

DEFORESTATION MONITORING AT DIFFERENT PERIODS BY SATELLITE IMAGERY

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ABSTRACT

The paper concerns on the topical problem of forestry connected with the destruction of forests including unauthorized deforestation. It is indicated that large-scale deforestation is one of the causes of social and environmental disasters. The method of determination of different periods of forests' cutting on the basis of usage of high resolution satellite images is proposed. The methodology consists in automatic definition of cutting areas based on controlled classification according to the Maximum likelihood method with further post-classification processing, which greatly improves the results of cutting areas determination. In addition, the conducted research is connected with cutting areas, which are defined for different periods of satellite imaging. The work was done using satellite images from satellites Ikonos-2 (2002), Ikonos-2 (2007), QuickBird-2 (2010), WorldView-2 (2014) on the forested area of Lviv region.

1. INTRODUCTION

In the system of forest management the problem arises, which is associated with the evaluation of the state and dynamics of forests development, including their destruction through cutting.

This problem may be solved with high reliability in a short period of time, using modern methods and means of information systems. Due to the high information content and data objectivity of remote sensing, the regularity of their receiving, and multifold possibilities during these data processing for the large areas, remote data sensing has become one of the major sources of organization of the forests monitoring (Bartalev et al., 2007; Slobodianyuk, 2014).

In order to meet the needs of forestry, the use of remote sensing space information is carried on the following directions: control of deforestation, forests inventory, mapping, detection of cutting framework dynamics.

In most of the cases, in order to obtain reliable results it is necessary to certify the remote sensing information in the field survey, which enables to perform the accuracy estimation of the conducted work.

The Forest Code of Ukraine contains a number of legal provisions related to important directions of forest management, preservation, and protection of forests. It includes a set of measures aimed at preservation of forests from the following adverse effects: fire; cutting; damage, weakening and other harmful effects; protection from pests and diseases.

Evaluation of deforestation becomes particularly topical among the tasks of forestry. In general, forestry legislation identifies four main types of cuttings (<http://www.dkfg.kmu.gov.ua>):

- Cuttings of main use;
- Cuttings of formation and improvement of forests (care, sanitary, forests-renovative, rearrangement, associated with reconstruction and landscape) as well as other activities of formation and improvement of forests (care for tellers, for underwood, for forest edge, according to the shape of the trunk and crown, laying quarterly rides and creation of fire-resistant breaks);
- Cuttings during other activities related to forest management (felling of woodlands, felling of single trees, cutting area definition, clutter clearing, construction (repair) of forest roads, care felling in free-growing forest plantations, etc.);
- Cutting during other activities unrelated to forest management (clearing of forest areas covered with woods, in connection with construction of hydroelectric power plants, pipelines, roads, extension of the existing engineering structures, security zones, lanes along the border etc.).

A set of guidelines is defined for each type of cuttings, which is contained in the relevant legal acts of forestry legislation.

Unauthorized cutting of trees is carried out mainly in deep woods. Ukrainian legislation provides criminal, administrative, civil and disciplinary responsibility for different types of illegal activities.

In general, in 2013 – 8264 cases of forest laws violation were recorded, including 7247 cases of illegal logging, resulting in the destruction or damage of 24.4 thousand M3 of wood that caused 63.7 million UAH harm. Most violations were recorded in Lviv Region – 1813 cases, estimated at 15.5 million UAH (<http://www.lesovod.org.ua>).

Google Inc. presented the project Global Forest Watch (<http://www.globalforestwatch.org>), developed in collaboration with the World Resources Institute and 40 organizations that enable to monitor deforestation around the globe in real time. Map at the project’s site is formed based on images from NASA satellites. However, algorithms of the images’ processing allow to calculate the volume the forests’ loss as well as new forests, which annually appear on each country’s territory.

The total loss of the Ukrainian forest area for 2000-2013 period consisted of 565.6 thousand hectares, while the increase for 2000-2012 period was 352.9 thousands ha (<http://www.eco-live.com.ua>).

In general, the project worth 25 million dollars is quite convenient in use, however it has global character. Therefore, small areas of forest are not identified, which leads to erroneous conclusions.

2. RESEARCH OBJECTIVES

The purpose of the work is to study the accuracy of the definition of forest cutting areas over different periods of time based on high resolution satellite images:

To achieve this goal the following tasks were performed:

- Satellite image pre-processing in software ENVI 4.5;
- Selection of types of forest cutting using test information;
- Identification of different periods of cuttings according to the method of controlled classification;
- Post-processing of image according to the controlled classification results with the assessment of cutting areas definition accuracy;
- Identification of the forest cutting areas according to different periods of satellite imaging and comparative analysis.

3. MAIN THEORETICAL APPROACHES TO THE CLASSIFICATION OF FORESTS

Forest monitoring using space data includes:

- Acquisition, accumulation and pre-processing of specific space information;
- Obtaining and accumulation of field survey test data containing forestry parameters;
- Combined processing of space and field survey test data using GIS technologies and software package such as ERDAS Imagine, ENVI;
- Management decision making and development measures concerning the creation of optimal conditions of natural resource use (Burshtynska et al., 2013).

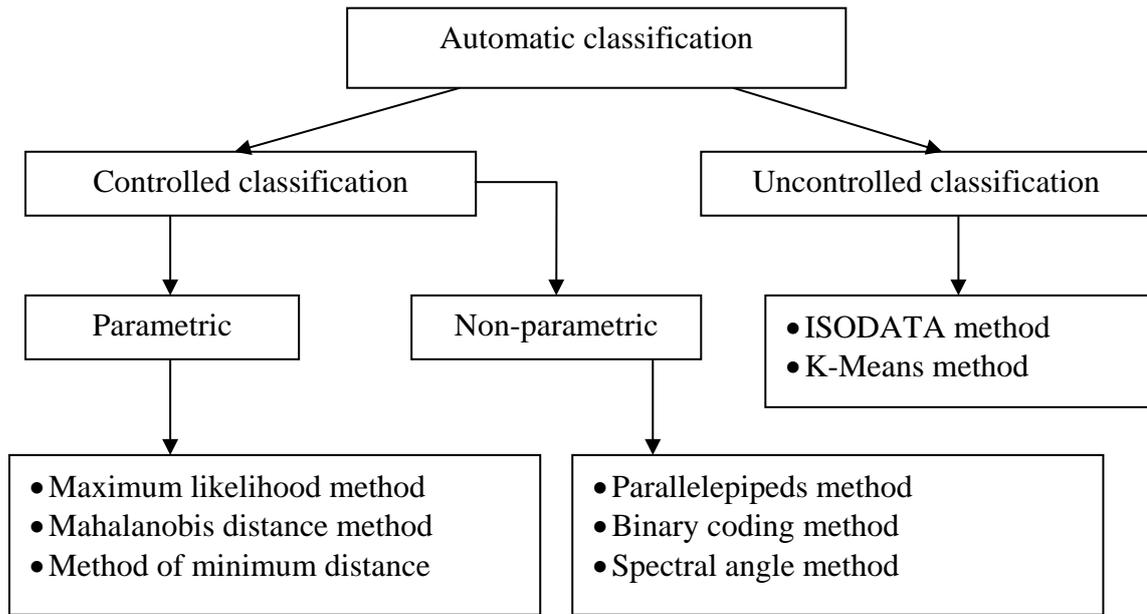
In order to implement forests monitoring by satellite data, the thematic classification of satellite images is done.

Classification – in fact, is the interpretation of images or computer-aided process of separation of image pixels into groups (classes) that correspond to different objects.

Automatic classification is the process of partitioning of the image’s pixels into categories based on their spectral values, resulting in the assignment of new value to each pixel.

Currently, there are two approaches to the implementation of automatic classification: controlled and uncontrolled (Lialko and Popov, 2006; Labutina, 2004; Svidzinska, 2014; Swain and Davis, 1978).

Based on these approaches the methods are established. The most important of these methods are shown in Fig. 1 (Burshtynska et al., 2013; Svidzinska, 2014).



Source: authors' study

Figure 1. Main methods of automatic classification

It is known from the literature (Lialko and Popov, 2006; Swain and Davis, 1978) that the maximum likelihood method has advantages concerning the reliability of the results compared to other methods. Classification by maximum likelihood method is performed according to the following algorithm:

$$D = \ln(a_i) - [0.5 \ln(|K_i|)] - [0.5 D_M], \quad (1)$$

where D - weighted distance (probability); a_i - probability percentage of the ranked pixel belonging to a class i (equals to 1.0 or is introduced based on a priori information); K_i – covariance matrix of pixels of class brightness i ; $|K_i|$ - determinant of covariance matrix K_i ; D_M - Mahalanobis distance.

The elements of covariance matrix K_i are determined by values of pixel brightness of signatures of different class. It is written in the following form:

$$K_i = \begin{pmatrix} \sigma_{11} & \sigma_{12} & \dots & \sigma_{1m} \\ \sigma_{21} & \sigma_{22} & \dots & \sigma_{2m} \\ \dots & \dots & \dots & \dots \\ \sigma_{m1} & \sigma_{m2} & \dots & \sigma_{mm} \end{pmatrix}, \quad (2)$$

where: σ_{jm} – elements of covariance matrix; $j = 1, 2 \dots m$ – quantity of channels. Mahalanobis distance is written:

$$D_M = (X - M_i)^T \times (K_i^{-1}) \times (X - M_i), \quad (3)$$

where: X – measurement vector of classified pixels in channel; M_i – average value of class brightness i ; K_i^{-1} – inverse matrix to K_i . Its dimension corresponds to the number of channels.

Pixel belongs to the class, in case D_M is minimum for it.

4. ANALYSIS OF THE INPUT DATA

Satellite images obtained on the forest area in Yavoriv district of Lviv Region from the satellites Ikonos-2 (March 2002), Ikonos-2 (June 2007), QuickBird-2 (June 2010) and WordView-2 (October 2014), were the source information for the classification of different periods of cutting. These systems provide satellite images in five spectral bands (panchromatic, blue, red, green, and near infrared). A spatial resolution of Ikonos system is 1 m in panchromatic range and 4 m in spectral ranges, system QuickBird-2 – 0.61m and 2.44m, and the system WordView-2 – 0.46m and 1.84m, respectively.

The area is dominated by coniferous and deciduous forests of different ages and breeds, and in northeastern and eastern parts of the image the agricultural areas (gardens) and locality are situated. In addition, the picture contains a number of cuttings made at different times and lands with herbaceous and shrubby vegetation. This causes significant changes of characteristics of the object’s brightness. Since the area is flat, it possible to disregard the impact of the relief on the image.

Test information was collected from data obtained through field survey, with the division of the image into landfills and appropriate description of each landfill with temporal interpolation of changes. Test information was received in 2011.

It has been established that cutting of vegetation is different. It indicates that they occurred in different periods of time. Based on the test information and visual interpretation the following main types of cuttings are defined: fresh cutting, not overgrown by vegetation; cuttings, covered by grassy vegetation; cutting of planting deciduous trees; cutting of overgrown shrubs; cutting of coniferous plantations. The visual interpretation data are controlled according to test information done by field survey.

Fig. 2 shows an image obtained from QuickBird-2 (2010). Each landfill with cutting is interpreted according to test information.



Source: authors’ study

Figure 2. Digitized cutting with division into 5-types objects

Data is collected according to the following parameters (Table 1):

- General description of the polygon (e.g, mature coniferous forest, uncontrolled underwood, etc.);
- Average height of the trees;
- Average thickness of trunks;
- Average distance between the trees;
- Species of the trees;
- Percentage of dominant tree type;
- Square of the polygon.

Table 1. Test information on the territory

№	Characteristics of cutting	Valuation characteristics					Square, ha
		Height, m	Thickness, m	Distance between trees, m	Species of trees	Species of trees relation, %	
1	Herbaceous vegetation						23,9
2	Young coniferous	2	0,08	2	pine/birch	85/15	38,8
3	New deforestation						16,3
4	Young deciduous	2,5	0,10	1,5	beech/birch	95/5	55,3
5	Overgrown bushy	0,8	0,05	0,5		100	51,0

In order to determine the classification accuracy, the boundary coordinates of some interpreted polygons are determined using a portable GPS – Garmin GPS MAP 62, the coordinate determination accuracy – 3 m.

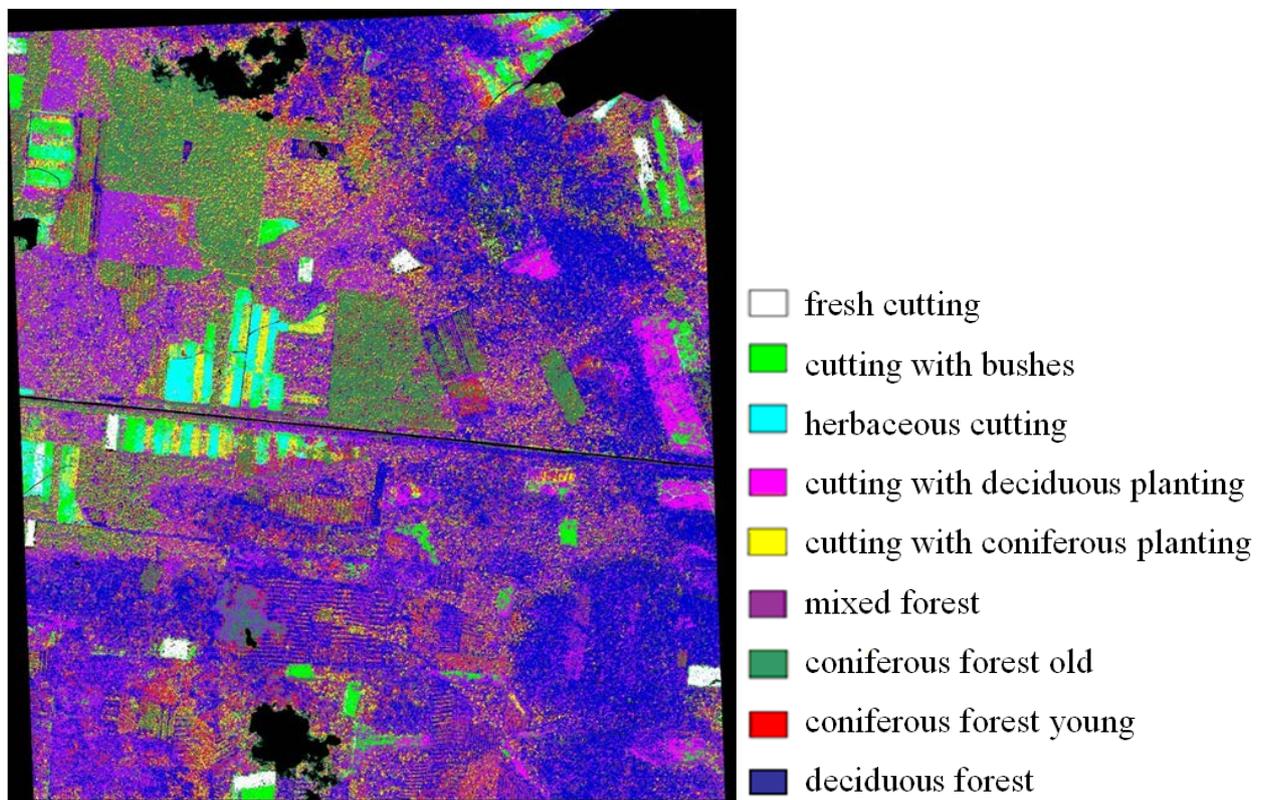
Images are referenced in the cartographical system WGS 84.

5. METHODOLOGY OF CONDUCTING THE CONTROLLED CLASSIFICATION, POST-PROCESSING OF THE IMAGE AND DEFINITION OF AREAS OF DIFFERENT PERIOD CUTTING

Previous processing of images provided channels of synthesizing and "masking" clouds, cities, roads. The combination in accordance with the reflectivity faculties of plants was applied for the interpretation of forests. The infrared, red and green channels were selected. The mask in software package ENVI 4.5 was created and the synthesized image was used.

The main interpretation features for the identification of cutting are geometry forms and spectral brightness.

The formation of signatures is the important step in the controlled classification. For this case the test information is used, gathered by the field survey. The number of pixels in each sample should not be small or large. According to the studied literature (Swain and Davis, 1978), if in the image there are n channels, so in each training sample there should be from $10n$ to $100n$ pixels. Accordingly, the size of standards about 400 pixels is selected for the research. Controlled classification is performed by maximum likelihood method. The method is selected on the basis of the studied literature (Lialko and Popov, 2006; Burshtynska et al., 2013; Sakhatsky et al., 2002). The results of classification of the image objects are shown in Fig.3. Classifying image divided into 9 classes includes: fresh cutting; cutting, covered by grassy vegetation; cutting of overgrown shrubs; cutting of coniferous plantations; cutting of deciduous plantings; old pine forest; coniferous young forest; mixed forest and deciduous forest.



Source: authors' study

Figure 3. Classified image according to the method of controlled classification with algorithm of maximum likelihood

From the previous studies it has been found (Burshtynska et al., 2014) that cutting of coniferous plantations correlates with coniferous forests and deforestation of plants with deciduous trees – with deciduous forests. Comparing visually this image with the results of test information and the original image, its clear that the reproduction may be seen according to the classification results by maximum likelihood method. At the same time, the calculated area according to the number of pixels of a certain

class does not meet the real square of class because of a complex brightness distribution of pixels. This famous phenomenon that occurs during the classification is called “salt-pepper”. For example, areas with coniferous plantations contain pixels that according to the characteristics correspond to young coniferous vegetation and pixels of underlying surface (herbaceous vegetation).

Accordingly, the error in areas defined by calculation according to the test information data and by the controlled classification method for certain classes reaches 35-50%. Only fresh cuttings and areas with dense vegetation are identified with high accuracy.

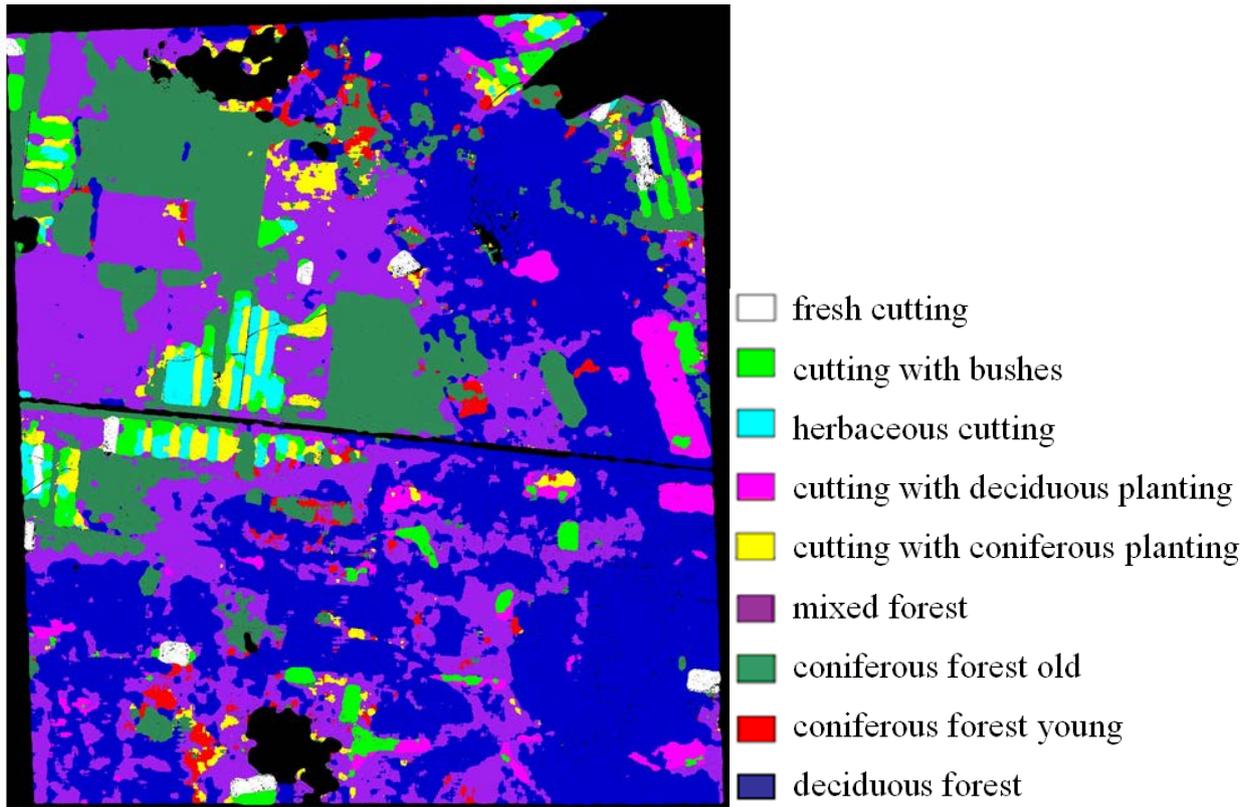
Individual pixels or even their groups within the complex image significantly distort the results of the areas definition. In order to improve them, the reclassification of pixels is made. For this case the tool of the program Majority Analysis is applied. We conducted the study for choice of the neighborhood within which reclassification of pixels is made. As result of the comparison of the cuttings areas obtained from the test information and calculated pixels from reclassification – the optimal neighborhood of reclassification is defined. Overall neighborhoods were investigated with a size 3×3, 5×5, ..., 17×17, ..., 23×23. It has made possible to determine that the neighborhood size 17×17 gives the smallest error in determination of the areas. Table 2 presents cutting areas identified during the field survey, and the areas identified during the reclassification at different meanings of neighborhood.

Table 2. Dependence of areas accuracy determination of the different periods cutting according to the size of neighborhood.

Types of cutting	Test results, ha	Size of neighborhood										
		3 × 3	5 × 5	7 × 7	9 × 9	11 × 11	13 × 13	15 × 15	17 × 17	19 × 19	21 × 21	23 × 23
		Determined areas, ha										
Fresh cutting	16,3	14,8	14,5	14,6	14,8	15,1	15,4	15,9	16,2	16,5	16,9	17,1
Cutting with bushes	51,0	59,4	56,8	55,3	54,5	54,0	53,7	53,5	53,4	53,3	53,3	53,4
Herbs cutting	23,9	29,2	27,8	27,4	27,3	27,3	27,4	27,6	27,7	27,9	28,2	28,3
Cutting with coniferous planting	38,8	117,2	89,2	71,3	60,5	53,6	49,5	46,6	44,3	42,4	40,8	39,3
Cutting with deciduous planting	55,3	90,0	69,9	60,6	56,2	53,8	52,3	50,9	49,6	48,3	47,3	46,3

Instrument (Majority Analysis) works according to the principle that for central pixel in the neighborhood will be assigned a value of the most of the pixels class in a given neighborhood.

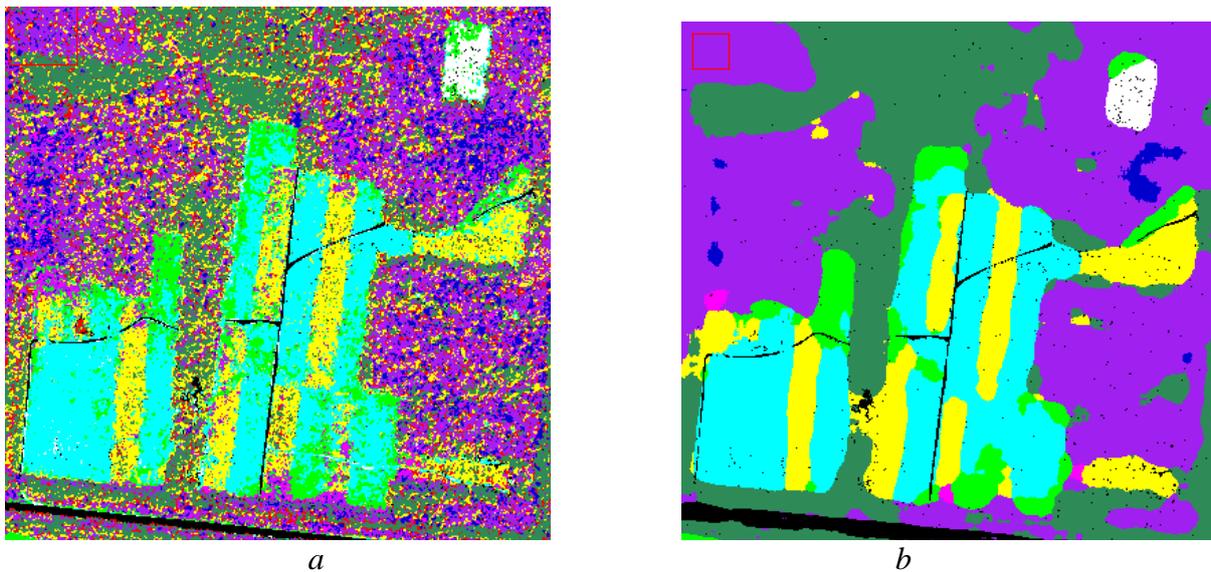
Fig. 4 shows the results of post-processing.



Source: authors' study

Figure 4. Results of post-classification image processing

For the visual comparison of the results in Fig. 5 fragments of classification results by the method of maximum likelihood and post-classification image are provided.



Source: authors' study

Figure 5. Image fragments: a) classified by method of maximum likelihood; b) post-classification image processing

Differences of type cutting areas obtained from post-classification image processing and testing areas are presented in Table 3.

Table 3. Differences of areas of different time cutting

Types of different time cutting	Testing areas ha	Areas calculated on the basis of post-classification ha	Differences of areas ha	Divergence of areas %	Accuracy of determined areas%
Fresh cutting	16,3	16,2	0,1	0,6	99,4
Cutting with bushes	51,0	53,4	2,4	4,7	95,3
Cutting with coniferous planting	38,8	44,3	5,5	14,2	85,8
Cutting with deciduous planting	55,3	49,6	5,7	10,3	89,7
Herbs cutting	23,9	27,7	3,8	15,9	84,1

So, fresh cutting and cutting with bushes are identified with the highest accuracy. This accuracy is respectively 0,6% and 4,7%. Herbaceous cutting, cutting with coniferous and deciduous planting are identified with accuracy 10-15%.

Based on the defined coordinates of sample points of cuttings boundaries with GPS – measurements, obtained after the post-classification processing, the Table 4 has been formed. Boundary points are selected on clear and non-clear contours.

The calculated RMS errors of measurements for clear contours are 4-5m and for non-clear contours are within 10-11m.

As a result of post-classification processing it is possible to create a thematic map of forest.

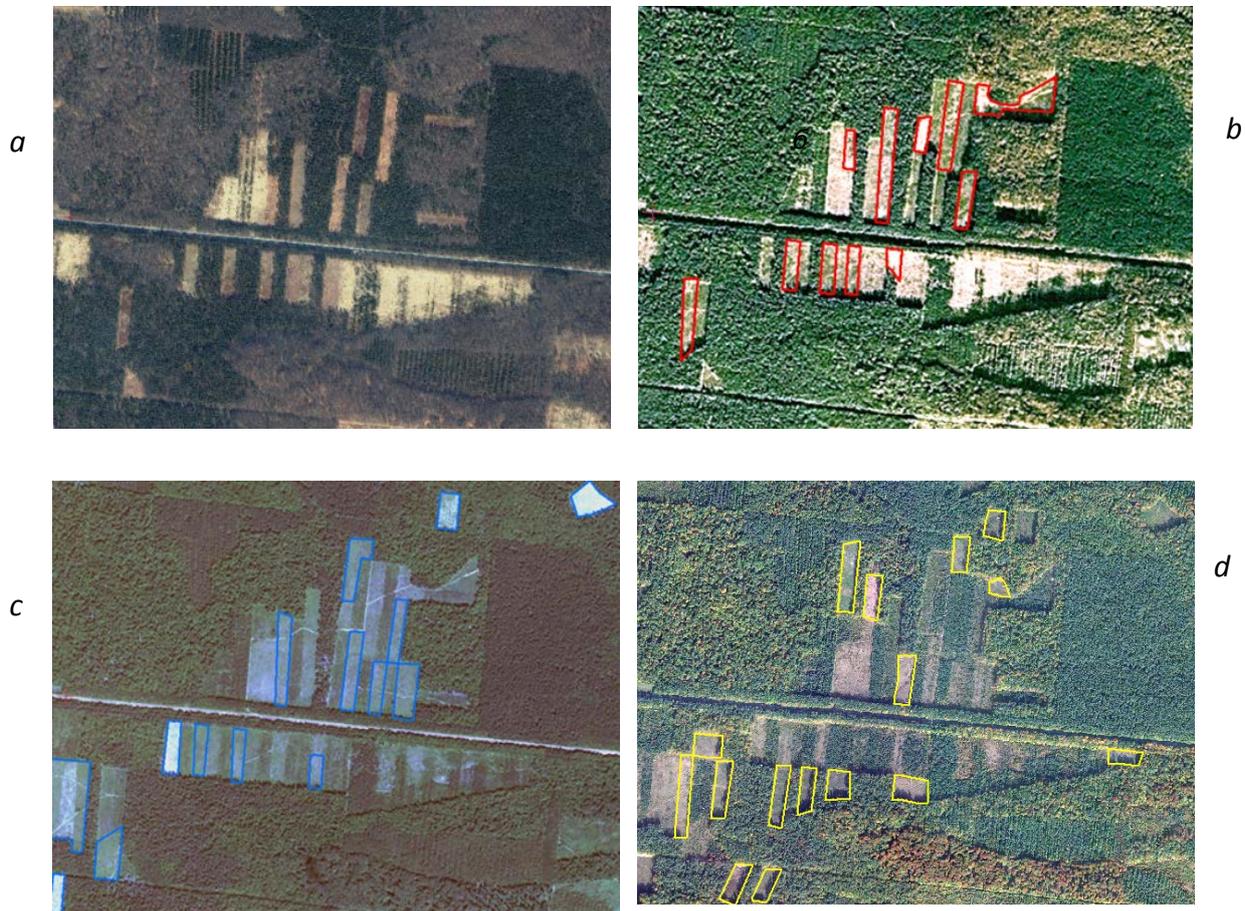
Table 4. Determination of accuracy coordinates of boundary points of cuttings after post-processing

№ of point	Measurement results				Differences		δX^2	δY^2
	GPS		Post-processing					
	Clear contours				δX	δY		
	X, m	Y, m	X, m	Y, m				
1	689708	5533403	689713	5533400	-5	3	25	9
2	689726	5533593	689730	5533588	-4	5	16	25
3	690125	5533665	690128	5533663	-3	2	9	4
4	692612	5535122	692608	5535128	4	-6	16	36
5	692575	5535123	692580	5535120	-5	3	25	9
6	690660	5534097	690655	5534098	5	-1	25	1
7	690819	5533650	690813	5533648	6	2	36	4
8	691297	5534513	691293	5534518	4	-5	16	25
9	690001	5532369	690008	5532373	-7	-4	49	16
10	691425	5531769	691428	5531773	-3	-4	9	16
						[$\Delta\Delta$]	226	145
						m, m	5	4
№ of point	Vague contours				δX	δY	δX^2	δY^2
1	690794	5532141	690775	5532138	19	3	361	9
2	689476	5533000	689488	5533008	-12	-8	144	64
3	689340	5533108	689333	5533105	7	3	49	9
4	689286	5533441	689270	5533430	16	11	256	121
5	690709	5534338	690708	5534345	1	-7	1	49
6	690557	5534187	690550	5534178	7	9	49	81
7	692615	5534864	692618	5534853	-3	11	9	121
8	690595	5534063	690608	5534050	-13	13	169	169
9	690507	5533825	690498	5533828	9	-3	81	9
10	690464	5533830	690473	5533848	-9	-18	81	324
						[$\Delta\Delta$]	1200	956
						m, m	11	10

6. IDENTIFICATION OF CUTTING AREAS ACCORDING TO SATELLITE IMAGES OF DIFFERENT PERIODS

Besides research of different periods cutting according to single satellite image of high resolution (QuickBird-2), the cutting area determination is carried out according to different periods images: Ikonos-2 for 2002, 2007, QuickBird-2 for 2010 and WordView-2 for 2014 years, which makes it possible to evaluate changes of

deforestation areas over a certain time period. We show in Fig. 6 elements of cuttings which are clearly identified and allow seeing how cuttings were carried out at certain times. The cutting areas are identified in software package ArcGIS9.3.



Source: authors' study

Figure 6. Identification of deforestations on the images: a) Ikonos (2000); b) Ikonos (2007); c) QuickBird-2 (2010); d) WordView-2 (2014).

Identification of deforestations is made according to images: Ikonos-2 (2002), Ikonos-2 (2007), QuickBird-2 (2010), WordView-2 (2014). Image Ikonos-2 (2002) that clearly identifies cutting serves as original to compare the scale of deforestation during the period from 2002 to 2007 (Fig. 6a). Differences of cuttings are presented as red polygons (Fig. 6b). Differences of cuttings for the period 2007-2010 are shown in Fig. 6c with blue colour, and the differences of cutting made for the period 2010-2014 are shown in Fig. 6d with yellow.

Cuttings areas and their changes, which happened over the period 2002-2007, 2007-2010 and 2010-2014, are shown in Table 5.

Table 5. Cutting areas at different time periods

Year	Cutting areas for the time period, ha	Cutting areas on average per year, ha
2002	68,6	13,7
2007		
2010	59,7	19,9
2014	52,4	13,1

Thus, the research results make it possible to assert that by using high resolution satellite images it is possible to identify deforestation, set the time of cutting and determine their areas.

7. CONCLUSIONS

1. It is defined that high resolution satellite images automatically allow, according to spectral characteristics of objects, to identify forests, including deforestation.

2. On satellite images of high resolution by QuickBird-2 satellite cuttings of coniferous and deciduous plantings obtained in result of controlled classification by method of maximum likelihood, correlate with other objects, similar by their spectral characteristics: coniferous forests, deciduous forests.

3. Application of post-classification images processing allows significantly improving the results of controlled classification of cuttings that allows determining their areas more accurately. On the basis of the area analysis obtained from the test information and from the post-classification it is defined that the results of divergence of cutting areas range from 0,6% to 15,9% for different types of underlying surface.

4. The methodology of comparison of high-resolution satellite images in appropriate time intervals is effective for the determination of deforestation areas.

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Internet-resources:

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<http://www.lesovod.org.ua>

<http://www.globalforestwatch.org>

<http://dklg.kmu.gov.ua/forest/control/uk/index>

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