

Original Research

Assessment of Forests of the Natural Park „Kandry-Kul” Using the Earth Remote Sensing Data

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Abstract

The study aims to substantiate the monitoring of protective forests actively used in recreational activities. Monitoring of the plantings state was carried out based on landscape and forest inventory and using geographic information systems, in particular Landsat satellite data allowing to cover the entire object area simultaneously and analyze the state of the object plantings over 30 years. The research involved the plantings of the natural park “Kandry-kul” located on the Belebeevskaya upland of the Southern Urals. Ground investigations and the results of processing satellite images allowed the conclusion that natural and artificial mixed coniferous-deciduous forests are basic. Artificial stands are mainly represented by young pine trees of IA-II growth class. Their sanitary and hygienic assessment is average since silver birch stands contain dropsy. Few landscaped and planted park areas and poorly developed pathway network have a negative impact on the plant community structure and reforestation. Thus, using technical capabilities of satellite systems working based on wide band electromagnetic radiation and ground inventory studies makes it possible to obtain data on the forest ecosystems state with high territorial and temporal resolution and use them when monitoring recreational facilities to solve forestry problems.

Keywords: biomass, forest vegetation, ground investigations, monitoring, natural park, recreational forest management, satellite image, vegetation index

Introduction

Recreational activities are a type of forest management permitted by forest legislation, and carried out particularly in natural parks. However, recreational activities often lead to violation of the ecosystem integrity and stability due to an increase in the maximum permissible recreational loads [1]. Forests used for recreation, especially along water bodies, face numerous problems, including depletion due to the active recreational use of forest and water resources limited within transport distance, or constantly changing climate and other anthropogenic and natural factors. According to Ciesielski and Sterenczak [2], forests are important for biodiversity and provision of environmental services. They affect the quality of people's lives and health. It is well known that the woody and shrubby vegetation on the shores of reservoirs reduces the intensity of landslides. The engineering protection norms for territories, the Code of Rules SP 116.13330.2012 "Engineering protection of territories, buildings and structures from dangerous geological processes. Basic principles" (as in the updated Building Codes and Rules of the Russian Federation SNiP 22-02-2003) consider forest reclamation one of the most important landslide measures. Proper forest management is necessary to maintain biodiversity, preserve the protective functions of forests, and their stable use. One of the main management tasks is to increase the accuracy and informative value of forest ecosystems monitoring results to predict possible changes and develop forestry measures. Therefore, objective methods of forest monitoring, contribute to improving assessment tools and solving problems of forest management and protection. They help create a forestry policy based on a consistent, objective and unified monitoring methodology [3]. The absence of monitoring can lead to irreversible consequences of unregulated forest management. Researchers Li et al. [4] presented forecasts for global reduction of natural ecosystems by 2100 under the influence of active land use. The authors note that the ways of global socio-economic development will influence the reduction of forest resources in the future. The scenario of slow technological innovation supposes overall reduction up to 4.74% compared to other scenarios. The lowest reduction of forests (0.08%) is typical for a scenario with a high level of environmental consciousness. The above results highlight the importance of targeted protection and monitoring of forests to ensure the long-term integrity of forest ecosystems. The international organizations FAO and FCCC of UN require of the signatory countries to maintain and increase the forests' areas.

Improving the management of forests in specially protected natural areas with limited forest resources and intensive recreational development is a scientific problem of great economic importance. The solution of this problem is facilitated by the close integration

of surface field and desktop forest studies and resource assessment using modern Earth remote sensing methods (ERS) and evolving GIS technologies that increase the efficiency and accuracy of evaluation works. The relevance of the work is the need to substantiate forest monitoring methods including the use of GIS technologies to obtain detailed and objective information on the state of forest ecosystems intensively used in recreational activities.

The purpose of the study is to substantiate the methods of monitoring the state of protective forests used in recreational activities based on a combination of forest and landscape inventory, geographical information systems (GIS technologies) with the determination of the NDV index (Normalised Difference Vegetation Index).

Research Objects

The object of the study is the plantings of the natural park "Kandry-kul" classified as protective forests and located along the lake Kandry-kul on the Belebei plateau-like upland of the Southern Urals where the broad-leaved forest and steppe zones are connected. The reason for creating the natural park "Kandry-kul" occupying an area of 6,348 hectares [5] was the protection of natural resources and their rational use for recreational purposes. The area covered by forests is 23.1%.

Materials and Methods

Five trial plots (TP) located on the territory of the Kandry-Kul Nature Park and laid down using accepted scientific forestry and inventory methods [6, 7] were used to determine forestry-inventory and landscape indicators of stands. The changes in indicators from 1986 to 2016 were estimated. To study the radial growth of trees at a height of 1.3 m, increment core samples were taken using Pressler increment bore. The samples were dried at room temperature and cleaned with a scalpel in a plane perpendicular to the wood fibers. The width of the annual rings was measured using a BSM (binocular stereoscopic microscope) with an accuracy of 0.05 mm. The dynamics of radial increment values were established based on data grouping by years of the tree development cycle.

Satellite images from Landsat-5 and 8 satellites were used to make the research. The images were processed in the ArcGIS program. Relying on foreign experience in conducting such studies [8] the popular Normalized Difference Vegetation Index (NDVI) was used to assess the state of plantings and determine the amount of photosynthetic active biomass. The values of the NDV index were calculated using the formula:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (1)$$

where NIR is the spectral reflection in the near infrared region; RED is the spectral reflection in the red region.

The NDVI values are in the range from -1 to 1. When calculating NDVI for woody and shrubby vegetation, its value has positive indicators, which are usually equal to 0.2-0.8 [9].

Statistical Analysis

On the test plots where the Garmin GPSMAP 78S navigator was used the coordinates of the points were captured. The coordinates were later used for statistical processing of the site data in the Statistica 6.0 application software package.

Results and Discussion

Analysis of inventory indicators of forests of the natural park “Kandry-Kul” for 1986 and 2016, allocated in 14 compartments No. 72-77, 83-85, 95-99 showed an increase in the area and number of allotments during the analyzed period. Thus, in 1986, there were 494 allotments on 1,306 hectares with a total timber volume of 145.7 thousand m³; in 2016, there were 558 allotments on 1466 hectares with a total timber volume of 199.1 thousand m³. The average timber volume per 1 ha increased from 140 to 160 m³. 70-year-old common pine trees showed the highest timber volume of 200-210 m³/ha.

The basis of the forests bordering on the lake Kandry-kul are coniferous-deciduous stands. Their primary natural stands are mainly located on the top of the watershed of the lake Kandry-kul. These are scattered trees or groups of 100-150-year-old English oak. Artificial stands are represented by coniferous species, mainly by common pine trees. The stands of the sample areas are mixed, medium stocked (0.5-0.7) belonging to growth class II. The exception

is PP No.5 pure artificial pine stand of a high growth class. The correlation coefficient of the stands’ diameter and height is high. A weak correlation is observed in stands where small-leaved linden trees predominate (PP No. 4) – $r = 0.22 \pm 0.03$ and where improvement cutting was carried out. In 1986, the average forest composition was dominated by silver birch (40% of standing volume - 4B3P2As1On+L,S,Ash,M,TM, cAl, L). However, by 2016, the proportion of artificial common pine stands increased – 4P3B1As1On1L +S, Elm, Ash, TM, M, cAl. Birch forests are represented by ripe and overripe stands (Fig. 1). Their growth class and canopy density indicators have deteriorated over the past 20 years due to the high recreational load in the coastal area. The sanitary and hygienic assessment is below average since there is a significant amount of dead standing trees due to the presence of bacterial dropsy in birch trees. The total value of dead standing trees in the natural park has decreased since 1986 from 2.6 thousand m³ to 2.09 thousand m³ thus indicating the need for intensive sanitary cuttings.

The study revealed a close connection between radial increment and recreational digression (the digression index is the trampling degree, %), which is expressed by the equations: pine - $Y = 7,415e^{-0.0723X}$; larch - $Y = 6,806e^{-0.00583X}$. There was a significant decrease in a radial increment of poplar depending on digression stage (Fig. 2). The active use of the territory for recreational purposes, the lack of landscaped and planted park areas, a poorly developed pathway network had a negative impact on the plant community structure and reforestation. When renewing the forest with 7M2As1L composition of vegetative origin up to 4.0 m 4.9 pcs/ha, the ground elder and grass-sedge forests prevail.

To study the state of stands using GIS technologies, two satellite images were considered (Fig. 3). The first image was taken on August 10, 1986 by the Landsat-5 satellite (scene LT05_L1TP_167022_19860810_20170

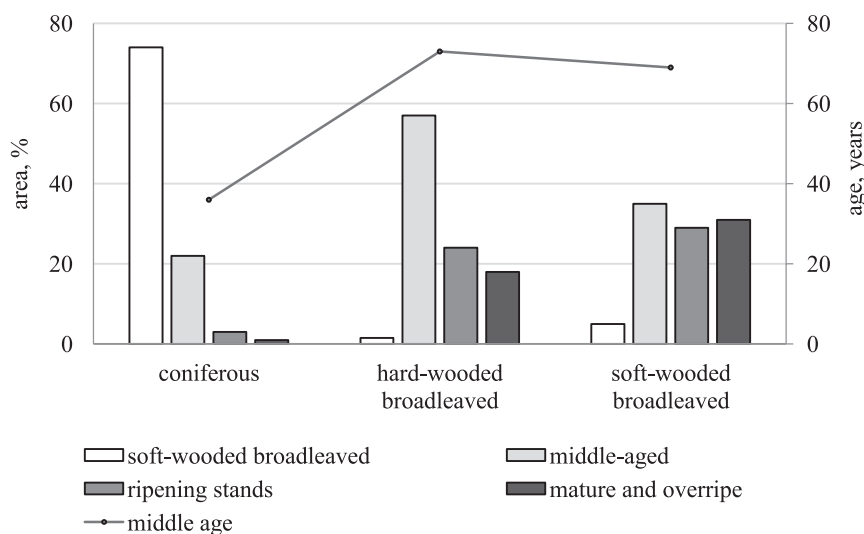


Fig. 1. Age distribution of standings.

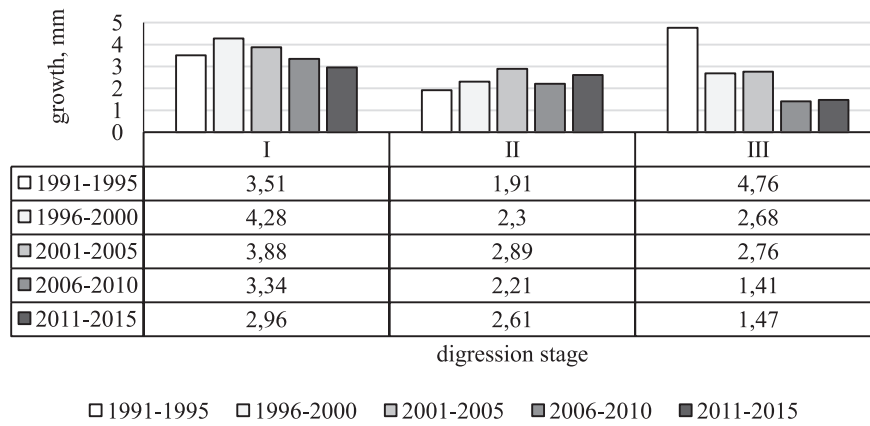


Fig. 2. Dynamics of radial increment depending on stages of poplar recreational Digression.

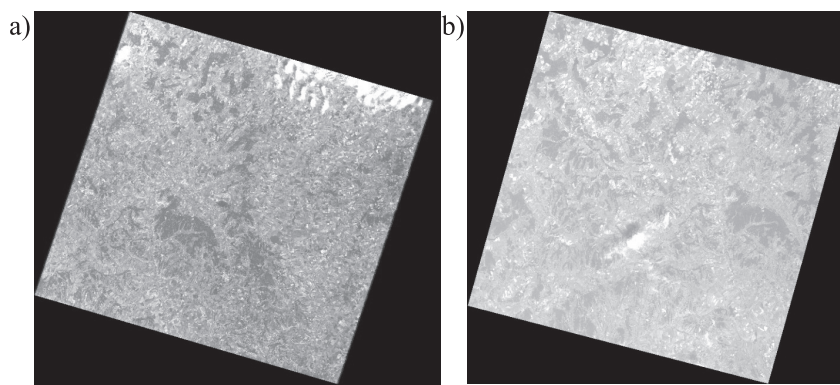


Fig. 3. Satellite images used to calculate the NDV index. a) image taken in 1986 by Landsat-5 satellite; b) image taken in 2016 by Landsat-8 satellite.

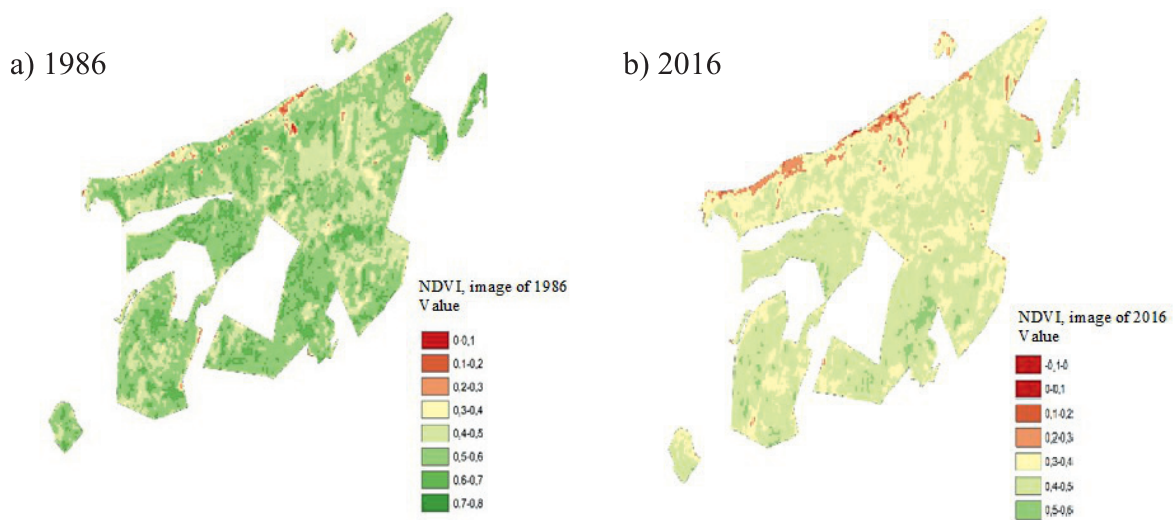


Fig. 4. NDVI index in various years.

216_01_T1). The second image was taken on August 03, 2016 by the Landsat-8 satellite (scene LC08_L1 TP_168022_20160803_20170322_01_T1). After the preprocessing of the images involving radiometric and geometric corrections, the NDVI index was calculated

for the selected images (Fig. 4). In 1986, the NDVI index was between 0.0617284-0.704918. In 2016, the NDV index ranged from -0.0260394 to 0.545866. Table 1 presents the distribution of each class of the NDV index. The average class of the NDV index for

Table 1. Distribution of the NDV index classes in different years.

NDV index class	Class range	Number of pixels, pcs.		Area, ha	
		a) 1986	b) 2016	a) 1986	b) 2016
0	-0.1-0	0	1	0	0.09
1	0-0.1	3	3	0.27	0.27
2	0.1-0.2	16	28	1.44	2.52
3	0.2-0.3	99	401	8.91	36.09
4	0.3-0.4	557	5,040	50.13	453.6
5	0.4-0.5	4,025	8,632	362.25	776.88
6	0.5-0.6	7,967	339	717.03	30.51
7	0.6-0.7	1,776	0	159.84	0
8	0.7-0.8	1	0	0.09	0

1986 was 5.74, and for 2016-4.61. The coordinates of the points were captured in the test areas using the Garmin GPSMAP 78S navigator. The coordinates were later used for statistical processing. The results are presented in Table 2.

The areas occupied by all NDVI classes are calculated pixel-by-pixel. There was a significant increase in the 4th and 5th classes of the NDV index of pine stands during the period from 1986 to 2016 (+414.63 ha and +403.47, respectively). At the same time, the stands of the 7th and 8th classes have completely disappeared after sanitary cuttings of birch stands damaged by phyto-bacteria.

Therefore, using technical capabilities of satellite systems working based on wide band electromagnetic radiation makes it possible to obtain data on the forest ecosystems state with high territorial and temporal resolution and use them when monitoring recreational facilities to solve forestry problems. [10]. These

methods can be used to predict and prevent fire-hazardous situations, the reduction of forest stability and areas under forest and monitor climate changes in forests [11-13]. The fundamental foreign research in the use of aerial photographs in the forestry sector is the work of Spurr [14]. Another fundamental scientific works reflecting the analysis of the features of different methods of GIS technologies and ERS (Earth remote sensing) data belong to Colwell [15], Avery and Berlin [16], Landgrebe [17], Lillesand et al. [18]. Remote sensing data are widely used in solving environmental problems since they have lots of advantages as they guarantee a fast, accurate, cost-effective and time-saving mapping of vegetation cover. Moreover, they can also be used to solve problems caused by various processes when using forests [19]. Similar studies have been conducted in Russia and in some foreign countries. German researchers Fischer et al. [20] are using remote sensing tools to study the forest structure and determine its biomass and productivity. According to Vicharnakorn et al. [21], it is the only available method for determining vegetation cover indicators, including land biomass, carbon content of large forest or hard-to-reach areas. There are many methods based on remote sensing adapted to various forest conditions and monitoring. They cover a wide range of spatial and temporal scales [22]. Thanks to the creation of a supercenter in Canada Earth remote sensing data of long-term forest research are becoming available [23]. The study of the planet's forests with different levels of biodiversity, species composition, and the degradation level is carried out around the world using optical satellite images and new remote sensing methods. For instance, the studies of tropical forests [24, 25] of Europe [26] and eastern countries [27] involve the specification of the areas of land covered by forest vegetation.

The research results obtained during the images processing correspond to ground investigations, which is reflected, for example, in the change in the stands

Table 2. Indicators of statistical data processing.

Statistical indicator of the NDV index	1986	2016
Number of points, pcs.	278	278
Average value	0.522	0.414
Median	0.526	0.415
Mode	0.6	0.414
Dispersion	0.005	0.002
Standard deviation	0.071	0.046
Variation coefficient, %	13.75	11.14
Standard error of the average	0.004	0.002
Asymmetry	-0.898	-0.653
Excess	1.080	1.505
Experiment accuracy, %	0.824	0.668

composition for each quarter and for the object in general. Besides, verification of the data of satellite images decoding and field and desktop forest inventory studies has shown that the transformation of the territory of the natural park occupied by tree stands and the deterioration of their sanitary state over 30 years are due to an increase in the area of overripe stands, intensive use of the object in recreational activities and insufficient measures for improving the forests sanitary state.

Research of foreign scientists confirms the authors' conclusions. They note that the combination of satellite observations and ground data processing contributes to an objective analysis of forest dynamics and can provide relevant and accurate information for determining the forest stands structure and solving forestry problems [28, 29]. Many methods for determining woody vegetation have appeared in recent years. These methods involve revealing trees with a crown diameter of over 3 m using optical and radar images of medium resolution, images taken from the Sentinel-2 satellite and radar images taken from Sentinel-1 satellite. Other methods involve using an artificial neural network [30] and a recurrent neural network [12], the random forest method [31], methods of k nearest neighbors and support vectors [32].

The NDV index is one of the most commonly used vegetation indices for the classification of soil and vegetation cover.

According to the research results, the NDV index is an effective and reliable indicator for determining the stands' state. The analysis of satellite images showed that from 1986 to 2016 there was a significant increase in the 4th and 5th classes of Scots pine trees NDVI, which dominated in the stands' composition. The stands of the 7th and 8th classes have completely disappeared due to an increase in the area of overripe stands, their thinning (mortality) and intensive sanitary cutting.

In Thailand, the NDV index was studied to monitor, prevent, and control forest fires in forest amelioration areas [33]. Canadian researchers studied the relationship between remote sensing data using NDVI and annual ring width indices of trees and shrubs in the northern mountains of southwestern Yukon. However, the correlation between these indicators was low [34]. In Ecuador, the relationship between woody vegetation biomass and carbon uptake was studied [35]. The relationship between the NDV index and coordinate-linked climate data for the period 1982-2015 was studied during the growing season in the Amur-Heilongjiang River. NDVI of coniferous forests, broad-leaved forests, mixed forests and woodlands correlated with temperature in all seasons, however, the correlation with autumn precipitation was negative [36].

A comparative data analysis for 30 years performed during the study showed the forest state deterioration because of its intensive recreational use. Gaire et al. [37] obtained similar results when assessing the stands' state. They noted the influence of anthropogenic

factors and environmental factors. Forest ecosystems need regular monitoring of the condition of all stand components. Otherwise irreversible digression changes may occur. The most promising monitoring method is obtaining thematic maps of vegetation cover based on remote sensing images [38]. The combination of stand maps with long-term Landsat data provides a good opportunity to detect and monitor historical shifts in the forest structure and boundaries. For example, a study conducted in the rainforest region of the Para state in Brazil aimed at mapping and monitoring forest changes from 2000 to 2019. The results of the study demonstrated that satellite observations give a boost to data acquisition based on the dynamics of forest conditions [28]. The given research confirms the effective use of satellite data in determining the stands' state and further forestry measures development.

The authors revealed the dependence of the change in forest inventory indicators of the natural park and its sanitary state on the increase in the area of overripe stands and their intensive use in recreational activities. Similar data obtained during studies involving satellite images indicate the prospect of using registered historical Landsat data to monitor the forests state and transformation [39].

Conclusions

A high-precision assessment of forest vegetation indicators needs detailed ground-based forest inventory measurements, which require a lot of labor and time. Methods for obtaining images using multi-spectral Earth remote sensing data have high potential for rapid and up-to-date determination of the forests' state. The research results obtained during the images processing correspond to ground investigations, which is reflected, for example, in the change in the stands composition for each quarter and for the object in general. Besides, verification of the data of satellite images decoding and field and desktop forest inventory studies has shown that the transformation of the territory of the natural park occupied by tree stands and the deterioration of their sanitary state over 30 years are due to an increase in the area of overripe stands, intensive use of the object in recreational activities and insufficient measures for improving the forests sanitary state.

Conflict of Interest

The authors declare no conflict of interest.

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