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MONITORING OF CONIFEROUS FOREST DRYING IN PRECARPATHIAN REGION USING REMOTE SENSING DATA

Purpose. The aim of this research is monitoring of coniferous forests of Tukhlya forestry in Precarpathian region using medium and high resolution satellite images and images obtained from an unmanned aerial vehicle (UAV). **Methodology.** To monitor the condition of forests of Tukhlya Forestry, a technique based on using satellite images with different spectral characteristics and resolutions, images obtained from UAVs and, accordingly, their processing by different methods, was used. To substantiate the methods of further image processing and to develop effective approaches to the identification of areas with coniferous trees drying, spectrophotometric measurements of healthy and damaged coniferous vegetation were carried out. The analysis of the obtained spectral curves made it possible to select the appropriate ranges of the electromagnetic spectrum for the identification of damaged and dry vegetation. The research is based on using high and medium resolution satellite images, obtained from GeoEye-1 and Sentinel-2. Unmanned aerial vehicle surveying was used to obtain validation information and to analyse the obtained results. **Results.** Researches were conducted in the territory of Tukhlya forestry, Skole district, Lviv region. Three expeditions were carried out for field research. During the last expedition, surveying from the unmanned aerial vehicle were conducted for two test sites. For efficient using of spectral reflectance ranges, samples of different coniferous vegetation types were selected for spectrophotometric measurements. The analysis of the obtained spectral curves was used to select the vegetation indices that allow identification of damaged and healthy vegetation. To improve the interpretation capabilities of index images, a synthesized image from three vegetation indices was created. Controlled classification by maximum likelihood method was performed to determine the areas of sites with damaged coniferous vegetation. The obtained results were then analysed. **Scientific novelty and practical significance**. The scientific novelty is processing of the methods for detection of damaged and healthy coniferous vegetation in the territory of the Carpathian region. Spectrometric measurements of healthy and damaged vegetation are the theoretical basis, which makes it possible to substantiate the choice of spectral ranges for the most efficient separation of different types of coniferous vegetation and the choice of vegetation indices for their identification. The developed methodology of using remote sensing data for identification of damaged and healthy vegetation allows to detect not only dry and healthy vegetation, but also damaged vegetation. This will contribute to the timely cutting of such trees, which will not only save the healthy forest from further spread of pests, but also obtain wood that can still be used in the wood industry.

Key words: forest monitoring, drying of coniferous forests, remote sensing, satellite images, vegetation indices, classification.

Introduction

The total area of forest land in Ukraine is 10.4 million hectares; 9.6 million hectares is land covered with forest. Forests cover more than 15.7 % of the territory of Ukraine and are located mainly in Polissia and Carpathian. Forests have an important role in many environmental processes, in particular, they affect the climate, the atmosphere, water objects, reduce the sharpness of temperature and humidity, and protect the soil from water and wind erosion.

Increased anthropogenic impacts, including changes in land cover, pollution of air, water, and soil, deterioration of soil quality, and loss of biodiversity threaten the productivity of forest ecosystems at regional and global levels [Sherbinin et al., 2007; Kumar, 2011].

Over the last 5–7 years throughout Ukraine, there has been widespread drying of forests species such as spruce, ash, oak, hornbeam, and birch, but the state of coniferous forests, in particular pine plantations, where the situation has become catastrophic, is a major concern. This process takes on a global character. This was emphasized during a meeting of the State Agency of Forest Resources of Ukraine on April 25, 2019 [State Agency of Forest Resources of Ukraine, 2019].

At present, the phenomenon of pine drying is widespread in Zhytomyr, Rivne, Volyn, Lviv, and other areas where pine plantations are significant. As of September 2019, the total area of forest drying was more than 413.000 hectares, of which are pine stands – 222.000 hectares, spruce – 27.000 hectares, oak – 100.000 hectares and other plantations – 64.000 hectares [State Agency of Forest Resources of Ukraine, 2019].

Coniferous forests are drying not only in Ukraine but also in Poland, Slovakia, Switzerland, Austria, and Germany. Widespread drying of forests has taken place in the forests of Siberia and North America [Katz, 2017].

Global climate change, rising temperatures and decreasing rainfall are provoking the spread of pests, most common in coniferous forests. [Zatserkovnyi et al., 2017] Among the forest pests, the most common are stem pests, including bark beetles. In the past they were considered secondary, but now they are a major killer in coniferous and deciduous forests. Over the last four years, the area of forests in Ukraine affected by stem pests has increased more than 7 times.

As stated on the official site of the State Enterprise "Lvivlizozahist", the area of coniferous forests in the territory of the State Enterprise "Slavsk Forestry" is 15.5,000 hectares, of which drying area at the beginning of 2016 is 6.7,000 hectares. The annual drying rate of coniferous forests is 0.3–0.4,000 hectares [SE "Lvivliso-zahist", 2016].

Also on the official site of the State Enterprise "Lvivlisozahist" is stated about different types of deadwood. There are six categories of deadwood: the sixth category is old deadwood without bark; five – fresh deadwood, that is, trees that have dried up this year; the fourth is withered, that is, they will die by the fall; the third is very weak plantings; the second – weakened trees; the first is absolutely healthy trees. The sixth, fifth and fourth categories are subject to mandatory cutting.

Changes in forest cover can be investigated locally using field research, but a method based on remote sensing data is necessary on a regional and global scale [Trigg et al., 2006].

Remote sensing technologies allow to create forest monitoring systems, including defining the structure of plantations, detecting changes in forests as a result of fires, cutting and other factors that cause negative changes in forests [Bochenek et al., 2017].

The feasibility of using remote sensing materials to identify damaged forest areas requires a high degree of monitoring efficiency over large areas of coverage, which is important for forest areas.

Using satellite imagery to detect trees drying, both visual and automated interpretation is used. Automated detection of damaged forest areas is based on the use of computerized classification of images. For single images it often uses different types of classifications using training samples, for example by the maximum likelihood method. Detection of changes by analysis of a series of images usually shows higher accuracy [Krylov et al., 2011; Franklin et al., 2003].

In the scientific literature, variants of spectral synthesis for better detection of objects are analyzed, also attention is paid to the patterns of absorption and reflection of radiation by vegetation in different spectral ranges. [Zatserkovnyi et al., 2017]. Vegetative indices are often used to obtain new images that can more effectively identify different vegetation condition. Vegetation indices are widely used for mapping of vegetation, estimation of indicators of bioproductiveness of crops, and chlorophyll content. Vegetative indexes allow to identify those features of images that are difficult to interpret even on synthesized images [Kokhan, Vostokov, 2009; Bardysh, Burshtynska, 2014].

In order to make effective use of remote sensing data, it is advisable to use a spectrum of natural objects that can be obtained with spectrometers. As a result, quantitative measurements of brightness, illumination, and reflection of the Earth's surface are obtained. Such data is needed to find out the best technical specifications of aerospace sensor [Stankevych et al., 2010].

The effectiveness of identifying areas with dry and damaged vegetation belongs to the difficult tasks of forestry. They consist in the use of an automated method for identification of dry and damaged vegetation (categories 2, 3, and 4). This separation is important in view of the use of wood: if the deadwood can be used only for burning, then partially damaged wood can be used in industrial production.

Purpose

The aim of this research is monitoring of coniferous forests of the Tukhlya forestry in Precarpathian region on the basis of medium and high resolution satellite images with using images from UAV, in particular the detection of areas with dry and damaged coniferous vegetation.

Methodology

To accomplish the task of identifying different categories of coniferous vegetation, a methodology of the effective use satellite images with different spectral characteristics and resolution, images obtained from UAVs, as well as a method for their processing was developed.

Spectrophotometric measurements of healthy and damaged coniferous vegetation were carried out in order to substantiate the methods of further image processing, to develop effective approaches to the identification of different types and sizes of conifer trees. The analysis of the obtained spectral curves allows us to choose the appropriate ranges of the electromagnetic spectrum for the identification of damaged and dry vegetation.

The research is based on using high- and medium-resolution satellite images, obtained from GeoEye-1 and Sentinel-2, to determine areas with coniferous forests drying. Unmanned aerial vehicle surveying was used to obtain validation information and to analyse the obtained results

Research materials:

1) orthophotoplan of forestry with marked sites with coniferous trees drying (2007);

2) medium-resolution images from Sentinel-2 satellites (August, 2017; August, 2018, August, 2019);

3) high-resolution image from GeoEye-1 satellite (August 2011);

3) images and orthophotos from UAV (June, 2019).

The Sentinel 2A and 2B satellites launched on June 23, 2015 and March 7, 2017, respectively. They are designed for 13 multispectral modes with a 10, 20, and 60 m spatial resolutions. Launched under the project Copernicus of European Space Agency.

The GeoEye-1 satellite was launched on September 6, 2008. The opto-electronic system of satellite allows to receive images in panchromatic mode with a spatial resolution of 0.46 m and in multispectral mode with 1.82 m. The GeoEye-1 satellite system operates in 5 modes.

The research methodology consists of three blocks.

The first block of work is field work. These include expeditionary research to analyze the condition of forests and selection of test sites to identify the degree of coniferous trees drying.

The second block is surveying from unmanned aerial vehicle (UAV), which includes the calculation of surveying parameters, projection of flight path, and actually surveying.

The third block is cameral work. They are first conducted on test sites, after that the results are used to investigate coniferous trees throughout all forestry. The final stage of cameral research is the analysis of the results.

The structural scheme of research is presented in Fig. 1.

An important step in research is the selection of vegetation indices that can most effectively identify healthy and damaged coniferous vegetation. Vegetation indices, as combinations of surface reflections from two or more spectral bands, reveal certain vegetation properties. More than 200 types of vegetation indices have been published in the scientific literature, but only a small subset has a substantial biophysical basis, which is being systematically improved.

In general, vegetation indices are grouped by vegetation characteristics [Cherepanov, Druzhinina, 2009; Cherepanov, 2011]. The vegetation indices are organized according to the groups given in Table 1.

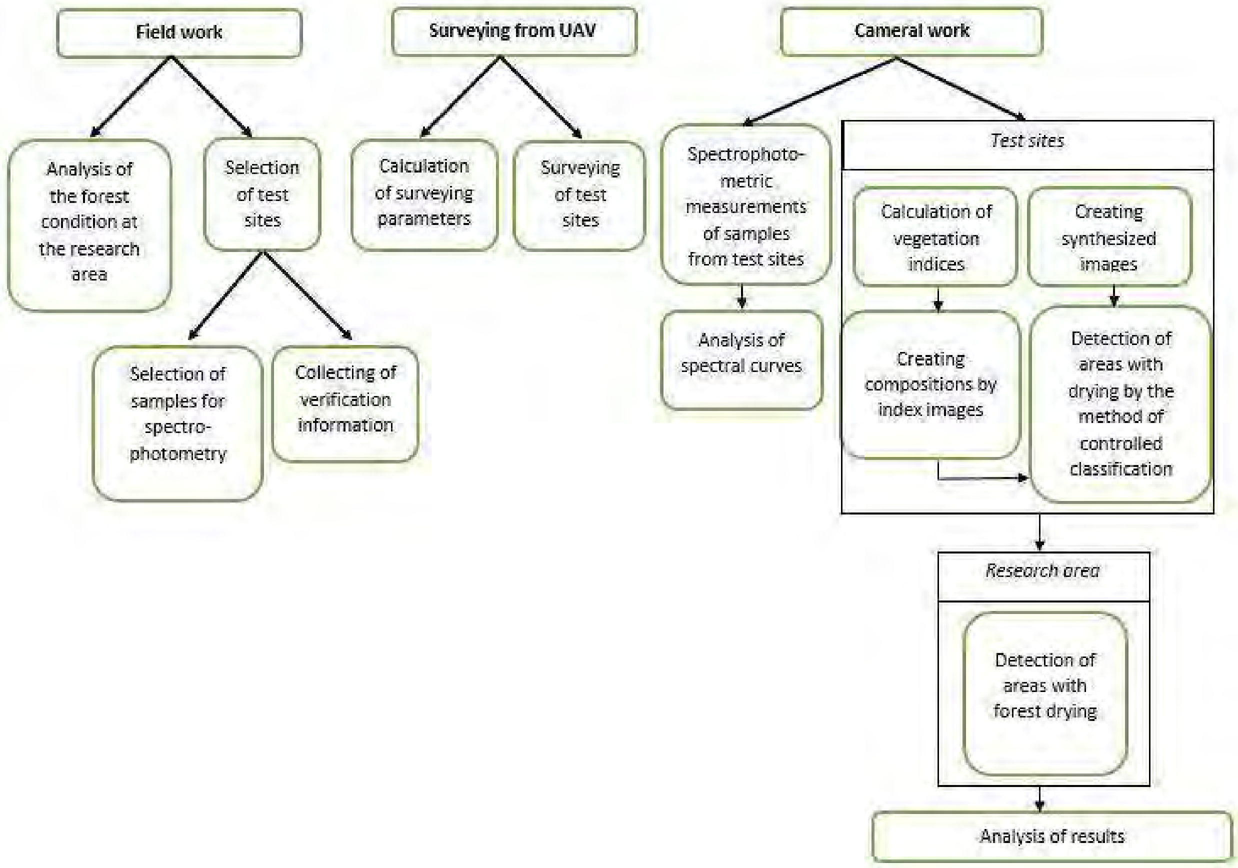


Fig. 1. Structural scheme of research

Table 1

Main groups of vegetation indices

No	Name of group	Description
1	Broadband Greenness	characterize the total amount of vegetation and its condition. The main purpose of these indices is to map the vegetation cover, identify the areas of land covered and not covered with vegetation, assess and monitor the condition of the vegetation, assess productivity and yield
2	Narrowband Greenness	used to estimate the amount and condition of vegetation, as well as the indices of the previous group. The difference is that for the calculation of these indices the area of the near infrared band ("red edge") is used, which allows to record even minor changes of vegetation status
3	Light Use Efficiency	take into account the correlation between different types of pigments to evaluate light efficiency. They correlate well with efficiency of carbon assimilation and growth activity. The indices of this group are also closely related to the absorption of active radiation
4	Canopy Nitrogen	used to evaluate the content and concentration of nitrogen in the vegetation. Nitrogen is a component of proteins, chlorophyll, and many other organic compounds. Under nitrogen starvation, the leaves become pale green and smaller
5	Dry or Senescent Carbon	provide an estimate of the amount of carbon in dry states of lignin and cellulose. Such carbon is present in large quantities in dead or dry plant tissues, an increase in these indicators may reflect the process of "aging" or dying of plants
6	Leaf Pigments	take into account the content of carotenoid and anthocyanin pigments, that are characteristic of damaged vegetation. Can be used for condition monitoring and yield estimation
7	Canopy Water Content	used to evaluate the moisture content of plants. High moisture content is characteristic of healthy vegetation

On the basis of spectrophotometry and analysis of groups of vegetation indices, such vegetation indices are selected, which allow to detect the biggest difference between damaged and healthy vegetation.

The obtained index images serve for conducting a controlled classification, which allows to determine the areas of sites with dry and damaged vegetation.

Results

The research was conducted in the territory of Tukhlya forestry, located in the Skole district of Lviv region. Tukhlya forestry is a part of the State Enterprise "Slavsk Forestry". By the nature of the relief forests in this territory belong to mountains. Differences in heights is about 500 m. The forest area is located in the Eastern Beskyds.

The total area of forestry is 4888 ha. In Fig. 2, the border of Tukhlya forestry with marked 27 sites where coniferous forest was drying in 2007 is shown.

Fig. 2. Border of Tukhlya forestry with marked sites with coniferous forest drying

For field research, three expeditions were carried out:

- September 2017;
- June 2018;
- June 2019.

Visual surveys of the general forest condition were conducted during the expeditions. In some sites, the fallen dry trees that have been overgrown with grass and bushes have been identified (Fig. 3), and areas with dry coniferous vegetation have been identified (Fig. 4).

Fig. 3. Site with fallen dry coniferous trees

Fig. 4. Site with dry coniferous trees

Also, the coniferous vegetation was monitored using Sentinel-2 satellite images. In particular, the analysis of images series from Sentinel-2 revealed that dry trees were cut down at seven sites. Fig. 5 shows the cutting of one of the sites area is about 5 hectares within an area of about 10 hectares.

a *b*

Fig. 5. An example of cutting of site with coniferous trees drying: a – 2017; b – 2018

Fig. 6 shows the complete cutting of two sites with drying, and also shows the spread of coniferous trees drying outside these sites. These new drying areas have also been cut down.

During the last expedition, surveying from the unmanned aerial vehicle for two test sites, located at different heights, were conducted. UAV Trimble UX5

HP with installed Sony 7R camera were used. The focal length of the camera is 35 mm. The height of surveying was 645 m for the first site and 432 m for the second. By parameters of surveying and characteristics of digital camera, resolution for contrast objects of two sites was calculated. Resolution are 9 cm for the first section and 6 cm for the second. Such accuracy of determination of the planned coordinates of the turning points of sites with damaged vegetation allows to conclude that it is possible to determine the areas of the test sites with high accuracy.

a *b*

c

Fig. 6. An example of the spread of coniferous trees drying and cutting of sites: a – 2017; b – 2018; c – 2019

The projected flight path is shown in Fig. 7. Fig. 8 shows the point cloud by which the orthophotoplan and image centers were created.

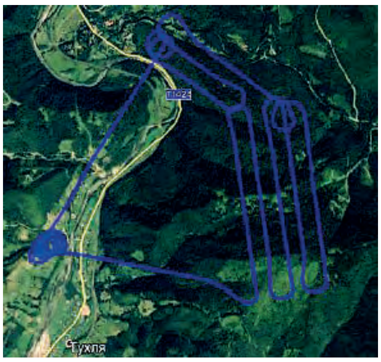


Fig. 7. The projected flight path

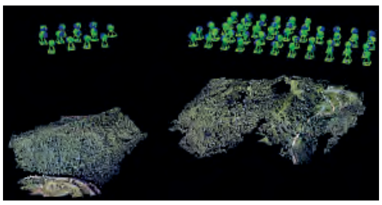


Fig. 8. Point cloud and image centers for test sites

As a result of surveying from UAV, an orthophotoplan was created, a fragment of which is shown in Fig. 9. The obtained data was then used as verification information for further research.

Fig. 9. Fragment of created orthophotoplan

On the orthophotoplan we can recognize healthy, damaged, and dry vegetation (Fig. 10).

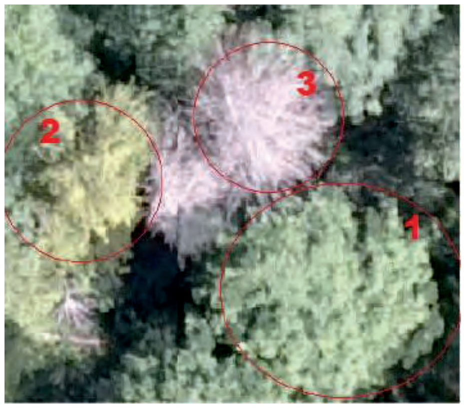


Fig. 10. Coniferous vegetation on orthophoto: 1 – healthy; 2 – damaged; 3 – dry

In order to make efficient use of spectral reflectance ranges, samples of various coniferous vegetation types were selected. The ASD FieldSpec-3 FR spectroradiometer was used for this purpose. Measurements were conducted in State Institution “Scientific Centre for Aerospace research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine”.

The spectral range of the ASD FieldSpec-3 FR spectroradiometer is 350–2500 nm; the reference interval is 1.4 nm in the wavelength range 350–1000 nm and 2.0 nm in the wavelength range 1000–2500 nm; spectral resolution is 3.0 nm at 700 nm and 10 nm at 1400 nm and 2100 nm.

The ASD FieldSpec-3 FR spectroradiometer has three component sensors. Usually a three-sensor circuit to provide better results and user-selectable range is used. All three sensors are separate spectrometers. The fiber optic cable has fiber optic harnesses, each of which is soldered directly into the spectrometer. The first sensor uses a fixed corrected holographic diffraction grating for the range of 350–1050 nm and a 512-element silicon photodiode line with a filter to optimize the sampling interval, sensitivity, and temperature stability in this wavelength range. The second and third sensors use reflective holographic diffraction gratings mounted with fast scanning and gradient InGaAs photodiodes with thermal coolers and blocking filters [Donets et al., 2014].

Fig. 11 shows samples of different types of coniferous vegetation selected during the last expedition.

As a result of spectrophotometry, we obtained a graph of spectral curves for different types of conifers (Fig. 12).

Analyzing the graph of the spectral curves (fig. 12), it is found that the areas in the middle infra-red range (about 1400–1900 nm) are effective for identifying different types of vegetation, in addition to the areas on the border of the red edge. As can be seen from the graph, healthy vegetation has the highest reflectivity in the range of 700–1150 nm, in the range of 1150–2400 nm the highest reflection has completely dry vegetation. Drying vegetation (categories 2, 3, 4) does not show a sharp change in the spectral brightness coefficient in the red edge region, but is characterized by a smoother curve in the 500-800 nm region and more correlates with soils by shape. Middle infrared range of the spectrum is responsible for changes in vegetation humidity, as well as changes in the structure of vegetation and leaves, and reflection in the near infrared range depends only on the internal structure of the leaf and is independent of water saturation. So, common usage of these two ranges of spectrum will increase the accuracy of determining plant moisture [Ceccato et. al., 2001].

After analyzing the literature [Sidelnik et al., 2018; Zatserkovnyi et al., 2017, Kokhan, Vostokov, 2009] and considering the features of the obtained spectral curves for different types of coniferous vegetation, vegetation indices which allow to identify coniferous trees, were selected. Chosen vegetation indices are given in Table 2.

a *b* *c*

d *e*

Fig.11. Samples of selected coniferous vegetation:
a – 1 category (healthy); b – 2 categories (weakened); c – 3 categories (very weak);
d – 4 categories (drying); e – 5 categories (fresh deadwood)

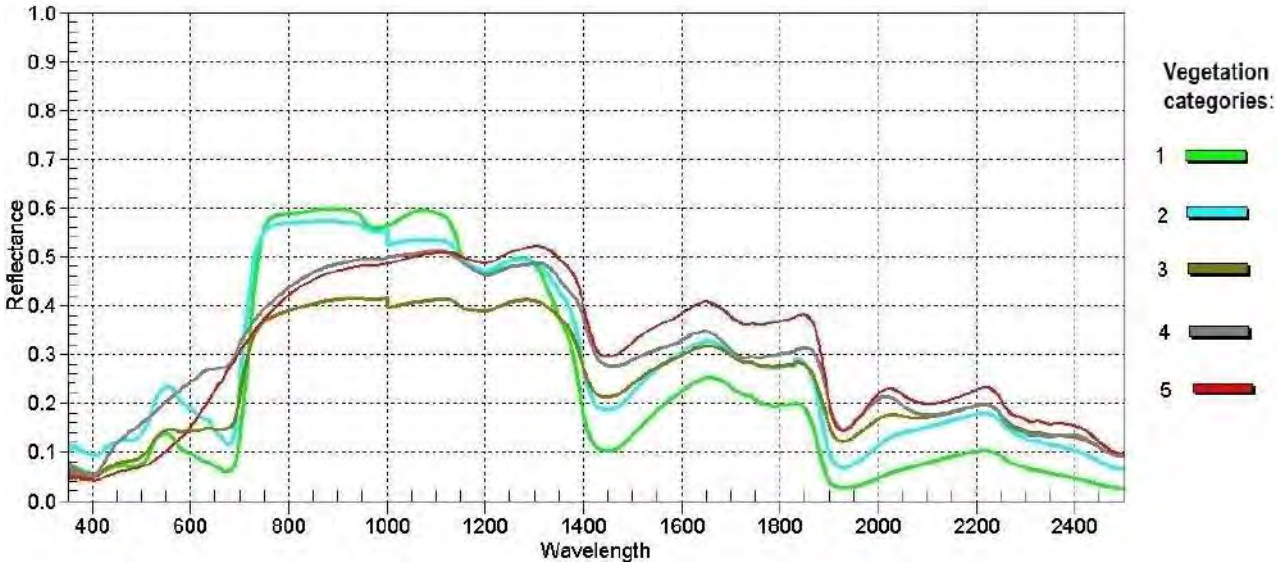


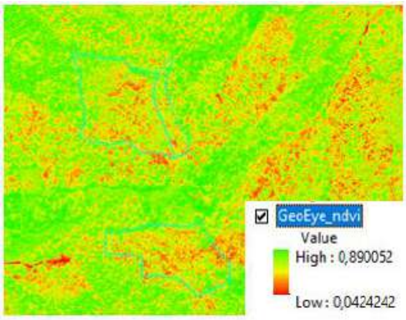
Fig. 12. Graph of spectral curves for coniferous vegetation of different categories

Table 2

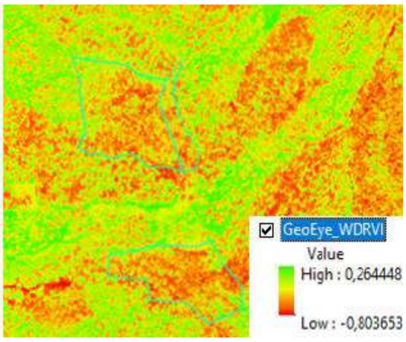
Vegetation indices for the detection of dry vegetation

Normalized Difference Vegetation Index	$NDVI = \frac{B_{NIR} - B_{RED}}{B_{NIR} + B_{RED}}$	Used to monitor the total amount of vegetation. The sensitivity to background reflection somewhat complicates the use of this index to determine the species composition of the forest cover
Enhanced Vegetation Index	$EVI = \frac{B_{NIR} - B_{RED}}{B_{NIR} + 6 \cdot B_{RED} - 7{,}5 \cdot B_{BLUE} + 1}$	Allows to allocate more gradations of forest cover than NDVI, which gives benefits for forest monitoring. The impact of the underlying surface and the atmosphere is minimized
Wide Dynamic Range Vegetation Index	$WDRVI = \frac{0{,}1 \cdot B_{NIR} - B_{RED}}{0{,}1 \cdot B_{NIR} + B_{RED}}$	Modification of the NDVI. Used to improve accuracy in vegetation analysis
Normalized Difference Water Index	$NDWI = \frac{B_{NIR} - B_{SWIR}}{B_{NIR} + B_{SWIR}}$	In case of damage of forest vegetation, vegetation sharply loses moisture and wilt, therefore, it is advisable to use a spectral index that takes into account plant moisture – the water index
Plant Senescence Reflectance Index	$PSRI = \frac{B_{RED} - B_{GREEN}}{B_{NIR}}$	In dry and damaged vegetation, the amount of coarse carbon increases that can be accounted by PSRI index. Used for general assessment of dry and dead vegetation
Dry Matter Content Index	$DMCI = \frac{B_{SWIR3} - B_{SWIR2}}{B_{SWIR3} + B_{SWIR2}}$	In the presence of damaged forest vegetation is a violation of the water balance and the formation of dry areas. The dryness index is used to determine the stress state of vegetation

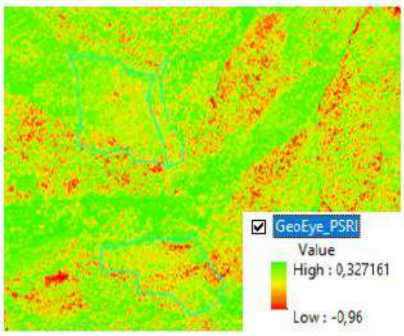
Fig. 13 shows index images, created by images from GeoEye-1 satellite, namely NDVI (a), WDRVI (b), PSRI (c) and EVI (d). The use of the other two indices, namely NDWI and DMCI, depends on the mid-infrared range. They can be used to processing images from satellites whose surveying systems provide band information in this range.



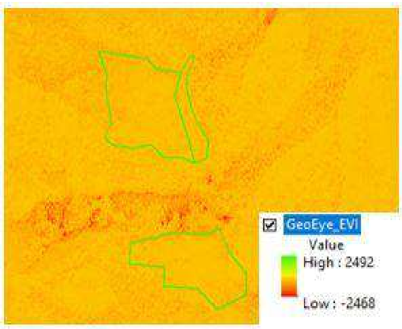
a



b



c



d

Fig. 13. Images obtained by vegetation indices:
a – NDVI; b – WDRVI; c – PSRI; d – EVI

To improve the interpretation capabilities of index images, a synthesized image was created using three vegetation indices – NDVI, WDRVI and PSRI (Fig. 14).

The analysis of the obtained image allows to conclude the clear identification of dry vegetation (blue color), as well as clearly distinguish between healthy coniferous and deciduous vegetation. For comparison, Fig. 15 shows a synthesized image from the NIR, RED, and GREEN bands, often used to analyze the condition of vegetation of different species.

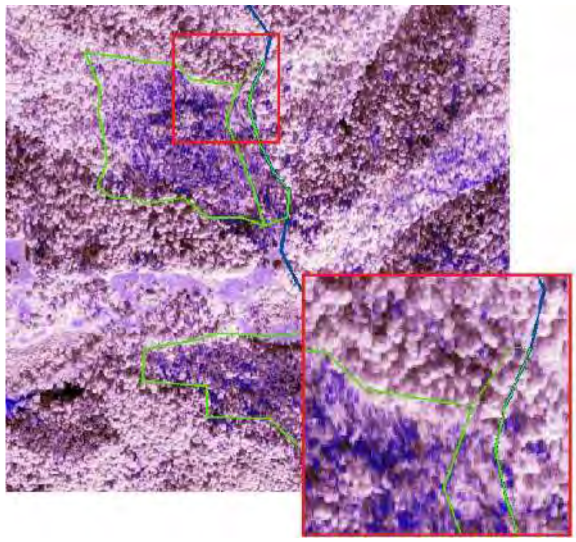


Fig.14. Composite image from NDVI, WDRVI і PSRI

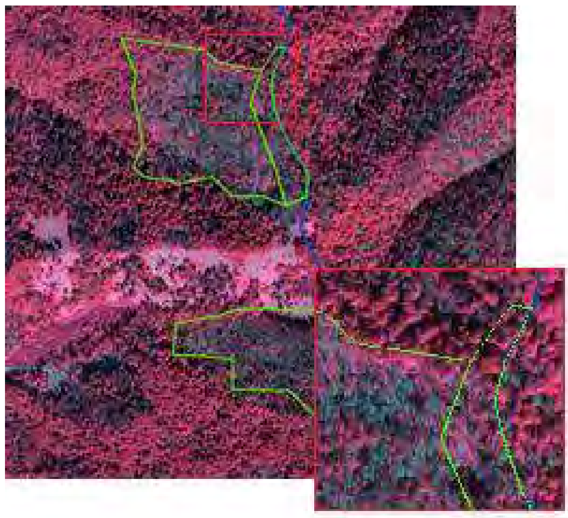


Fig. 15. Synthesized image from NIR, RED and GREEN bands

To determine the areas of sites with damaged coniferous vegetation, a controlled classification by the maximum likelihood method for the synthesized and composite index image was performed [Burshtynska et al., 2016; Burshtynska et al., 2014].

Controlled classification by the maximum likelihood method is performed by the formula (1):

$$D = \ln(a_m) - \left[0.5\ln\left(\left|COV_m\right|\right)\right] - \\ -\left[0.5\left(X - M_m\right)^T\left(COV_m^{-1}\right)\left(X - M_m\right)\right], \quad (1)$$

where D is weight distance (probability); a_m is the percentage of probability that a classified pixel belongs to class m (equal to 1.0 or entered based on a priori data); COV_m is a covariance matrix of pixels in signatures of class m; COV_m^{-1} is inverted matrix to COV_m; T is transposition of the matrix [Shpak, 2012].

For the estimation of accuracy, 10 cells of drying on two test sites were selected and their area was determined by the orthophotoplan (Fig. 16).

Also, the areas of these 10 test cells were defined by synthesized and the composite index image. The results are presented in Table 3.

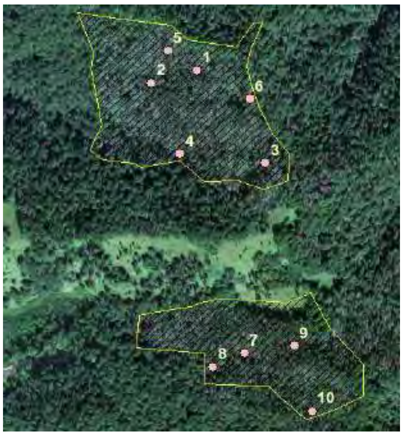


Fig. 16. Test areas cells for accuracy assessment

Table 3

Evaluation of the accuracy of obtained results

No	Test	GeoEye (NDVI-WDRVI-PSRI)	GeoEye (NIR-RED-GREEN)	Test – GeoEye (NDVI-WDRVI-PSRI)		Test – GeoEye (NIR-RED-GREEN)	
	Area, m²	*Area, m²*	*Area, m²*	*Differ, m²*	*Accuracy, %*	*Differ, m²*	*Accuracy, %*
1	1510	1428	1784	82	95	274	82
2	813	724	952	89	90	139	83
3	380	392	360	12	97	20	94
4	450	444	468	6	98	18	96
5	130	112	164	18	87	34	76
6	142	136	168	6	96	26	82
7	1000	980	1024	20	98	24	98
8	602	584	644	18	97	42	93
9	135	128	144	7	95	9	93
10	95	92	112	3	97	17	83

The analysis of the results of determining the areas using the composite image from NDVI, WDRVI, PSRI indicates high reliability (87–98 %), the analysis of the synthesized image indicates a reliability of 76–96 %. The identification of the boundaries of sites with drying by synthesized image is more influenced by the underlying surface and the spectral brightness of the neighbouring forest objects.

Scientific novelty and practical significance

The scientific novelty is processing of the methods for detection of damaged and healthy coniferous vegetation in the territory of the Carpathian region. Spectrometric measurements of healthy and damaged vegetation are the theoretical basis, which makes it possible to substantiate the choice of spectral ranges for the most efficient separation of different types of coniferous vegetation and the choice of vegetation indices for their identification. The developed methodology of using remote sensing data for identification of damaged and healthy vegetation allows to detect not only dry and healthy vegetation, but also damaged vegetation.

This will contribute to the timely cutting of such trees, which will not only save the healthy forest from further spread of pests, but also obtain wood that can still be used in the wood industry.

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Conclusions

1. Based on the processing of medium and high resolution satellite images using UAV images, a technique for identification areas of terrain with damaged and healthy coniferous vegetation was developed.

2. It is recommended to use surveying from UAV for the selection of test sites, which makes it possible to determine with high accuracy the area of drying and to establish the degree of damage of coniferous vegetation.

3. The analysis of spectral curves obtained by the method of spectrophotometry of the samples of selected coniferous vegetation allows to choose the optimal spectral bands for the purpose of determining the appropriate types of vegetation indices and creating composite index images.

4. A controlled classification of 10 cells for determining the areas of coniferous vegetation drying by composite index images and synthesized images indicates a higher reliability of the results (87–98 %) obtained using the composite index image.

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МОНІТОРИНГ ЗАСИХАННЯ ХВОЙНИХ ЛІСІВ ПРИКАРПАТСЬКОГО РЕГІОНУ З ВИКОРИСТАННЯМ ДАНИХ ДИСТАНЦІЙНОГО ЗОНДУВАННЯ

Для моніторингу стану лісів Тухлянського лісництва застосовано методику, що ґрунтується на використанні різних за спектральними характеристиками і розрізненістю космічних зображень, знімків, отриманих з БПЛА і, відповідно, їх опрацювання різними методами. Здійснено спектрофотометричні вимірювання здорової та пошкодженої хвойної рослинності для обґрунтування методів подальшого опрацювання зображень, розроблення ефективних підходів до ідентифікації ділянок із засиханням хвойних дерев. Аналіз отриманих спектральних кривих дає змогу вибирати відповідні діапазони електромагнітного спектра для ідентифікації пошкодженої та сухої рослинності. Дослідження ґрунтується на використанні космічних знімків високого та середнього розрізнення, одержаних із супутників GeoEye-1 та Sentinel-2 на територію Тухлянського лісництва. Для отримання звіркової інформації та аналізу результатів використано знімання з безпілотного літального апарату. Дослідження виконано на території Тухлянського лісництва Сколівського району Львівської області. Для проведення польових досліджень здійснено три експедиції. Під час останньої експедиції знято з безпілотного літального апарату дві тестові ділянки. З метою ефективного використання спектральних ділянок відбиття відібрано зразки різного типу хвойної рослинності для проведення спектрофотометричних вимірювань. Аналіз отриманих спектральних кривих використано для вибору вегетаційних індексів, що дають змогу ідентифікувати пошкоджену та здорову рослинність. Для поліпшення інтерпретаційних можливостей індексних зображень створено синтезоване зображення за трьома вегетаційними індексами. Щоб визначити площі ділянок із пошкодженою хвойною рослинністю, виконано контрольовану класифікацію за методом максимальної вірогідності. Проаналізовано отримані результати.

Ключові слова: моніторинг лісів, засихання хвойних лісів, дистанційне зондування, космічні знімки, вегетаційні індекси, класифікація.

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