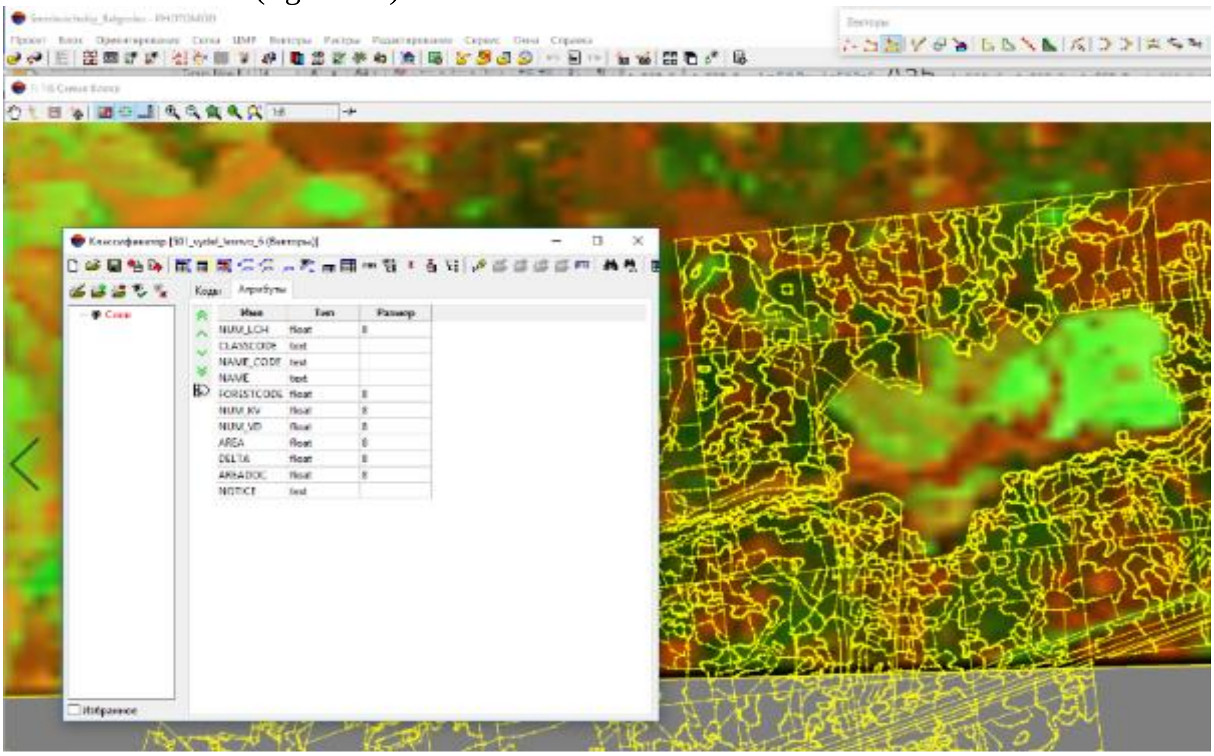



Figure 4.6 – Import of the database from the file *SHP *DBF

The object signatures are created by any of the attributes: *Vectors > Attributes > Create signatures >Attribute value*: FOREST CODE (figure 4.7).

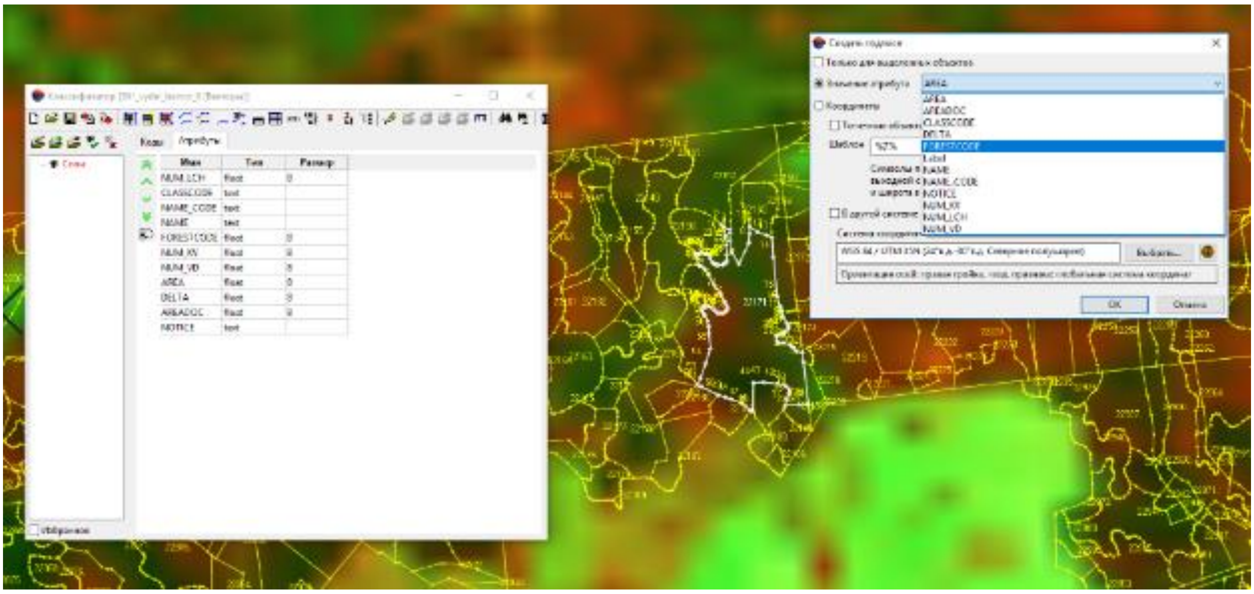


Figure 4.7 – Creation of the signatures by the attribute value

The selected object is assigned the desired code, with the icon, in the layer with the classifier Vydel polygon (figure 4.8).

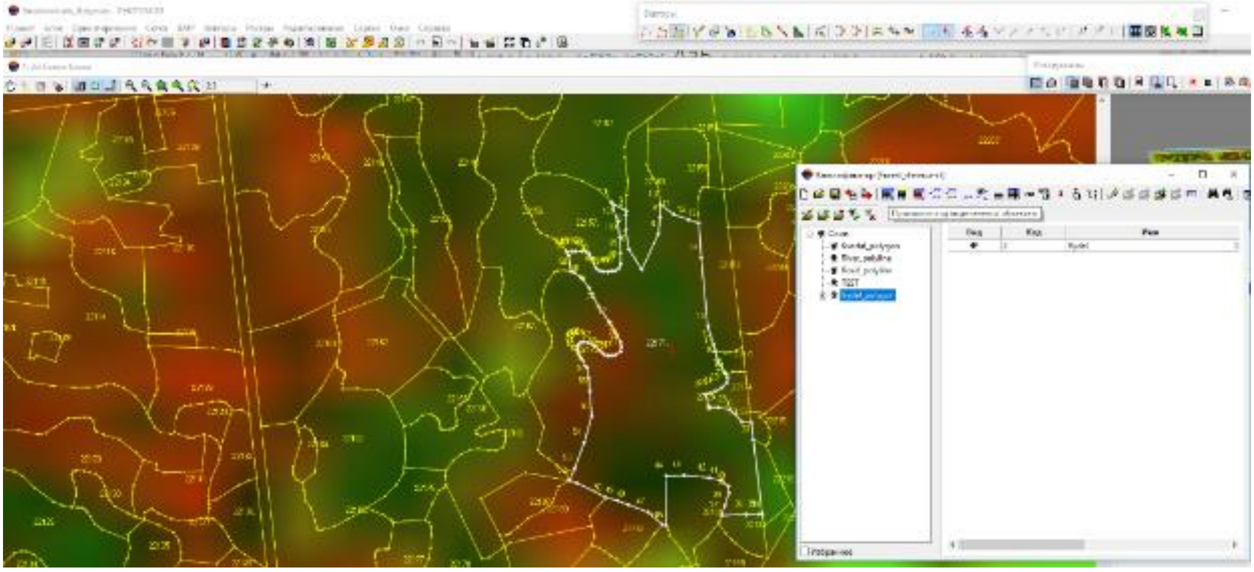


Figure 4.8 – The database structure inheritance from the file *SHP *DBF

The selected object is exported to the exchange format: *Vectors > Export > Shape*. The export file is assigned the layer name Vydel_polygon for the formation of the database internal file *DBF (figure 4.9).

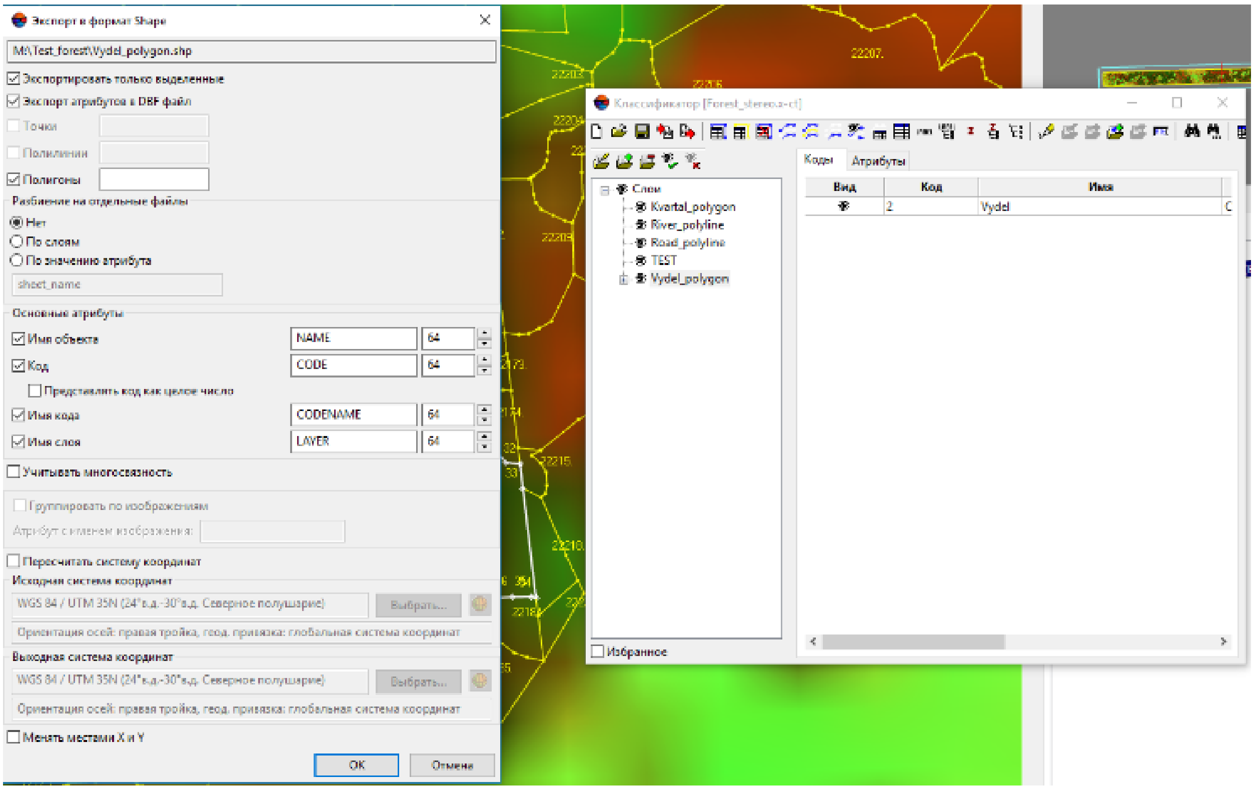



Figure 4.9 – Parameters of the object export to the format *SHP

The generated PHOTOMOD file: *Vectors > Import > Shape > Vydel_polygon shp* is imported to the layer with the classifier. The layer attributes appear in the tab *Classifier attributes* (figure 4.10).

*Step 4.* The classifier is stored in the project resources with the icon *Save*. If necessary the export to the external file *RSC is performed. As a result of the database structure creation, the existing and additional data layers, their attributes and values are combined. The data are ready for editing of the geometry and semantics of the objects under decoding (figure 4.11).

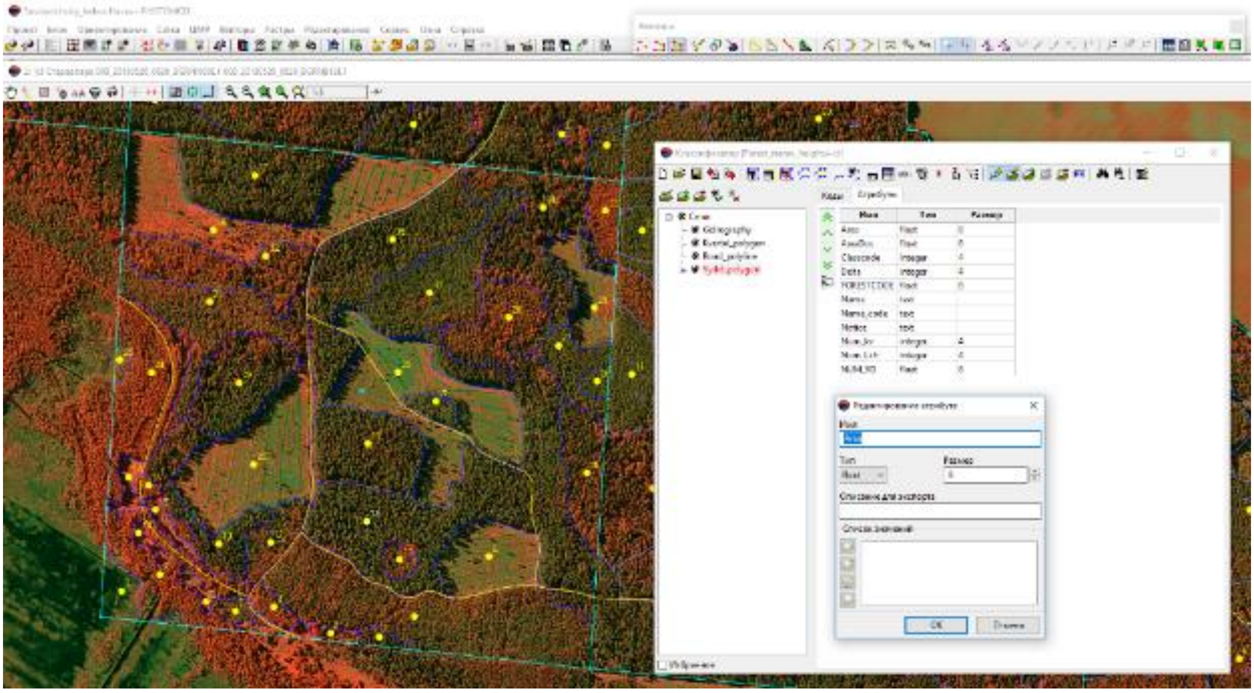


Figure 4.10 – Vectorization by the classifier in the stereo pair mode

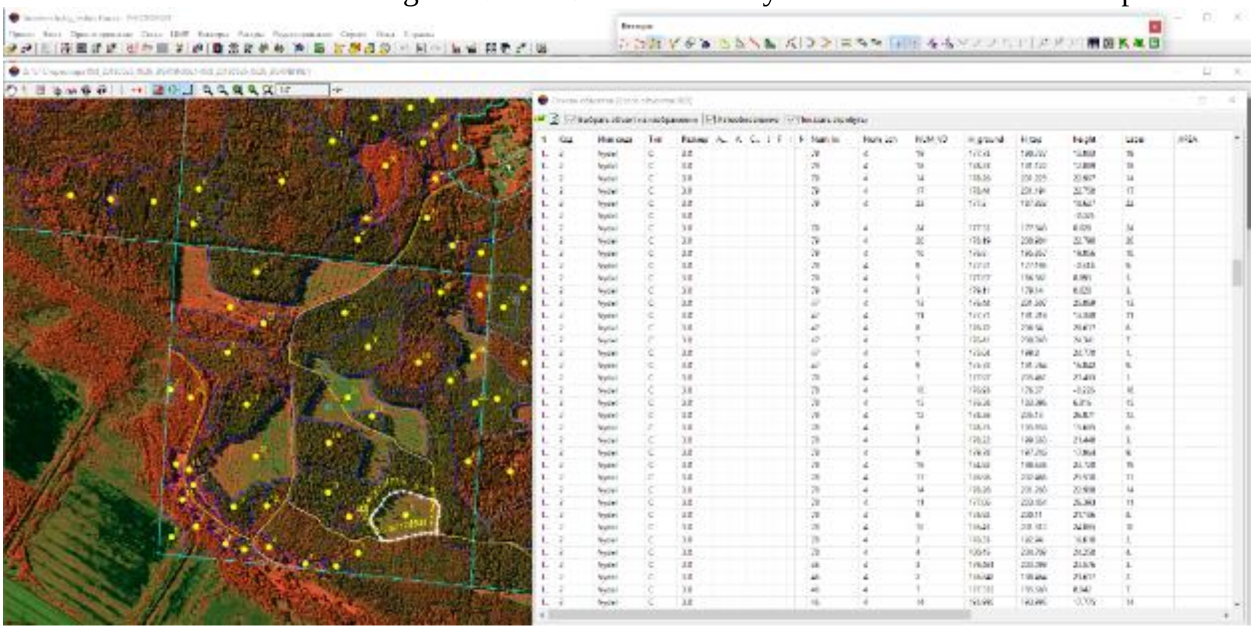


Figure 4.11 – The database structure in the form of the table *DBF

**5. Creation of the digital model of the terrain and of the relief**

The software package »PHOTOMOD» provides the possibility to create the DTM and the DEM according to various sets of data. The digital model of the relief is a digital cartographic representation of the earth's surface both in the form of a regular grid of heights (DEM) and in the form of an irregular grid of triangles (TIN). For creation of the digital elevation model, there are used the following data sets, individually or collectively:

- pickets – point vector objects located on the surface of the relief;

- irregular spatial network of triangles (TIN, Triangulation Irregular Network) – a spatial-coordinated data model used when creating the digital elevation model in the form of elevations in the nodes of an irregular network of triangles corresponding to Delone triangulation;

- horizontals – vector lines connecting the points with the same elevations on the ground;

- matrix of heights – a digital cartographic representation of the earth's surface in the form of a regular grid of height values.

When carrying out this work, the following technological scheme was used (figure 5.1)

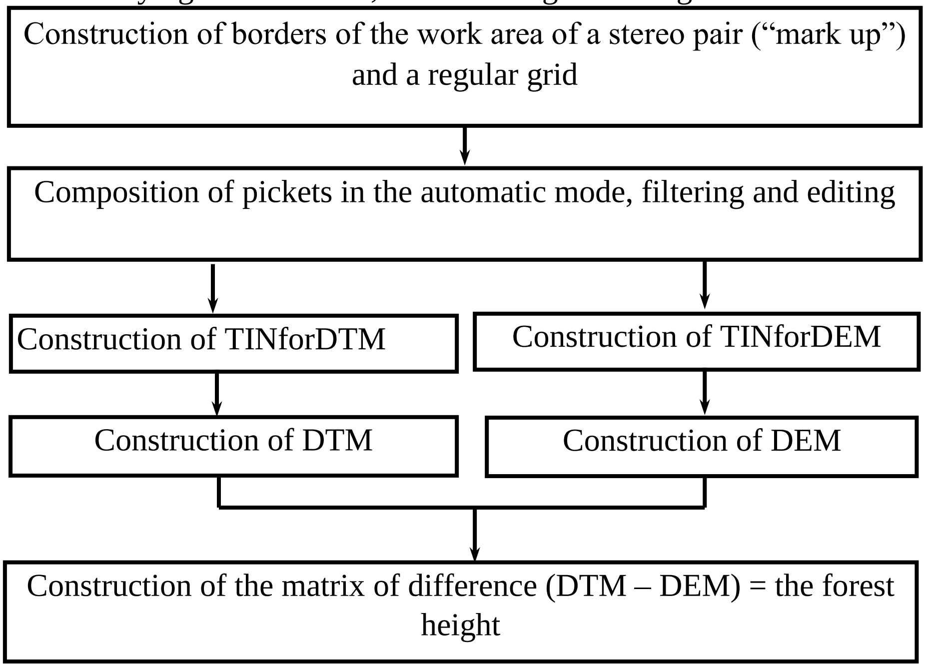



Figure 5.1 – The technological scheme of constructing the matrix of difference (the forest canopy heights) in the software package "PHOTOMOD"

**Construction of the regular grid**. The grid is built both on the entire image block and on any part of the block or on the selected stereo pair. The shape of the grid borders can also be both rectangular and in the form of an arbitrary polygon. To create the grid, select *Grid > Create (Ctrl+N,G)* or press the button on the main toolbar. A new layer *Grid* is created in the window *Layer manager*. The area of the grid creation is determined in one of these ways:

- to create a grid with a given rectangular border, simultaneously hold the key *Shift* and drag the rectangular area on the image block or on the selected stereo pair with the mouse button;

- to create a grid with an arbitrary area, define the area of the grid creation in the polygon group selection mode, and, with the pressed key *Shift*, define all the border nodes with the mouse – the areas of the grid creation. Complete the process with a double click.

To use the vector layer polygons as the area for the grid creation, perform the following actions:

1) Select *Vectors > Create a layer* to create a vector layer without the classifier or load a layer with the polygons which are used as the grid borders.

2) Create a polygon so that its borders coincide with the borders of the area used for the grid creation.

3) Select polygons to use as the borders for the grid creation, otherwise, the grid is built taking into account all the polygons of the layer.

4) Select *Grid > Create borders from vectors*. As a result, the grid border goes along the created polygon border.

To create a grid on the entire image block without explicitly defining the borders, select *Grid > Properties;* set the grid parameters and click *OK*. The grid is built automatically on the entire block and goes along the block outline.

**Composition/picketing of the pickets.** The system provides the following modes for creating pickets:

- manually in the stereo mode – the points are added manually in the stereo mode with or without the correlator; The correlator parameters are set in the general system settings window in the tab *Correlator*;

- in a semi-automatic profiling mode with a preliminary creation of a regular grid of nodes – there occurs a sequential passage of all the regular grid nodes and manual addition of the pickets (with or without the correlator) or a skip of the node and passage to the next;

- in an automatic mode with a preliminary creation of a regular grid of nodes. Wherein, in the vicinity of the grid nodes (using the correlator), there are calculated the spatial coordinates of the points, and if the coordinates are successfully calculated, the pickets are created. In the automatic mode, there are performed: the grid node traversal in a specified number of times with various correlator parameters, accuracy control, picket rejection and filtering, preservation of quality assessment. It is the automatic set of pickets that is proposed to be used with their subsequent filtering and editing.

The created pickets are used as the vector basis for the DEM creation. Some additional options for editing pickets allow to get the vector basis for the TIN construction and creation of the matrix of heights.

The principle of picket automatic calculation is the following: For each selected oriented stereo pair, there is automatically performed a traversal of all the grid nodes that fall into the overlap of the stereo pair images; and an attempt is made to calculate the spatial coordinates in the vicinity of each grid node using the correlator. In case of successful correlation, there is performed the control of accuracy of the coordinates of each found point; according to the results of which, the point is either added to the vector layer as a point object or excluded. If it isn’t possible to calculate the spatial coordinates in the vicinity of some grid node, it is skipped and there comes the transition to the next grid node.

Before starting the automatic calculation of the pickets, follow these preparatory steps:

1. Determine the search area: select the block stereo pairs for automatic calculation of the pickets.

2. Build a regular grid of nodes for the selected search area.

3. Select *DEM* > *Pickets* > *Picket calculation*. The window *Picket calculation* opens.

In the section *Correlator configuration*, select one of the types of the terrain. *Countryside* or *Countryside 2* are more appropriate for forest territories.

4. In the section *Search area*, set the search area for which the pickets are automatically calculated

After all the indicators are set, click *OK*. The picket calculation process starts.; this process is quite lengthy.

The received pickets can be edited: change the position in height, add/delete in the stereo mode. When creating the DTM, it’s possible to add the pickets to forest areas, by “planting” them at the tops of the trees. When creating the DEM, the position of the pickets should correspond to the ground level, including the forest areas. In this case, the pickets, located in the forest, should be “planted” on the level of the ground in the stereo mode.

The software PHOTOMOD provides the possibility of the automatic removal, correction and detection of the pickets that hit houses, trees, pits, and of filtering random emissions: *DEM >. Pickets > Filtering* (figure 5.2).

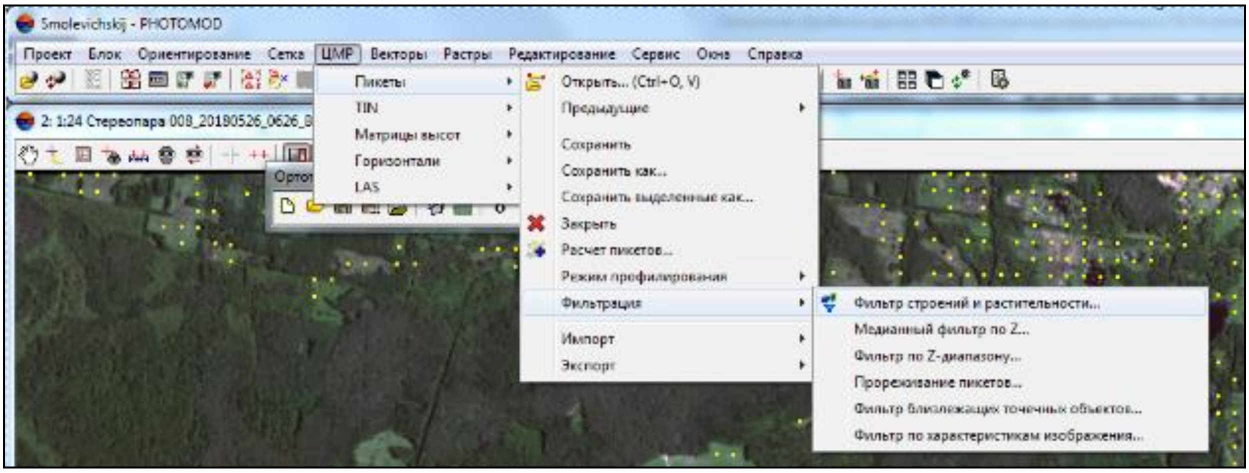



Figure 5.2 – A filter of pickets in the software package PHOTOMOD

Types of filters :

- thinninhg of pickets – thinning of tightly spaced points with a specified degree of thinning;
- filter by Z-range of points – filtering of points and vertices of polylines/polygons, which Z-coordinate goes out of the set range;
- median filter by Z-range – filtering of points and vertices of polylines/polygons by the mask of a specified size;
- filter for nearby point objects – filtering of points located closer than a specified distance;
- filter for constructions and vegetation –filtering of points falling on high-rise objects. It’s used to get a layer of points depicting only the terrain relief;
- filter for surface objects – filtering of points falling on separate high-rise objects or pits of a specific size;
- image characteristics filter – filtering of objects depending on the raster characteristics. At the preparatory stage”*Training*”, the operator manually selects the characteristic raster areas which serve as the references/standards when filtering.

For elimination of gross ettors, it’s recommended to filter by Z-range, changing the values of the minimum and mximum heights: *DEM→ Pickets→ Filtering → Filtering by Z-range*, (figure. 5.3).

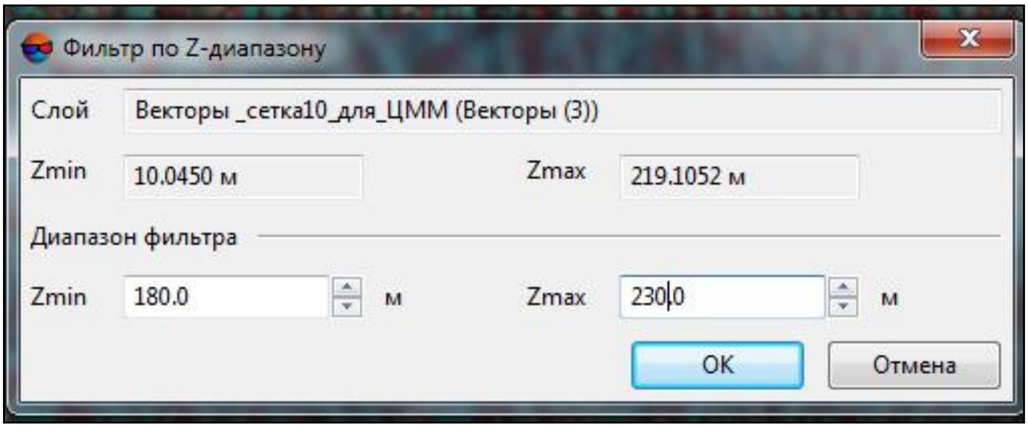



Figure 5.3 – A filter by Z-range in the software package “PHOTOMOD”

Then, it’s possible to use “the image characteristics filter”. This filter is recommended for usage when constructing the DEM, as it removes the pickets, built in the forest zone and “not lying” on the ground. At the preparatory stage, the operator manually selects the characteristic/specific regions of the raster (in our case – forest areas) which serve as the reference/standard when filtering. Then, it’s necessary to point the marker to this specific raster region and press the button *Add* in the section *Training.* Repeat the action changing the marker position. In order to test the training, point the marker to the raster area different (or similar) to the reference and press the button *Check.* The results “-“ or “+” indicate a match or mismatch of the characteristics of the area under test with the obtained references in the process of training. In the section *Statistics,* press the button *Collect*. Within the size of the half-mask, there are calculated the parameters, for each color channel, depicting statistic features of the pixel brightness distribution.

**Construction of the TIN**. The irregular spatial network of triangles (TIN, Triangulation Irregular Network) – is a model of spatially-coordinated data used in creating the DEM in the form of elevations in the nodes of the irregular network of triangles corresponding to Delone triangulation. Delone triangulation is a triangular polygonal network created on a set of discrete points connected by disjoint straight line segments in the way that the circle, circumscribed around each triangle, doesn’t contain (inside itself) the points of the original/source set.

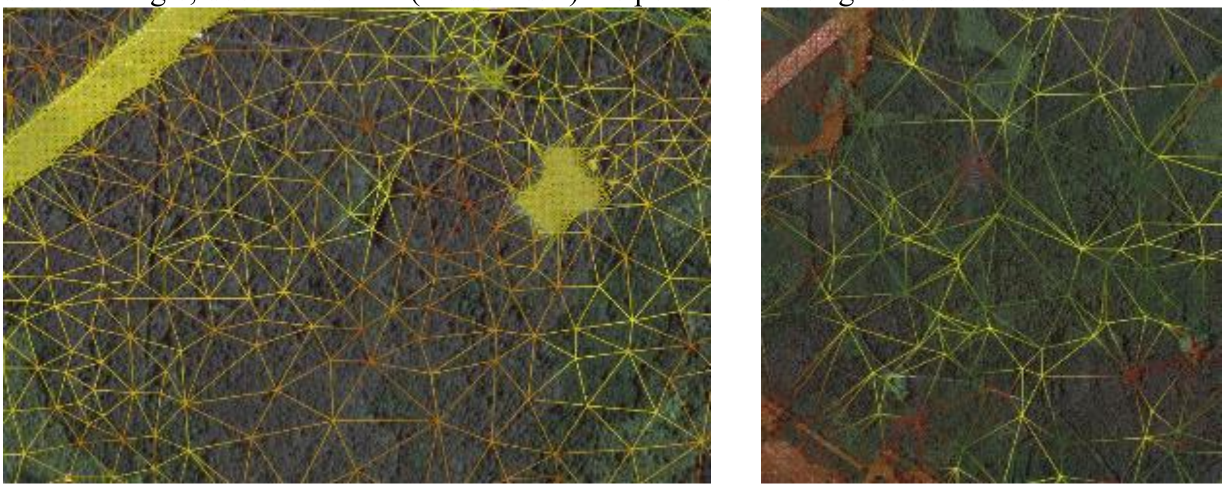


Figure 5.4 – An irregular spatial network of triangles (TIN), created for the DTM (left) and the DEM (right) on a forested territory in the software package “PHOTOMOD”

**Construction of the matrix of heights (DTM, DEM)**.The matrix of heights is a digital cartographic representation of the earth’s surface in the form of a regular grid of height values. The source data for constructing the matrix of heights are the following data, individually or in combination:

-TIN;

- regular or irregular pickets (point objects);
- vector objects.

The software package PHOTOMOD provides the possibility of local equalization of the values of the heights in the DEM area, limited by a polygon on the vector layer. For example, in areas of a continuous forest with no possibility to accurately project the pickets onto the ground.

To align a fragment of the matrix, the following steps are required:

- create a vector layer;
- create one or several polygons which limit the selected matrix fragments or load the layer with the polygons for use as the borders;
- select at least one boundary polygon for interpolation of the height values of the cells inside the polygon;
- select *DEM→ Matrix of heights→Interpolate the height from the selected polygons**;***
- specify the input resource and the path to the output folder, select the default interpolation method (polynominal model).

As a result, the matrix cell height values inside the selected polygons are interpolated by the selected method. But the given process takes much time – 5 hours for a plot of 4 km$^2$.

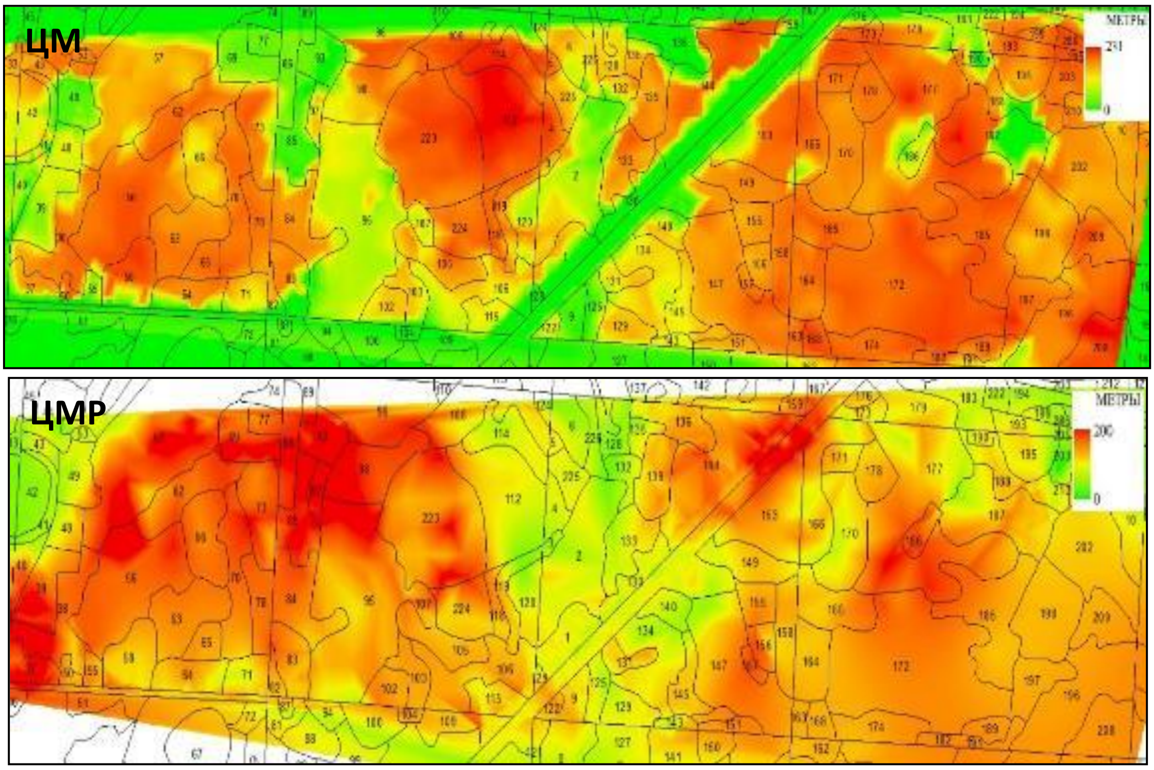



Figure 5.5 –The DTM (above) and the DEM (below), created in a forest area in the software package “PHOTOMOD”

**Construction of the matrix of difference**. The software package “PHOTOMOD” provides the possibility to construct the matrix of difference by substracting one matrix of heights from the other (DTM – DEM). As a result, the forest height value may be obtained by the matrix of difference. Use the constructed DTM and DEM. This process requires the folloing steps:

– load the matrices of heights for substraction;

– select *DEM→ Matrix of heights→Accuracy control → Construction of the matrix of difference;;*

– the window *Parameters of substraction of matrices of heights* opens**.** In the opened window, firstly **-** select the DTM, and then – the DEM**. .** The default is the difference option with the size of the cell of the first matrix of heights (i.e. the DTM). Mark the option «*Difference*»;

– holding the key *Ctrl,* specify both the matrices;;

– indicate the path to save the output matrix in the section *Output matrix of heights*

.

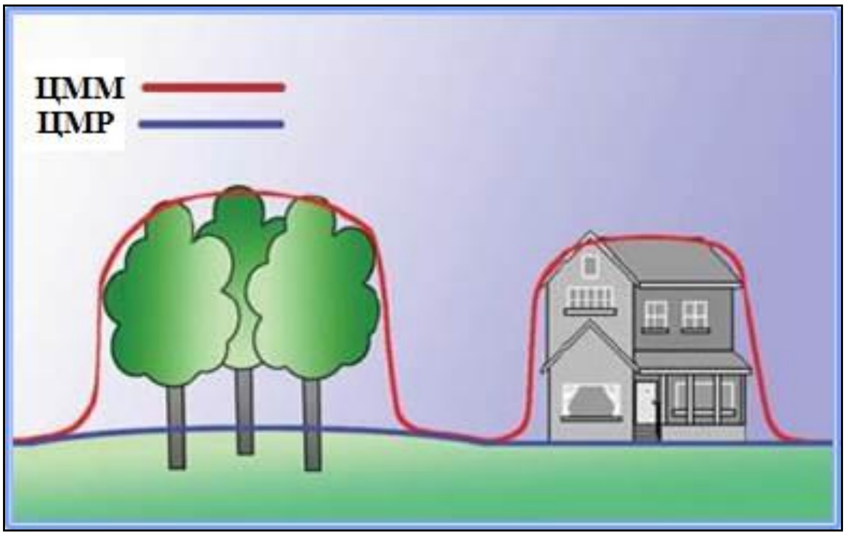



Figure 5.6 – The DTM and the DEM

The software package “PHOTOMOD” provides the possibility to record the difference between the matrix of heights and the vector oblect height as the object attributes, i.e. to automatically write (into the attribute table) the height of the subcompartment trees after the stereo-vectorization of the borders in the presence of the DEM (figure 5.6). This requires the following actions:

- load the vector layer and the DEM in the project;
- select *Vectors→ Attributes → Record the object heights over the matrix of heights in the attribute* and set the parameters in the opened window.

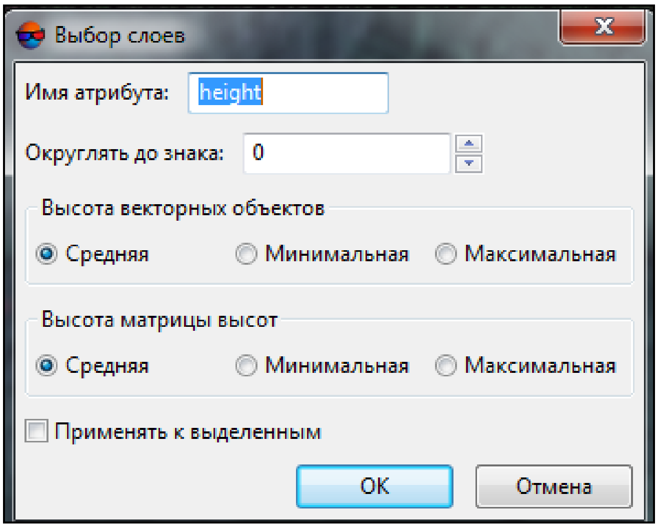



Figure 5.7 – The window of the parameters of recording the heights of objects over the matrix of heights into the attribute in the software package “PHOTOMOD”

After entering all the attributes of the layer, the following error checking is performed (the function is available/accessible only for the software package “PHOTOMOD” StereMeasure version):

- blank attribute values (missing values of the numbers of quarters and subcompartments);
- mismatch of the attribute values to the specified type;
- presence of a duplicate specified set of attribute values within the vector layer ((for example, presence of objects with the same numbers of subcompartments within one forest

inventory quarter, presence of objects with the same number of quarters and subcompartments within one forestry).

The values of difference between the DEM and the DTM are used for determining the average heights of plantations within the subcompartment.

## 2. The technology of prompt/rapid detection of areas of dead, damaged and drying out forest plantations with the help of unmanned aerial vehicles

The forestry institutions currently widely use unmanned aerial vehicles (UAVs) for control over the forest fund, forest fire reconnaissance, monitoring of forest plantation conditions and other tasks.

The RUE "Belgosles" together with the PC "Armosoft" developed the technology of prompt/rapid detection of damaged forest plantations based on the data obtained with help of unmanned aerial vehicles in the automatic monitoring system "Forest Guard".

The following tasks are performed using the software package:

1. **The choice of the boundaries of the flight around the territory under survey for its subsequent photography.**
2. **Photography of the territory and formation of the block editing of the snapshots on the site.**
3. **The automatic flight around the chosen area without manual control.**
4. **Visual confirmation and verification of the coordinates and boundaries of the damaged site of the forest fund.**
5. **Determination of the location of the damaged site within the boundaries: "quarter – subcompartment".**
6. **Preliminary determination of the area of the damaged site.**
7. **Work with the cartographic materials and detailed definition (decoding) of the damaged sites of the forest fund.**
8. **Transfer of the data for carrying out field natural surveys and for assigning business activities.**

The software is installed on a tablet computer or an Android smartphone.

Preparation of the vector forest inventory data (the quarter, the subcompartment, their numeration) is carried out for the software work with the cartographic materials. If necessary, settlements, forest and other roads, and other information layers are added. The prepared vector layers are used for formation of the map of the forestry institution territory and are loaded into the software and to the server to work on line.

The survey is carried out by the principle "the flight mission". The interface is simple and intuitive.

The information, collected by the program, can be transferred to the system for a photo- or video-fixation of the flight-around site

When working with the application, it's necessary to select the appropriate mission:

- a mobile observation tower;
- inspection of the territory on a given route;
- a free flight with manual control;
- a flight of creating a photo plan of the photography area.

The application has the following functionality:

- presentation of the information about the location of the UAV and its operator on the map;
- output of all available operational information from the UAV to the operator's monitor (a tablet) and to the dispatcher monitors on line;
- Media-archive service;

- examination and display of the operational information on an interactive map;
- determination of the area of the surveyed objects;
- linking of the UAV information (route, photo, video);
- creation of a mosaic photo of the given territory.

Micro unmanned aerial vehicles are supposed to be most widely used because light and average UAVs require specialists for their maintenance and control. They are aimed at replacing aviation and, consequently, have all the aircraft restrictions, but they don’t have the aircraft advantages. Their flight requires a special take-off platform.

**Work with the UAV control application**

When you first start the application, it requires permission to use the mobile device resources. Then, it’s necessary to enter the system user credentials, confirm the change and log in. The first log-in requires internet connection for verification of the credentials and getting settings from the server.

For direct work with the application (program), it’s necessary to go to the web-page for logging in. After logging in, the application will automatically detect the UAV, its setup for working in the system.

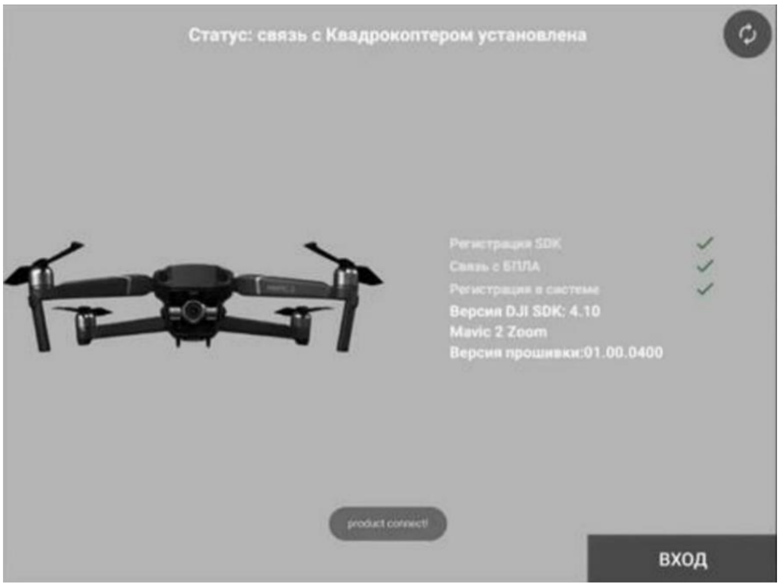



Figure 1 – Logging in with the UAV

After completing auto settings, it’s necessary to press the button “INPUT” in the lower right window of the application (figure 1}. After entering the program, the main interface window will be loaded.


Figure 2 – The view of the interface of the main window of the application

The description of the figure 2 interface user:
1. Coordinates of the user *Latitude/Longitude*
2. Compass readings from 0 to 360. 0 - North, 90 - East, 180 - South, 270 - West.
3. Switch to the UAV control mode. Enable the photo- or video-mode (figure 3).

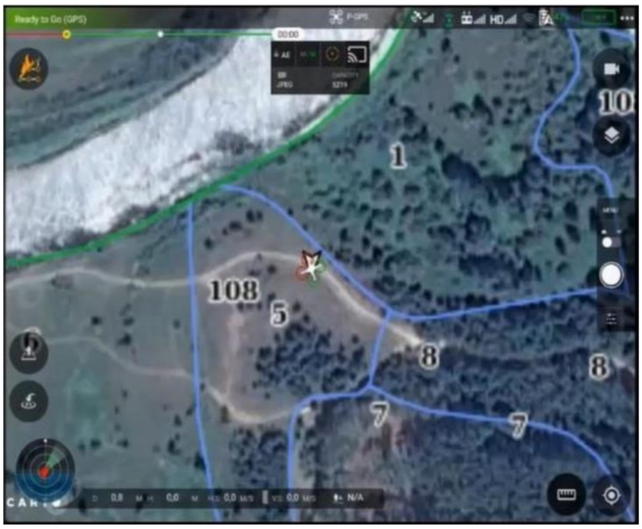



Figure 3 – The video- (photo-) camera on mode

4. Map layer management. When you click on the given application icon, the following window will appear (figure 4):

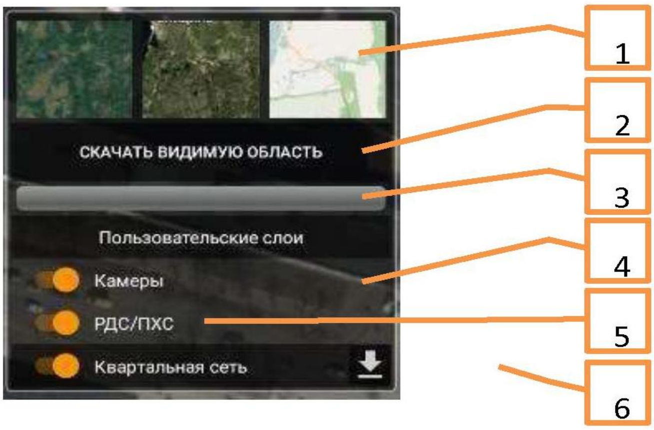



Figure 4 - The layer management window

4.1 Selection of the map base layer.
4.2 The button of downloading all visible area of the base map at all scales to the memory of a mobile device for further off-line use.
4.3 The pumping indicator in the visible area of the map.
4.4 The list of custom layers.
4.5 Enable/Disable layer visibility.
4.6 The button to download a layer to the memory of a mobile device.
5. The Compass.
6. Retrieving the data from the server.
7. Centering the map by the user location.

After the preparatory steps for logging in and launching the UAV – go to carrying out the flight mission.

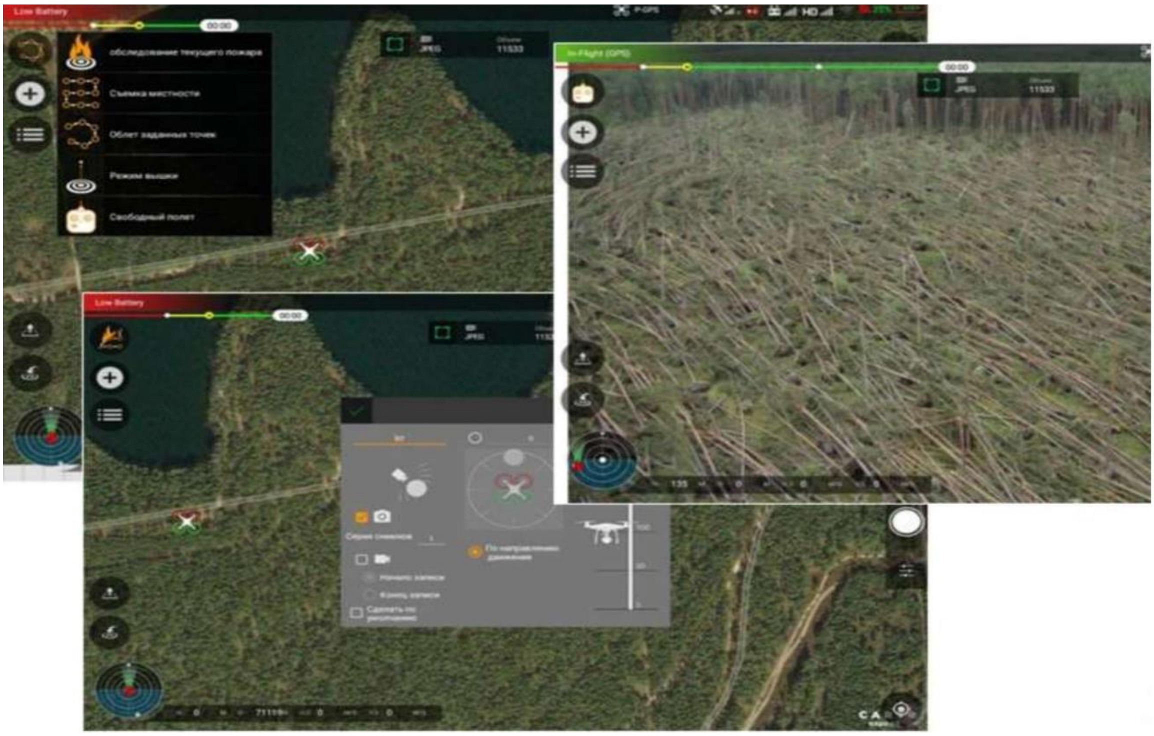


Figure 5 – Visualization of the forest fund damage in the video.

The flight mode selection menu is called up (figure 6).


Figure 6. The menu of the flight mode selection

1) Inspection of the damaged areas, fires. This mode allows to load the data on damages and fires for their further inspection, create and edit messages/reports about fires and damages.

2) Photography of the terrain. The mode which allows to capture the user specified territory, transfer the data to the system, merge the snapshots into a common map and snap it to the area.

3) The flight over the given points. The mode allows to create a point in any place (authorized for flights) with indication of the UAV direction, flight altitude, camera tilt, photography mode.

4) The tower mode. The auto mode which allows the UAV to take off to a specified height and take 6 pictures in all directions.

5) The free flight. The UAV manual control mode.

A “patrol” mission is carried out for the purpose of exploring the area. At this mission, a specific route is set: this is the route of the flight-around and visualization of the forest plantation condition.

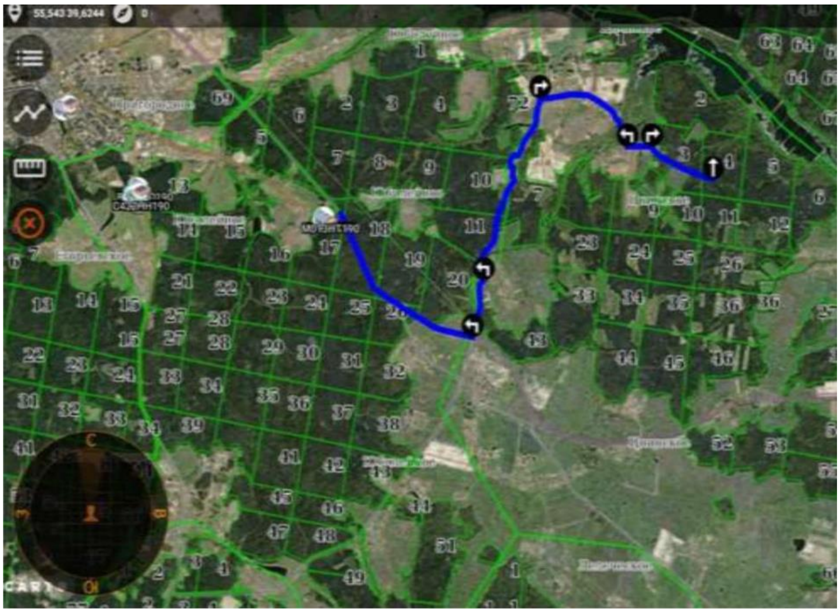


Figure 7 – The UAV routing for the survey of forest plantations

*Recording of the UAV flight track.*

In order to start recording a track, click on the button  on the right side of the screen. All the recorded tracks are saved in the menu “*Tracks*”.

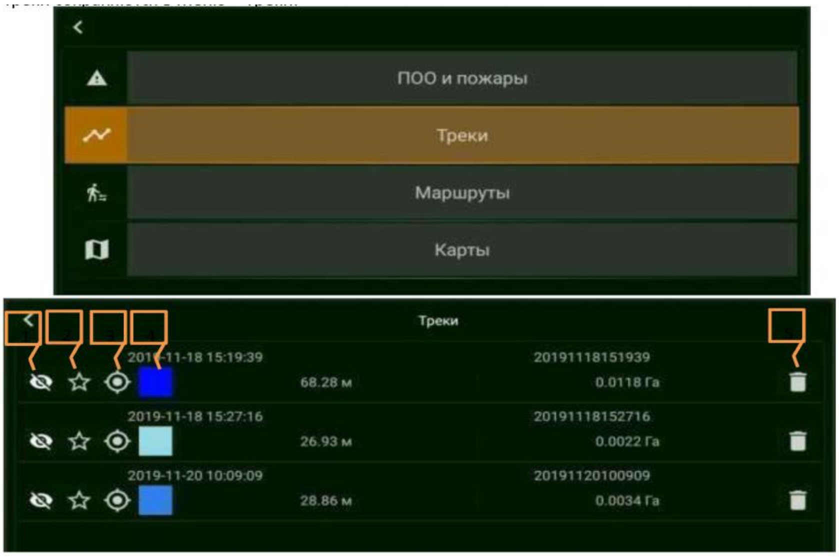



Figure 8 – The window interface when working with tracks

Functions when working with the tracks window interface:

1- Display the route on the map;
2- Add to the favorites;
3- Show the route location;
4- Open the color picker;
5- Delete the route.

*Construction of the route of movement.*

In order to construct the route of movement, click on the button  on the left side of the screen, select the desired flight start and finish places (figure 9).

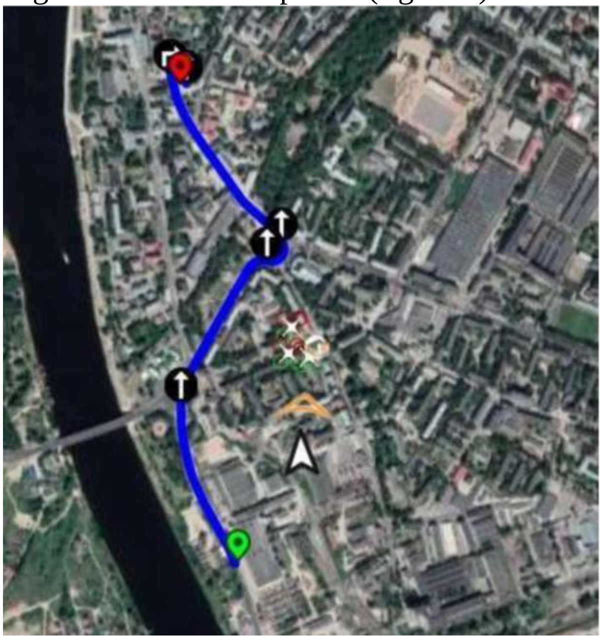
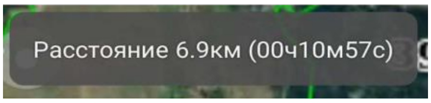


Figure 9 - Construction of a flight route

After determining the start and finish places, the route will be shown on the map.
The distance and the estimated time will be displayed at the bottom of the screen.




*Patrol modes.*

For selection of the desired patrol mode (ground/air), go to the application settings and click on the appropriate button.

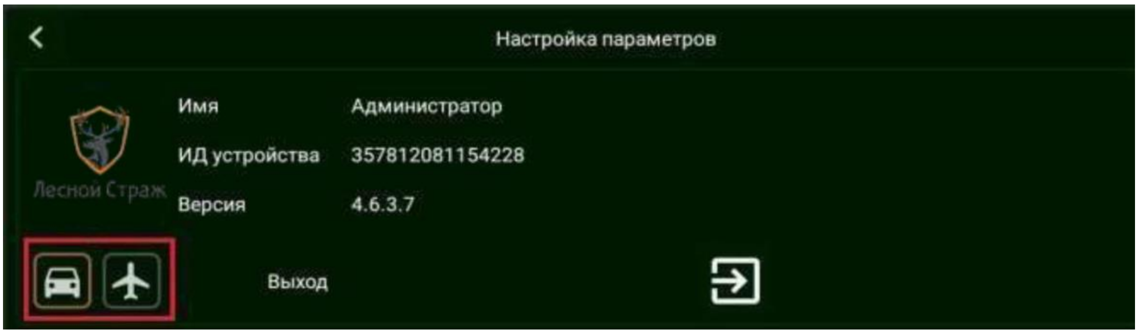


Figure 10 - The patrol mode selection

The icon on the map should change  or .
At the very bottom of the screen, the panel will indicate:
1.- The current altitude;
2.- The current speed;
3.- The azimuth movement direction.


Figure 11 - The patrol window interface

*The mission "flight to create a photo-plan of the survey"* (figures 12, 13).

With this mode in the tablet, the map shows the borders of the photographed object and the photography height. Then, the program automatically calculates the optimal flight route and the required photography options. After launching the UAV, the photography is carried out and the UAV returns to the take-off place.

The map shows (besides substrate cards/space photography-google) the boundaries of quarters and subcompartments with their numbering, and the boundaries of the objects within which the survey is carried out. All information is pre-prepared and loaded into the system. Preparation of the given territories for survey can be saved on the tablet in advance to ensure work in areas where there is no connection.

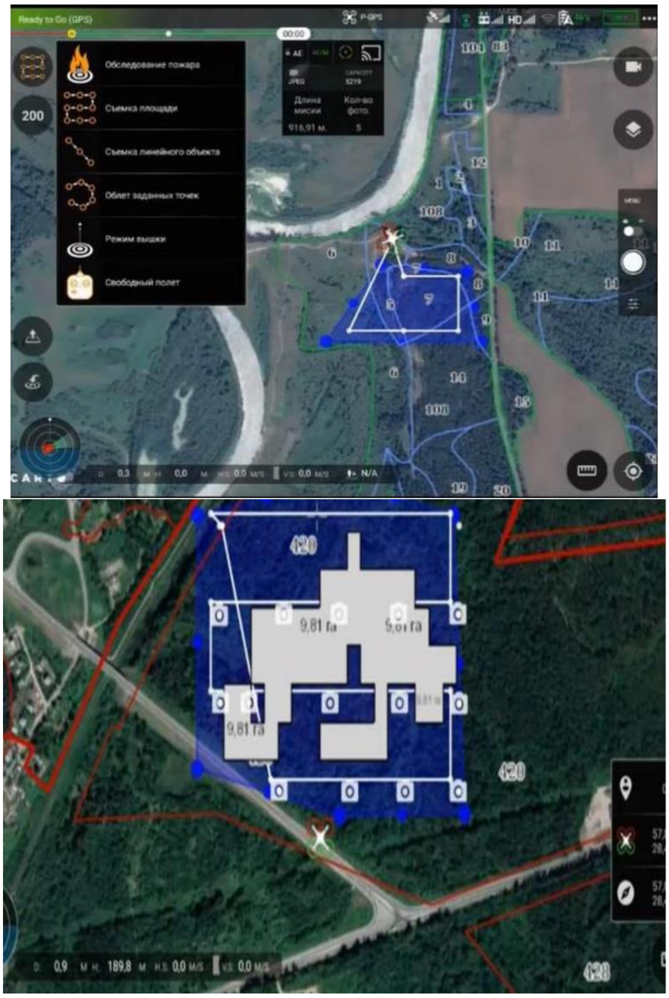



Figure 12 – Photography of a site facility


Figure 13 - Formation of the block layout of photography of a site facility
(a photo-plan of the object)

The mission execution process can be controlled on the tablet in two ways:

- watching the UAV move on the map;
- watching a video-picture from the UAV (figure 14).

It should be noted, that the software package automatically calculates the coordinates of the photography frames, and reflects the location of the UAV within the bounderies “quarter-subcompartment”.

The photography results and other data (photo, video, tracks of the UAV and the operator movement) are transferred to the system and can be displayed as a layer of a cartographic system. This allows further calculations of the survey area at the moment of photography.

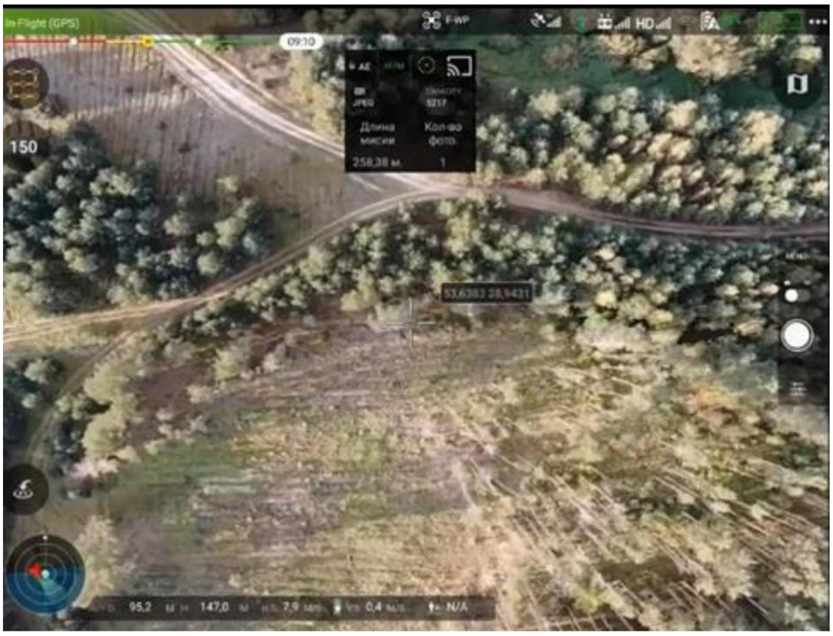



Figure 14 – Control of photography of a site facility

All the information about the completed mission – photos, route, photography points, survey site, mosaic parameters (formed on a tablet) – is stored as a common media collection (figure 15) and can be sent to the media library of the system for future use.

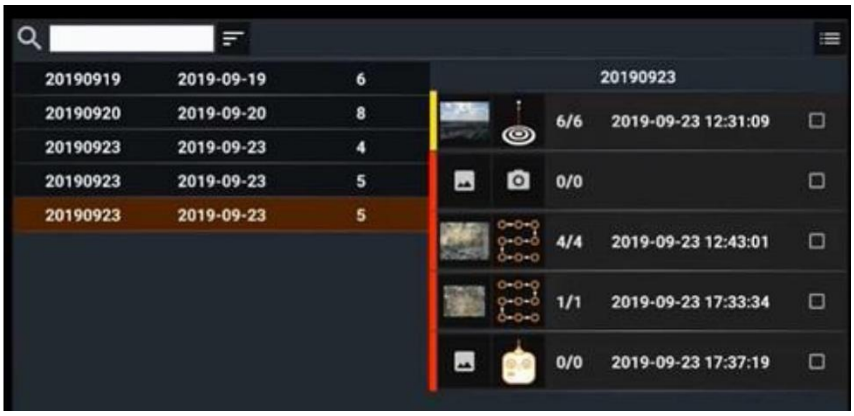


Figure 15 – The survey data archive

The information about the mission (date, time, place, operator, quadrokopter) cannot be changed by the UAV operator, so it can be considered as the data of the objective control.

There are options for calculating the route of movement to a given point. During the patrol or examination all the materials, obtained from the UAV and from the photo-camera of the tablet/smartphone, are grouped in collections. The program provides different additional functionality for different collections.

For a “photomosaic” in the block mode, it’s possible to manually adjust the frame position for a more precise alignment.

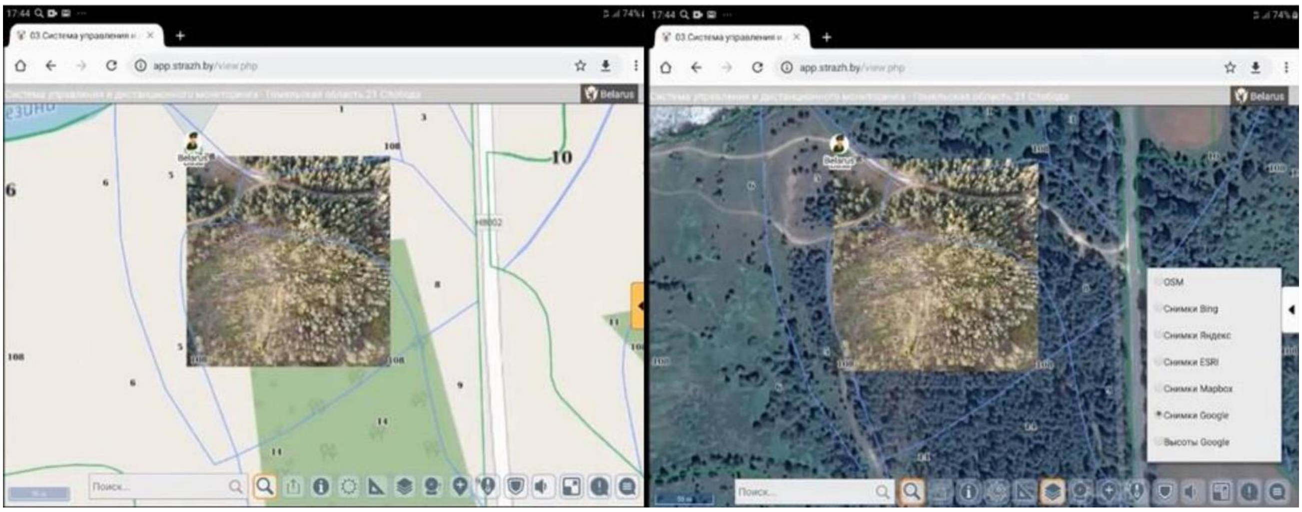


Figure 16 – Presentation of data in the after-flight mode in the server software application

The video panorama mode works for the “mobile tower” mission

The site area calculation mode works for inspection of a damaged site of the forest plantation

When flying and detecting a damaged site of the forest or separate trees, photography with transfer of the data to the tablet/smartphone is performed, the coordinates are determined automatically. And then, switching to the mode “map” and the record “guarter-subcompartment” are performed.

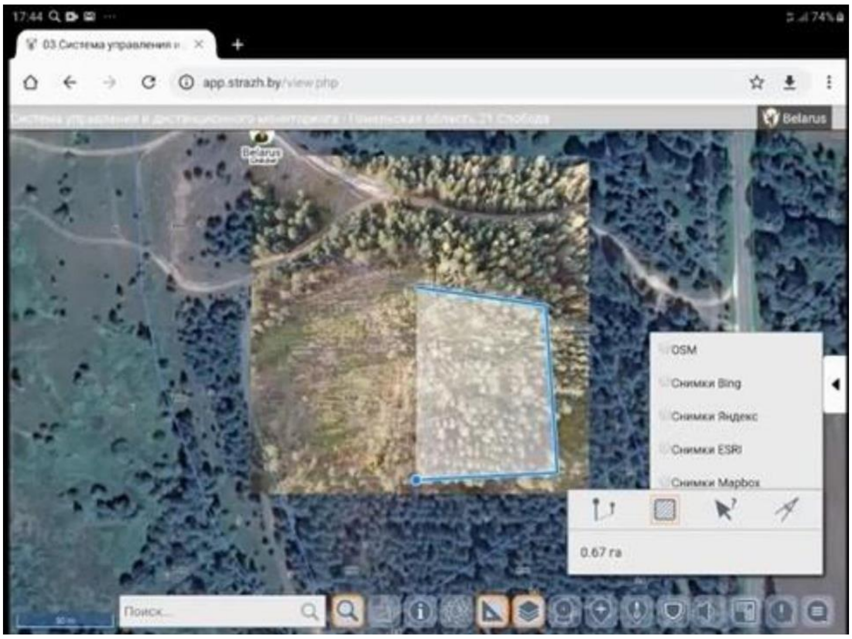



Figure 17 – The measurement mode of a damaged area

All the materials of the territory survey and examination can be used for data advanced processing using other specialized software products, including the GIS-packages with the possibility to use the cartographic and subcompartment databases of the forest inventory information for obtaining a more detailed analysis and adopting correct decisions on assigning forestry activities in the territories of the damaged site of the forest plantation

## 3. The methodological guidelines for formation of permanent economic sites with the divisional method of forest inventory

### 1. General provisions

The divisional method is a method of forestry management by plantations. based on the predominant tree species. This method stipulates formation (during forest inventory management) of economic sites consisting of taxation subcompartments. differing in their taxation characteristics but having the same soil-typological conditions

This method is used when there is a practical possibility of an individual approach to carry out all kinds of forestry and other activities on each economic site. The object of the forest inventory management must be characterized by a high level of intensity of forestry management and of forest harvesting/use, a full sale of wood. a well-developed road network in the forest fund.  In the forests, there must be carried out a soil-forest-typological survey (examination), confirming the prevalence (dominance) of the soils with hydrotope 1 – 3, with a high potential of productivity (bonitet of not less than 2) of the indigeneous target tree species.

### 2. Requirements for formation of permanent economic sites

1. The permanent economic site (further – the PES) is a territorial economic unit. selected with the aim of formation of a promising subcompartment by carrying out a set of various forestry and other activities aimed at receiving the forest stand of one promising tree species.

The territory of the forest quarter is divided into permanent economic sites consisting of one or several taxation subcompartments.

2. The minimum area of the economic site is 1 ha. the maximum area isn't limited. The PESs, exceeding the maximum size of the cutting area, of the appropriate type and way of cuttings of principal harvesting (established by the rules of cuttings for the target tree species), can be divided into cutting areas without formation of new subcompartments. Taxation subcompartments with the area of less than 1 ha are added to the nearest in location PES.

3. The basis for formation of economic sites are the selected soil-typological groups (STGs). The borders of the STGs serve as the basis for selection of economic sites. the borders of the taxation subcompartments can be corrected. if necessary.

The planned cartographic materials of forest inventory and soil examinations are used for selection and establishment of the PES borders.

4. The economic site is preferably selected on the basis of one STG. In some cases (in case of shallow contours of taxation and soil subcompartments) one economic site can be formed on the basis of two and more STGs. having one promising target tree species.

5. The permanent economic site is formed as part of one category or subcategory of the forest, depending on the established regime and restrictions on forest harvesting/use and forestry management. If the area of a taxation subcompartment is less than 1 ha, it is added to a taxation subcompartment with a stricter regime for forest harvesting/use restriction or. in case of the possibility of choice, it can be added to a subcompartment with the most similar taxation characteristics in terms of the subsequent transformation into the target plantation.

6. The initial economic site is formed on the basis of the most common STG that is most suitable for the given forest-vegetation conditions and possesses the highest productivity for growing plantations. In case of the presence of promising conditions, a large economic site can be divided into smaller sites on the basis of the uniformity of the predominant tree species and the age group. The extreme age differences of subcompartments which allow them to be merged into one site are the following: for coniferous and hardwood tree species - 20 years, for deciduous tree species – 10 years. The maximum possible wood stock/reserve of a promising plantation is calculated on the basis of the optimal ratio of the tree species in the composition.

7. When forming the subsequent economic sites. it's necessary to take into account their options for the difference in the predominant tree species, ages, forestry activities, categories of lands and their anticipated changes. The following combinations of subcompartments within the boundaries of one STG are possible:

- mature plantations entering the cutting with creation of forest cultures and of unclosed forest cultures with one target tree species;
- mature plantations of various predominant tree species with the same designed methods and types of cuttings of principal/final harvesting and reforestation activities;
- subcompartments of unclosed forest cultures and adjoining uncovered forest areas (cut down and burnt out places. clearings) or non-forest lands. where creation of forest cultures of one tree species is designed;
- plantations of various tree species where thinnings (cuttings of forest care) will contribute to formation of plantations with the similar to the main target composition;
- subcompartments with the designed measures for reconstruction of the plantations;
- plantations where the target composition is achieved by cuttings of forest renewal or of formation (re-formation) of forest plantations.

8. The final formation of the PES is carried out with the account of the technical and economic possibilities for economic activities by their priority and intensity. The intensive zone contains the STGs with hydrotopes 1 – 3 (all types of thinnings and cuttings of principal/final harvesting. creation of forest cultures); the average intensity zone contains the STDs with hydrotope 4 and reclaimed plantations with hydrotope 5 (mainly. clear cuttings; creation of forest cultures and tree care in young stands are limited); the weak intensity zone contains not-reclaimed STGs with hydrotope 5 (clear cuttings with natural forest renewal. without thinnings) that can't be transformed and, therefore, should be recognized as indigenous forests.

When carrying out the subsequent forest inventory activities, the PES borders are specified. If there have been any changes in the taxation or hydrological characteristics of the plantations, the PES borders are adjusted/corrected.

9. In case of shallow contours of borders of soils and taxation subcompartments. economic sites are formed by combining ecologically adjacent STGs with the account of their natural combinations (one economic site can include STGs of bilberry and cowberry pine stands.

eagle-grown and sourish spruce stands etc. by the accepted combinations). It’s necessary to abide by the condition that the STGs of the combined subcompartments should have one promising tree species.

10. When forming permanent economic sites. it’s required to strive to make their borders of the most possibly correct configuration. Clear natural and artificial frontiers (roads. glades. objects of hydrography and the like) should be used as the borders of PESs. If possible. curved border lines of PESs should be adjusted to make them straighter.

11. On the planned-cartographic materials (tablets. plans of plantations), borders of STDs are marked in solid brown lines and their numbers are put down. The plan of the STGs is printed. A list of taxation characteristics of the subcompartments and the designed activities is given for the selected in the quarter STDs.. The above-given features serve as the basis for formation of the PES with marking its borders in blue and assigning its number within the boundaries of the quarter. A list of the included into the PES subcompartments is made up separately.

12. All forestry activities, cuttings of principal/final harvesting, cuttings of intermediate harvesting and other cuttings are assigned for taxation subcompartments. but separately for each permanent economic site. The volume of forest harvesting/use and forestry activities is determined by summation of the volumes for each kind of activity and additionally appointed ones when forming the PES.

The annual volumes of all types of cuttings are determined on the basis of the deadline for achieving the assigned tasks.

**3. Demarcation of permanent economic sites on the ground.**

Demarcation and removal to the terrain (on the ground) of permanent economic sites are carried out by the established forestry signs, accepted methods and means of designation of borders on the ground. When the border of the site runs along the quarter glades, objects of road or hydrographic network or other clearly marked demarcation lines on the ground, the designation of borders on the ground isn’t made. When the border of the PES passes through taxation subcompartments, then, in order to mark the border on the ground, there are laid viziers with paint application on the trees and with mandatory geodetic photography with the use of GPS navigators (similar to the work carried out when selecting areas for forest cuttings). The methods and means, applied for designating (delineating) the borders, should provide clear demarcation of the borders of the forest site on the territory of the forest fund.

The final procedure of carrying out activities for delimitation of the permanent economic site on the ground should be accepted for each forestry institution separately.

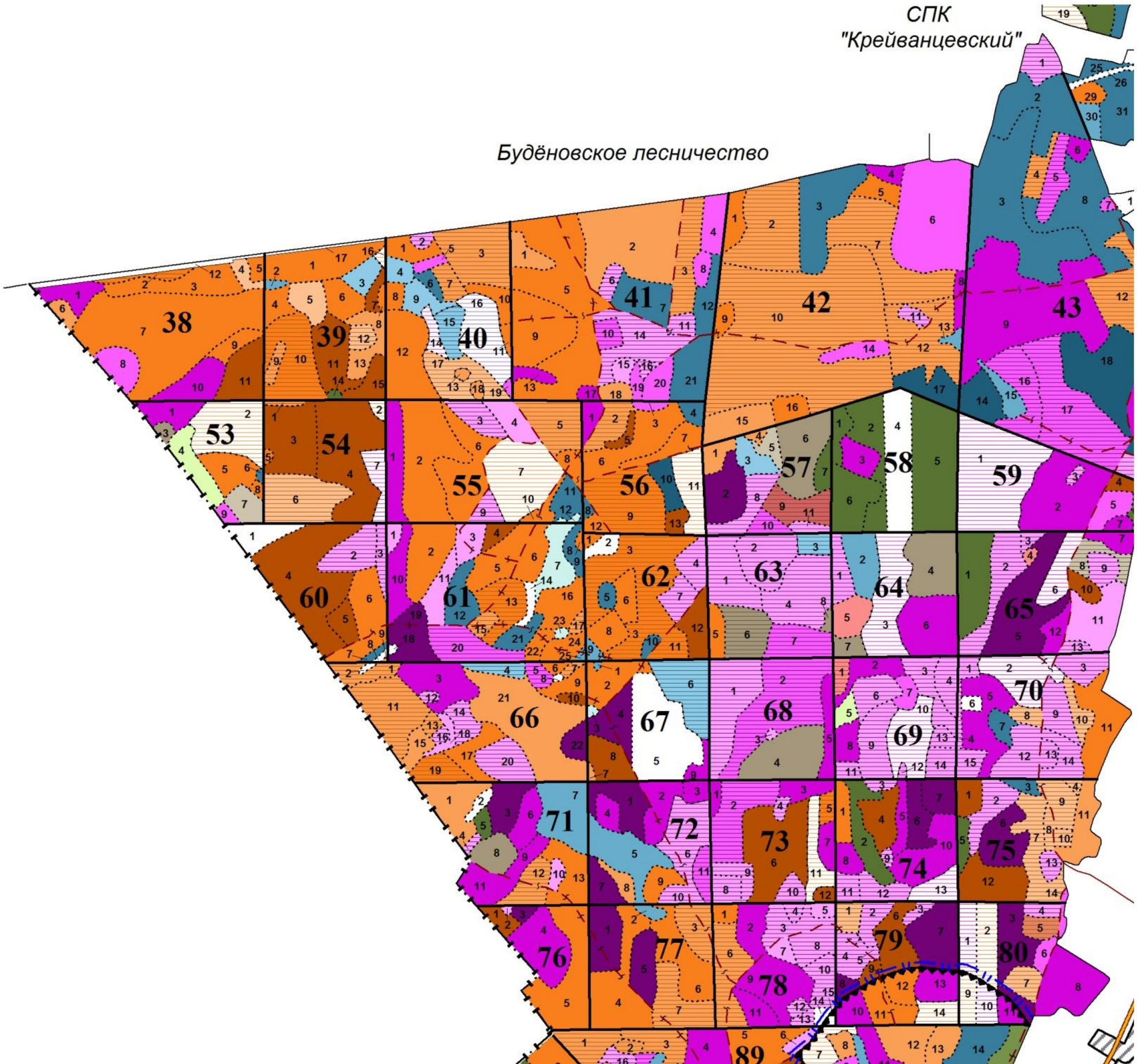
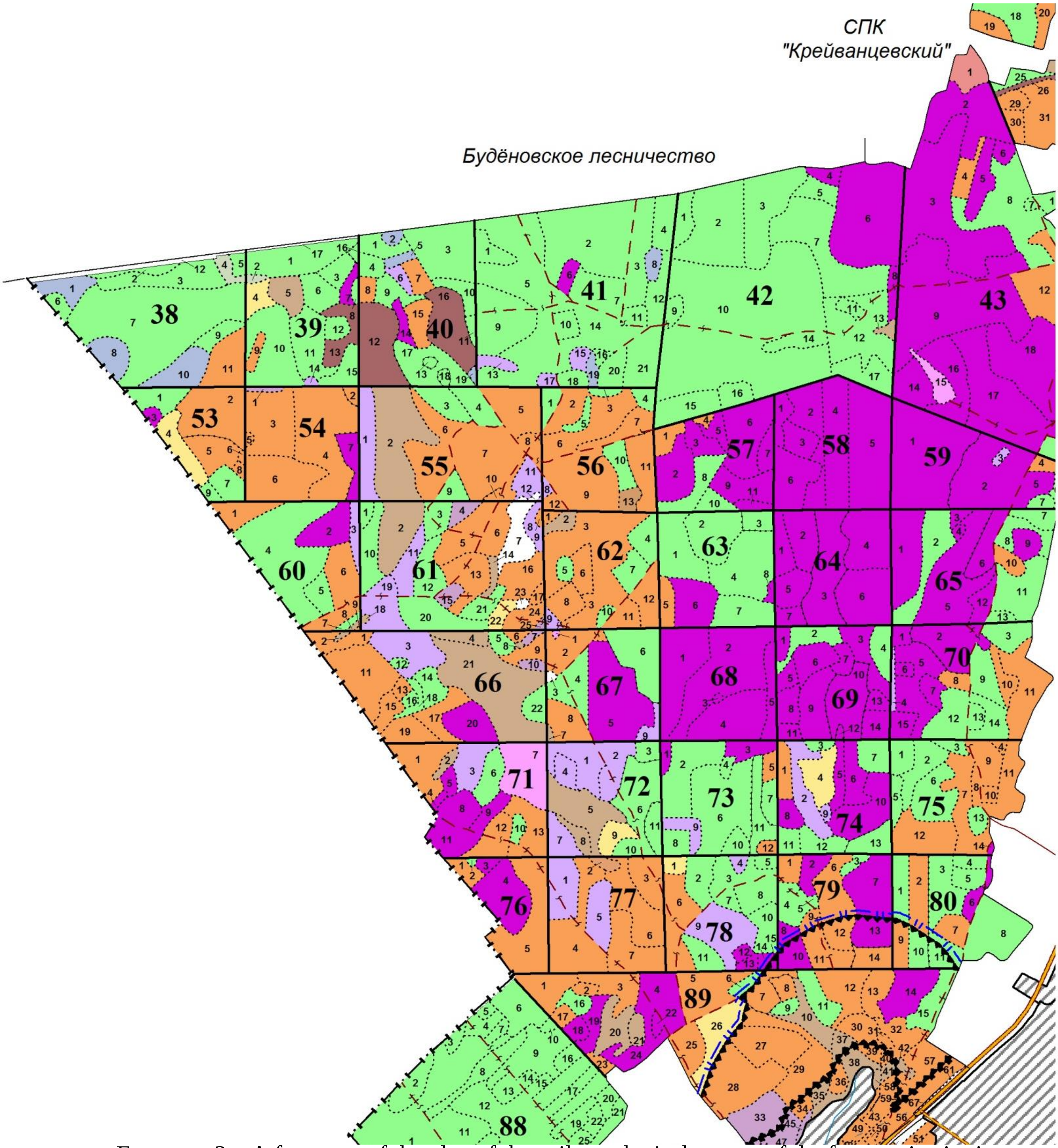



Figure 1 – A fragment of the plan of the forest plantations of the forestry institution




Fragment 2 – A fragment of the plan of the soil-typological groups of the forestry institution


Picture 3 –A fragment of the plan of formation of the permanent economic sites of the forestry institution

For notes

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