Vegetation Cover Change in Kologrivsky Forest Nature Reserve Detected using Landsat Satellite Image Analysis

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Abstract. Remote sensing of the Earth data and the results of their thematic interpretation are of great importance in monitoring forest biodiversity. Using the example of the Kologrivsky Forest Nature Reserve, a thematic interpretation of Landsat 5 images was carried out. The best quality classification of natural objects was achieved using the Random Forest and CatBoost algorithms. For the period from 1984 to 2011, thematic maps of prevailing tree species were obtained, according to which the main directions of changes in the vegetation cover were identified.

1. Introduction

The Kologrivsky Forest nature reserve was created in 2006 in the Kostroma region, Russia. The reserve consists of Kologrivsky and Manturovsky sites. One of the main topics of scientific research is the study of changes in vegetation cover in the areas used for forestry [1, 2]. In different years, significant areas that later became part of the reserve were covered by logging and forest fires. Monitoring of forest biodiversity should provide an assessment of its current state, analysis and forecast of possible changes against the background of natural processes and under the influence of anthropogenic factors [3].

Remote sensing of the Earth allows you to obtain objective information about the state of the vegetation cover. In forestry, remote sensing data and the results of their thematic processing have found wide application in mapping forest resources, determining the species composition of forests, in studying the negative processes affecting forests (pests and diseases, forest fires, etc.) [4]. In thematic remote monitoring tasks, the most popular images were from Landsat spacecraft. The use of satellite images from these devices is based on the availability of information, the relatively high frequency of re-obtaining information, the presence of several spectral ranges of shooting and a wide viewing band [5].

2. Methods and Materials

The research materials were data from Landsat 5 (TM sensor) satellites for 1984 and 2011. Images obtained from open sources (United States Geological Survey). Thematic decryption was performed for scenes LT51750191984177XXX02 (1984) and LT51750192011235KIS01 (2011). The criteria for the selection of images was that the images were obtained during the growing season (from May to September) in the daytime, and the cloud cover was less than 10%. Work with geographically
The classification of objects in the images was carried out according to five classes: 1 - dark coniferous forests, 2 - light coniferous forests, 3 - deciduous forests, 4 - open areas (burning, logging, fields, meadows, etc.), 5 - water surfaces. A training sample for classification was formed using data from field surveys of forest subcompartments in the territory of the Kologrivsky Forest Nature Reserve and forest inventory materials.

The sample for each scene was checked for outliers and was divided into training and test samples in the ratio of 7:3. Data analysis was performed using Python 3.7 and the Scikit-learn 0.20.2, CatBoost 0.12.2 libraries. The best solution was chosen among the following algorithms: Logistic Regression, Linear Discriminant Analysis, Quadratic Discriminant Analysis, Random Forest, Gradient Boosting, CatBoost (implementation of gradient boosting from Yandex [6]), k-nearest neighbors (KNN), Multinomial Naive Bayes, Gaussian Naive Bayes, C-Support Vector Classification. Table 1 shows the quality metrics of the algorithms in the test samples.

**Table 1.** Quality metrics (macro average) of classifiers on test samples.

| Method                     | Landsat scene | LT51750191984177XXX02 | Precision | Recall | F1 score | LT51750192011235KIS01 | Precision | Recall | F1 score |
|----------------------------|---------------|------------------------|-----------|--------|----------|------------------------|------------|--------|----------|
| Logistic Regression        |               |                        | 0.914     | 0.899  | 0.903    | 0.927                  | 0.915      | 0.919  |
| Linear Discriminant Analysis |             |                        | 0.913     | 0.882  | 0.894    | 0.925                  | 0.908      | 0.914  |
| Quadratic Discriminant Analysis |           |                        | 0.922     | 0.925  | 0.923    | 0.939                  | 0.930      | 0.933  |
| Gradient Boosting          |               |                        | 0.964     | 0.965  | 0.965    | 0.952                  | 0.945      | 0.948  |
| CatBoost                   |               |                        | 0.968     | 0.969  | 0.968    | 0.956                  | 0.949      | 0.952  |
| KNN                        |               |                        | 0.959     | 0.956  | 0.957    | 0.961                  | 0.953      | 0.957  |
| Random Forest              |               |                        | 0.968     | 0.968  | 0.968    | 0.961                  | 0.953      | 0.957  |
| Multinomial Naive Bayes    |               |                        | 0.897     | 0.858  | 0.871    | 0.820                  | 0.775      | 0.766  |
| Gaussian Naive Bayes       |               |                        | 0.902     | 0.903  | 0.902    | 0.922                  | 0.908      | 0.914  |
| C-Support Vector Classification |         |                        | 0.933     | 0.930  | 0.931    | 0.945                  | 0.932      | 0.937  |

The best classification quality was achieved using the Random Forest and CatBoost. For the LT51750191984177XXX02 scene, the F1 score for Random Forest was 0.968, and for CatBoost it was 0.969. For the LT51750192011235KIS01 scene, the F1 score for Random Forest was 0.957, and for CatBoost it was 0.952. Random Forest was chosen as the final classifier model (Cohen's kappa = 0.932 for the LT51750191984177XXX02 scene and Cohen's kappa = 0.923 for the LT51750192011235KIS01 scene). The error matrix for test samples is shown in table 2.

The Random Forest algorithm has recently been one of the most common when classifying objects in aerial and space images. For example, it is used as an element of the method in solving problems of determining and mapping phytomass reserves [7] and site indexes [8] based on satellite images. But it is worth noting that the CatBoost is promising for use.

The most feature importance in the classification problem under consideration (Random Forest algorithm) are 4th band (spectral range 0.75-0.90 μm), 5th band (1.55-1.75 μm) and 6th band (10.40 -12.5 μm) Landsat 5. In addition, 7th band (2.09-2.35 μm) has a higher information content compared to 1st band (0.45-0.515 μm), 2nd band (0.525-0.605 μm) and 3rd band (0.63-0.690 μm). The feature importance content of the channels is shown in figure 1.
Table 2. Error matrix for test samples (Random Forest).

| Predicted answers | True answers |         |         |         |         | Total  |
|-------------------|--------------|---------|---------|---------|---------|--------|
|                   | $y = 1$      | $y = 2$ | $y = 3$ | $y = 4$ | $y = 5$ |        |
| $a(x) = 1$        | 245          |         | 15      |         |         | 269    |
| $a(x) = 2$        | 2            | 296     | 0       | 1       |         | 299    |
| $a(x) = 3$        | 16           | 1       | 311     |         | 0       | 328    |
| $a(x) = 4$        | 0            | 0       | 1       | 115     | 0       | 116    |
| $a(x) = 5$        | 0            | 0       | 0       | 26      | 0       | 26     |
| Total             | 262          | 306     | 327     | 117     | 26      | 1038   |

|                   | $y = 1$      | $y = 2$ |         |         |         |         |
| $a(x) = 1$        | 547          |         | 8       |         |         | 561    |
| $a(x) = 2$        | 42           | 398     | 1       |         |         | 441    |
| $a(x) = 3$        | 18           | 9       | 334     |         |         | 361    |
| $a(x) = 4$        | 0            | 8       | 5       | 320     |         | 333    |
| $a(x) = 5$        | 0            | 0       | 0       | 0       | 29      | 29     |
| Total             | 607          | 421     | 348     | 320     | 29      | 1725   |

3. Results and Discussion
The results of thematic interpretation of images for 1984 and 2011 for the Kologrivsky part of the reserve are shown in figures 2 and 3, respectively. In 1984, sections of forests that had not been clear-cut were preserved mainly along the Seha, Londushka and Ponga rivers and the site of the Kologrivsky forest nature monument. Despite the measures on forest reproduction at the places of felling, the upper canopy of regeneration is mainly represented by deciduous trees, under which there were oppressed forest plantations of spruce. The lack of timely silvicultural care of forest plantations and the natural regeneration of spruce led to the formation of birch stands in most of the territory [1].

Figure 1. Feature importance.
Figure 2. Vegetation cover of the Kologrivsky part of the nature reserve (1984).

Figure 3. Vegetation cover of the Kologrivsky part of the nature reserve (2011).
In 2011, most clearings were covered with forest timber species. The restoration of spruce stands actively proceeds along the channels of forest rivers. In these places, firstly, the presence of uncut areas was a source of seeding of clearings, and secondly, spruce and fir have an advantage over birch and aspen on waterlogged soils with signs of gleying. An analysis of the materials of the permanent trial plots laid in the Kologrivsky forest nature monument (1970-1990 years) shows that restoration of spruce mixed-aged stands after felling requires a minimum of 150-200 years [9]. In the next 25-50 years, the proportion of areas occupied by spruce stands should increase, due to the aging of deciduous stands, especially in the areas of felling of 1950-1960.

At the beginning of the 20th century, on the left bank of the Unzha River on the Manturovsky part of the reserve, spruce forests with an underwood of linden and maples were dominant [10]. In the 1960s, some sections between the Katrel and Pumina rivers underwent intensive reclamation. A network of deep trunk channels runs through almost all quarterly glades. A significant part of the Manturovsky part of the reserve suffered from a major forest fire in 1972. The areas covered by the fire were cleared, and subsequently, pine seedlings were planted in plow furrows and air seeding. At the end of the 1970s, chemical care of the forest was used in some areas to remove birch and aspen.

The results of thematic decoding of the 1984 image are shown in figure 4. 12 years after the fire, more than 85% of the territory was covered by forest timber species, with pine being a predominant species over a large area. By 2011, pine occupied a dominant position in the forest fund (figure 5). But despite the fact that 39 years have passed since the fire in the northwestern part of the reserve, there are unclosed pine plantations. As a rule, they are confined to drained areas on peat-illuvial soils with close occurrence of groundwater. Although the drainage system is open and is in working condition, it is likely that it cannot cope fully with the functions assigned to it.

![Figure 4](image-url)

**Figure 4.** Vegetation cover of the Manturovsky part of the nature reserve (1984).
4. Conclusion
Landsat satellite imagery serves as a reliable basis for compiling thematic forest maps with the prevalence of certain formations of vegetation cover (groups of tree species). The territory of the Kologrivsky forest nature reserve in the 20th century underwent strong economic development. By the 1990s, more than 90% of the Kologrivsky part was cleared. In the 1960s, the Manturovsky part underwent intensive drainage reclamation, and in 1972 there was a large forest fire on a large area. The weakening of the economic impact in the early 2000s and the introduction of the reserve regime contributed to the process of restoration of vegetation cover.

References
[1] Dubenok N N, Chernyavin P V, Lebedev A V and Gemonov A V 2016 Forest Dynamics in the «Kologrivsky Les» Nature Reserve Vestnik of Volga State University of Technology. Ser.: Forest. Ecology. Nature Management. 31 pp 5-18
[2] Dubenok N N, Chernyavin P V, Lebedev A V and Gemonov A V 2017 Hydrological and Morphological Characteristics of Permanent Water Courses in Kologrivskiy Forest Nature Reserve Vestnik of Volga State University of Technology. Ser.: Forest. Ecology. Nature Management. 35 pp 58-72
[3] Isaev A S, Knazyeva S V, Puzachenko M J and Chernenkova T V 2009 Use of Satellite Data for Monitoring Biodiversity of Forest Earth Observation and Remote Sensing. 2 pp 55-66
[4] Malyshova N V 2002 Remote sensing for the study of forest ecosystems, accounting, control and management of forest resources Forestry Information. 1 pp 31-61
[5] Hamedov V A and Mazurov B T 2015 Evaluation of the accuracy of determining areas of forest felling using images from the russian satellite "Resurs-P" № 1 Vestnik of SSUGT. 32 pp 42-50
[6] Prokhorenkova L, Gusev G, Vorobev A, Dorogush A V and Gulin A 2018 CatBoost: unbiased boosting with categorical features Advances in Neural Information Processing Systems.
pp 6639–49

[7] Sochilova E N, Surkov N V, Ershov D V and Khaledov V A 2019 Assessment of biomass of forest species using satellite images of high spatial resolution (on the example of the forest of Khanty-Mansi autonomous okrug) Forest Science Issues. 2 pp 1-19

[8] Sochilova E N, Surkov N V, Ershov D V, Egorov V A, Bartalev S S and Bartalev S A 2018 Mapping of forest site index classes in Primorskiy Krai based on satellite images and terrain characteristics Current problems in remote sensing of the Earth from space. 15 pp 96-109

[9] Lebedev A V 2018 The progress of natural processes in the stands of the core of the «Kologrivsky Forest» Nature Reserve Contribution of Specially Protected Natural Areas to the Ecological Sustainability of Regions: Current Status and Prospects (Kologriv: Kologrivsky Forest Nature Reserve) pp 6-14

[10] Lazareva N S, Preobrazhenskaya E S and Popov S Y 2012 Flora of the surroundings of the Kostroma taiga research and experimental station of the IPEE RAS and the Manturovsky part of the Kologrivsky Forest nature reserve [in Russian - Flora okrestnostey Kostromskoy taejnoy nauchno-opytnoy stantsii IPEE RAN i Manturovskogo uchastka zapovednika «Kologrivskiy les»] (Saint-Petersburg: Intermedia Publishing Center) p 89