

Possible use of remote sensing for reforestation processes in Arctic zone of European Russia

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Abstract

This article considers the possibility of using remote sensing to monitor reforestation as exemplified in the Severodvinsk and Onezhsk forestry districts of the Arkhangelsk region of Russia's Arctic zone. Remote sensing makes use of medium spatial resolution satellite images and high resolution unmanned aerial vehicle (UAV) images. In the course of work on the project, a preliminary method was developed for reforesting land previously subjected to cutting, fire, or windfall. Steps include detecting a reduction in forest cover and collecting field data through the use of UAVs to create a training set, which is used to classify satellite images according to the two classes of 'restored' or 'not restored'. Various data processing tools are used to perform these steps. The Tasseled Cap multi-channel satellite image transformation method is employed as a tool for detecting a reduction in forest cover and analysing reforestation. The k-nearest neighbour algorithm is employed to classify satellite images. This article provides a step-by-step algorithm for monitoring and an assessment is provided of the situation in relation to forest regeneration in the Severodvinsk and Onezhsk forestry districts. The work carried out has shown that it is possible to use UAV images to monitor forest recovery, which is of significant importance for the conditions of the Arctic zone of European Russia.

Keywords

reforestation, forest monitoring, forest cutting, forest dynamic, boreal forest, Landsat, Sentinel, remote sensing, ERS, unmanned aerial vehicle, UAV

Introduction

It is of great importance to monitor forest regeneration in the Arctic zone in a changing climate and while the areas are under active development, especi-

ally when these factors are shown to have an effect on forests with low reforestation potential. It would be impractical to employ only ground-based monitoring tools in this area, which can be characterized by limited transport accessibility, a fact that leads directly to

the limitation of regular and comprehensive monitoring of reforestation in the Arctic zone.

The introduction of remote reforestation monitoring will make it possible to monitor a large area and receive timely and relevant information.

The use of remote sensing to assess the successfulness of reforestation has not been widely studied. There are examples in the existing literature of the use of multi-temporal images obtained from the Landsat satellite to monitor reforestation (Krankina et al. 2005; Vorobev et al. 2016). The use of these images with the application of spectral brightness or index characteristics derived therefrom point to the possibility of obtaining information about reforestation processes in disturbed areas (Maltese et al. 2005). Spectral indicators employed on the basis of the visible or near-infrared band (for example, the normalized differential vegetation index) tend to be sensitive to foliage and to provide a sign of early regeneration (Franks et al. 2013). It is possible to estimate with a high degree of accuracy the success of woody plant regeneration with the help of spectral characteristics for plantations closer to the age of 15 years; this conclusion was reached during studies of the regeneration of Douglas-fir in the western part of the Oregon Cascade Mountains, USA (Fiorella and William 2009).

Reforestation on lands not occupied by forest vegetation can also be assessed using the Tasseled Cap method. An assessment of reforestation following a fire in northern Canada has provided an example of this method's successful usage (Frazier et al. 2015). The study found that the channels of satellite images transformed into values for brightness, greenness, and wetness tend under successful reforestation to show an increase in humidity and greenness and a reduction in brightness. The reforestation period analysed was 29 years; following that, channel values corresponded to those of mature forest.

A new tendency in the forestry industry has seen a rise in the use of unmanned aerial vehicles (UAV). Footage taken from UAVs boasts a number of advantages over that taken from space: it possesses higher spatial resolution and efficiency and the ability to shoot in cloudy conditions. Foreign experience shows unmanned aerial vehicles used to map vegetation and

to classify species of trees (Yu et al. 2006). UAVs are likewise valuable tools for establishing forest parameters while taking stock of forests (Wallace et al. 2012; Fadaei et al. 2010; Brandtberg 1999; Sperlich et al. 2014). Speed of setup and ease of transportation and operation make the UAV system an ideal tool for monitoring forest land and that includes the reforestation process (Denisov et al. 2016).

Using field methods to monitor the success of reforestation is a complex task involving considerable temporal and financial resources, for which reason new methods are being sought to identify certain indicators. The use of medium resolution satellite imagery to monitor reforestation often does not provide sufficient resolution, and high resolution satellite imagery is not always available for the Arctic territory due to increased cloudiness in Russia's northern latitudes. For this reason, the main task of our work is: to determine the possibility of evaluating the success of reforestation by using a combination of medium-resolution space survey data and survey materials from unmanned aerial vehicles with high spatial resolution.

The ultimate goal of this study is to create a methodology for assessing reforestation through remote sensing in accordance with the rules established by the Russian Federal Agency for Forestry and to achieve reforestation.

Materials and methods

All work to determine the possibility of remotely monitoring reforestation was divided into the following stages:

- creating a layer of forest cover reduction;
- carrying out field work, which includes establishing test plots and surveying the territory with a UAV (unmanned aerial vehicle);
- analysing the information collected in the field and creating a training sample for the transfer of forest land to forested areas in accordance with Earth remote sensing (ERS) data;
- creating a layer of land to transfer to forest cover.

The project started with the creation of a layer of forest cover reduction for the two forestry districts of Severodvinsk and Onezhsk. The first step was to create satellite coverage to identify changes in the forest cover for the year. For this purpose, images from the Sentinel 2 and Landsat 8 satellites for 2015 and 2016 were used. Data on forest disturbances for the period of 2001 to 2015 was taken from the data set of the Global Forest Change website, created by the University of Maryland (USA).

Next followed the conversion of satellite imagery channel values into Tasseled Cap composite data (developed in 1976 by researchers R.J. Kauth and G.S. Thomas for the purpose of analysing changes in vegetation cover) for wetness, greenness, and brightness and their analysis to identify clear cutting and mature forest thresholds. Transformation is a special part of the principal component method, which transforms image data into a new coordinate system with a new

set of orthogonal axes. The goal of this conversion is to reduce the data dimension with the least possible loss of information (Kauth and Thomas 1976). The brightness channel is associated with open or partially hidden soil and artificial and natural sites such as concrete, asphalt, gravel, outcrops of rocks, and other open areas. The second component, greenness, marks the level of green associated with green vegetation. The third component, wetness, comes perpendicular to the first two components and is related to the wetness of soil, to water, and to other 'wet' sites (Huang et al. 2014).

To analyse changes in the forest cover, we collected the values from the wetness, greenness, and brightness channels of the Tasseled Cap composite for the following land categories: clearance areas, swamps, and forested areas. It is easy to identify the threshold values for clearance areas, swamps, and forested areas on the graph of the values of these objects within the coordinates of wetness and greenness (Fig. 1).

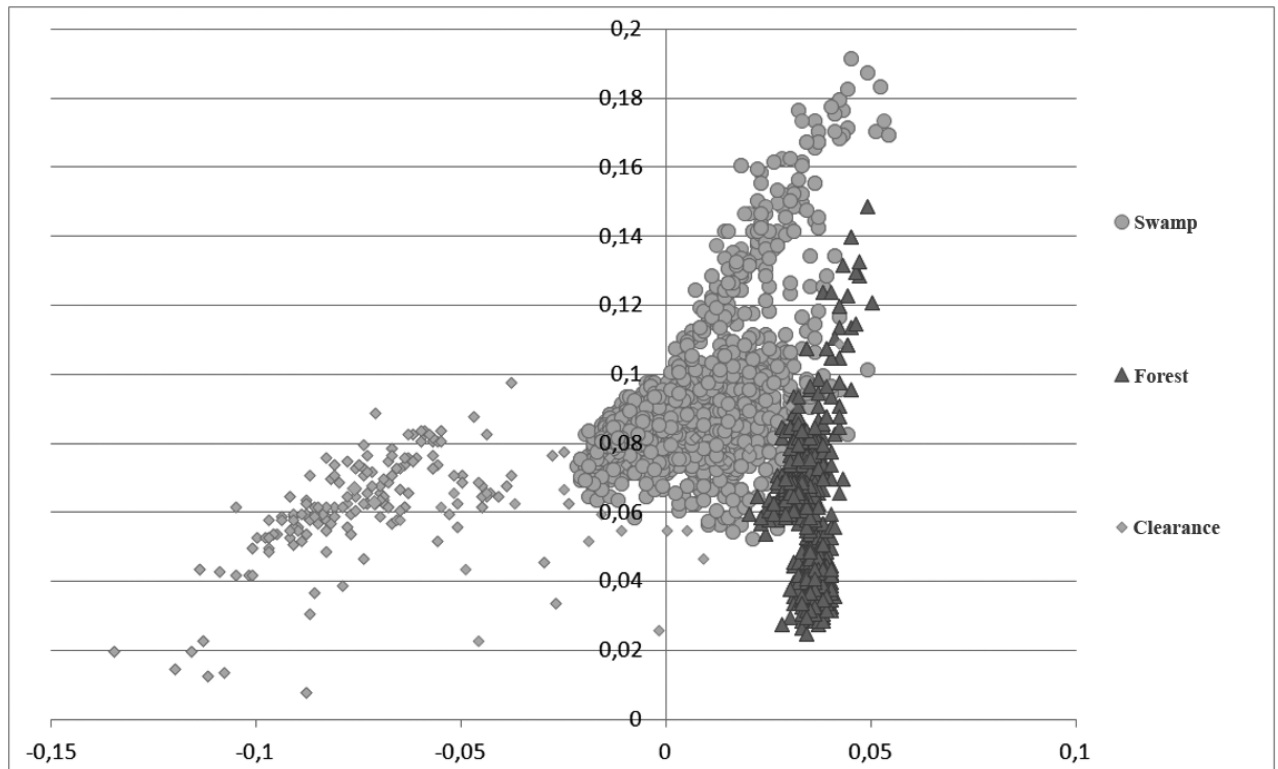


Fig. 1. Axis x: wetness channel values, axis y: greenness channel values

Threshold values for clearance areas in the wetness channel range are -0.15 to 0 , and in the greenness channel from 0 to 0.1 .

To assess remote method reforestation processes, it is first necessary to create a mask of forest cover reduction. The detection of clearance is based on a simple technique for creating bit-mapped masks with the use of threshold values.

The algorithm for creating a clearance mask consists of the following steps:

- 1) A clearance mask is created for the selected year. The mask is created in accordance with threshold values in the brightness, greenness, and wetness channels for fresh clearance within the selected year. To collect statistics, the fresh clearance in the image is highlighted with a polygon, after which 3% of the values falling outside the sample are discarded and the maximum and minimum threshold values for each channel are determined.
- 2) A forest mask is created from a snapshot of the previous year. To create this mask, we use the same algorithm as in step 1, but in this case untouched areas of forest are highlighted with a polygon. This step is required to exclude clearance areas from previous years and sites not related to clearance

from the mask constructed in paragraph 1. As can be seen from the graph presented in Fig. 1, swamp values intersect with the fresh clearance value, which makes it impossible to create a reliable mask from a single shot.

- 3) In the case of cloud cover, the edges of the clouds possess spectral characteristics similar to fresh clearance. To exclude unwanted sites in the clearance mask, a cloud mask must be created for the subsequent removal of cloud pixels.
- 4) To create an accurate clearance mask, non-forest pixels must be subtracted from the clearance mask with the use of the forest mask, and the cloud mask is subtracted. To filter out incoherent data, single pixels should also be removed. (Healey et al. 2005).

Fig. 2, picture A is an example of a Tasseled Cap composite obtained from Landsat 8 satellite image values. The composite contains clearance areas for the period of 2015–2016 as well as for earlier periods. Clearance areas for the period 2015–2016 are highlighted in black on picture B. This clearance layer was obtained with the help of the algorithm described above.

The field data collection phase included a survey from a UAV at an altitude of 50–70 m. The UAV survey was carried out at 2 sites, of 32 hectares and 19

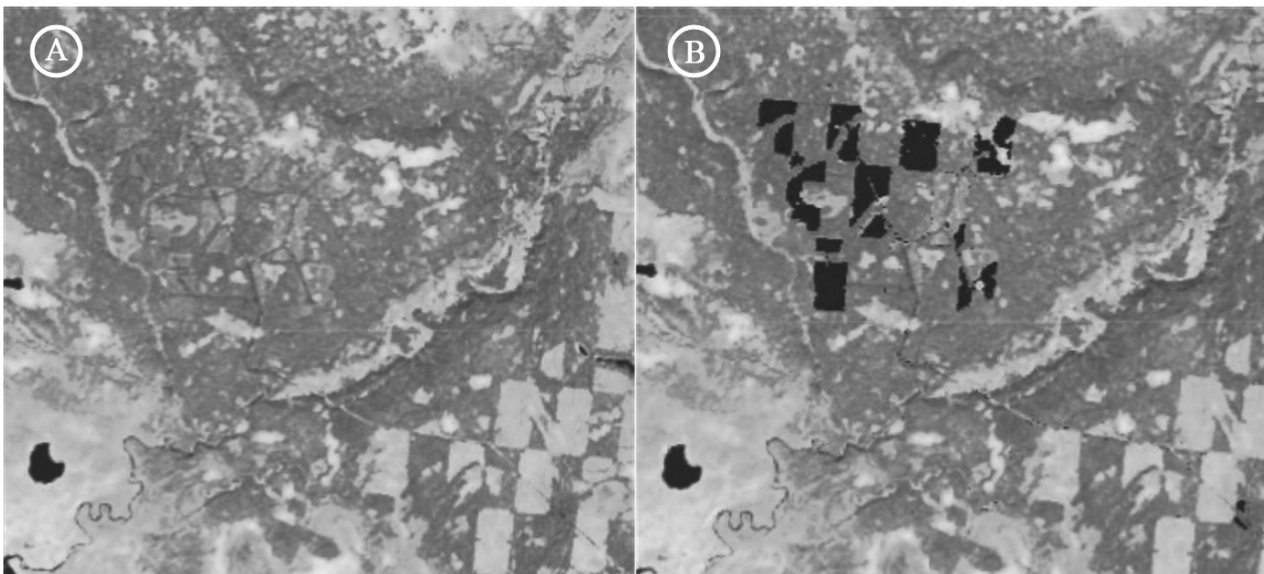


Fig. 2. The Tasseled Cap composite is on the left; on the right there is a superimposed mask of changes detected in the forest cover from a Landsat 8 photograph

hectares, in the Severodvinsk forestry district of the Unsk forestry division. The UAV flight was carried out along a previously prepared route. A ground survey of the areas was carried out to assess the objectivity of the data collected. The field work was carried out in accordance with the temporary methodology for state monitoring of forest reproduction in 2017. In the course of the work, data was collected for the following indicators: the number of trees of the principal species, the average height of trees of the principal species, and species composition of young forest growth.

The next stage of work consisted of analysing the data collected. Survey materials obtained from UAVs during field work on the number of trees, the average height, and the species composition of the sites surveyed were received for processing in Forgis's fully automated chain. An assessment was then made of how successful the restoration of the plots had been in accordance with the criteria of existing reforestation rules for two classes: 'restored' and 'not restored'. The main criteria and requirements for young growth areas attributed to lands occupied by taiga zone forest plantations are: the quantity and the average height of trees of the principal species.

Analysis of sample site results showed reforestation according to the criteria currently in place to be successful at 65% of the sites. At 35% of sample sites, the quantity of trees of the principal species or the average height of the trees of the principal species fell below current reforestation rule requirements.

Data obtained from field tests and UAV surveys was processed to obtain a training sample for the classification of medium-resolution images. UAV survey results were recalculated using a medium resolution image pixel size (Sentinel 2 – 10 m, Landsat 8 – 15 m), and each pixel was marked as 'restored' or 'not restored'.

Next followed the classification of medium resolution satellite images to identify how successful reforestation had been in the territory falling outside the forested area in accordance with the training sample based on the materials from the UAV.

It is more difficult to create a layer of land transferred to forested area than to create a layer of forest cover reduction. For this reason, the clearance values

of various years in the wetness, greenness, and brightness channels of the Tasseled Cap composite were analysed first.

In this study, one 2016 Landsat 8 snapshot was used to analyse reforestation. The use of a single image for the analysis of reforestation is based upon phenological variation in vegetation and different atmospheric conditions for images of different years. Sites that are identical and not subject to change may show different values in different images resulting from different phenological and atmospheric conditions.

Clearance values for various years over the periods of 1986–1989 and 2001–2015 have been collected in the graph (Fig. 3). The greenness and wetness channels are important for assessing reforestation. As can be seen from the graph, wetness channel values continue to grow over a period of 15 years and then reach mature forest growth values. Greenness values begin to increase one year after clearance and then continue to grow.

The graph (Fig. 3) shows average values at clearance areas in the Severodvinsk forestry district for various years. Before collecting the values, an unsupervised classification following the ISODATA method was performed, which excludes forest roads and wetlands lacking reforestation from the boundaries of the clearance areas. By excluding these sites from the boundaries of the area being analysed, the average greenness and wetness values were calculated for the sites where reforestation is underway.

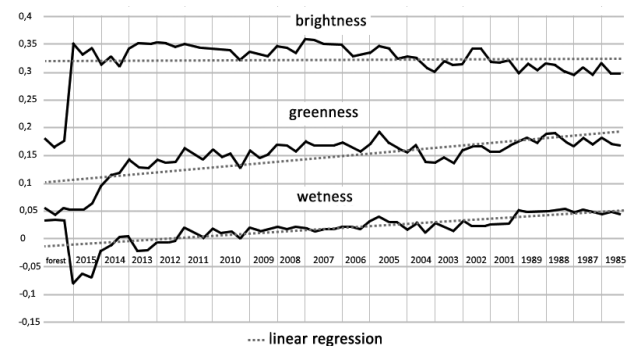


Fig. 3. The clearance values of the Tasseled Cap channels for various years

The values located near the trend line and above it correspond to the values for successful reforestation, and the values below are valued as unsatisfactory reforestation.

Field data was used to create a layer for transferring land to forested area. The data collected was used as a training set for mapping the success of reforestation from data obtained in accordance with the Tasseled Cap method. The *k*-nearest neighbours algorithm (*k*-NN), a metric algorithm for automatic object classification, was employed for the automatic classification of clearance pixels. When using a classification method, the object is assigned to the class most common among the *k* neighbours of the given element, whose classes are already known. In our case, training was conducted to classify data obtained from 3037 test plots measuring 10 by 10 meters, some of which represented successful reforestation and some of which represented unsatisfactory reforestation.

Based on the analysis of the species, the number of trees per unit area, and the average height of the trees, all of the pixels for the surveyed areas were separated into two classes: ‘young growth’ and ‘non-restored areas’.

Results

Using the techniques developed, a layer of forest area reduction for the period 2001–2016 was obtained along with a layer of reforestation sites for 2016 that can be transferred to a forested area for the territory of the Onezhsk and Severodvinsk forestry districts. Using the layers obtained, a map-scheme of lands transferred to a forested area was created at the places of forest area reduction for the period 2001–2016, which is presented in Fig. 4.

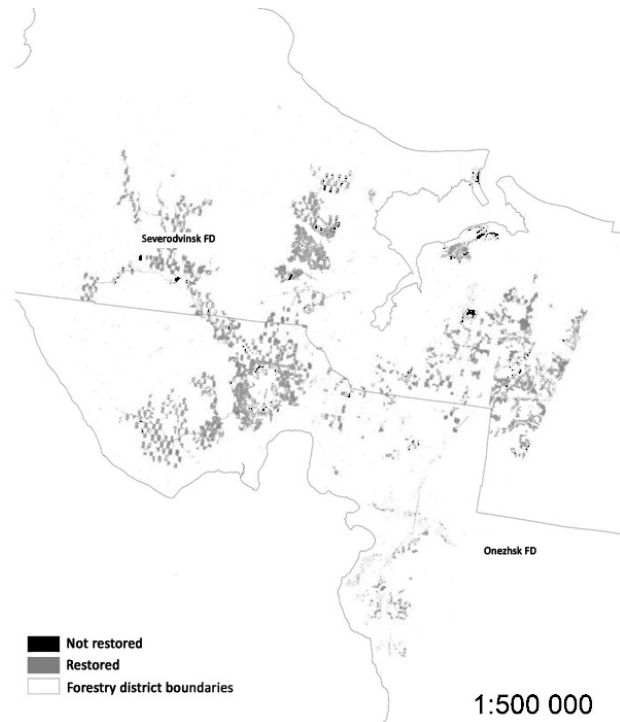


Fig. 4. Fragment of a reforestation success map in the Severodvinsk and Onezhsk forestry districts

The use of UAVs made it possible to cover a large number of trial plots. 3037 trial plots were built for reforestation analysis with the help of UAVs.

An analysis of data obtained as a result of the interpretation of satellite images showed that reforestation had been successfully completed on 73% of the study area. 27% of the clearance area had not recovered.

A comparison was made of data obtained by remote methods on the reduction of forest cover for the period 2011–2016 and data from the State Forest Register (SFR) within the territory of the forestry districts. The information collected is presented in Table 1.

Table 1. Data on the reduction of forest cover

Year	Severodvinsk forestry district		Onezhsk forestry district	
	SFR data, ha	ERS data, ha	SFR data, ha	ERS data, ha
2011	2458	2295	5596	4922
2012	4927	5403	4281	11749
2013	2192	1566	3008	4168
2014	1790	1783	2694	2528
2015	–	1835	–	2764
2016	–	2237	–	3401

This technique can be applied for both Landsat 8 satellite imagery as well as for Sentinel 2 imagery and other satellites operating within optical range and possessing multispectral channels in the visible and infrared wavelength bands and possessing medium spatial resolution.

Discussion

To assess the success of reforestation during a full-scale survey of sites, an enormous number of test plots is required. The number increases with an increase to the requirements for data accuracy and with an increase to the study area.

Considering that several criteria (the number of trees of the primary species per unit area, the average height of the principal species) are employed when transferring young growth to lands occupied by forest vegetation, the sample size must be significant.

The preparation of a large number of sample plots requires the involvement of a large number of people and enormous material expenditures. The use of remote sensing data is most promising option for reducing costs and time for test plot preparation.

An assessment of the likelihood of obtaining high spatial resolution satellite images from Russian spacecraft (Resurs-P, Canopus V) has shown that it is impossible to build a mosaic of images over the study area due to high cloud cover in the Arctic zone of the European North, and the few cloudless images obtained were spread out over different seasons, which further reduces the number of available images for satellite coverage. To evaluate forest cover transformations, namely to identify clear cutting and the resulting regeneration of tree vegetation, medium re-

solution satellite images from Sentinel 2 and Landsat 8 can be used.

The Tasseled Cap composite was chosen for the analysis of the reforestation process, since this method contains the following positive points:

- 1) the possibility of reducing atmospheric interference on satellite images, which improves the quality of the analysis;
- 2) the ability to compare the values of various satellite images directly such as comparisons of Tasseled Cap components obtained from Landsat 8 and Sentinel 2;
- 3) good differentiation of forest vegetation according to species groups: coniferous, deciduous, mixed, and also a clear distinction between forest plantations, clearance, fires, and swamps. The method employed is highly sensitive to the closeness of the canopy of woody vegetation.

This technique calls for a preliminary collection of information on reforestation sites. The collection of field data to create a training sample to be used to classify a satellite image requires a large number of sample plots. It would be advisable to use an UAV to reduce work time and labour costs.

Application

This scientific work was carried out as part of a state task to conduct scientific research from the Federal Forestry Agency on the topic of assessing the state of forests in the Arctic zone of European Russia and preparing scientifically-based proposals for improving the monitoring of state forest pathology and monitoring reforestation in this zone.

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