УДК 630*1
DOI: 10.37482/0536-1036-2020-3-83-92

METHOD FOR TRANSFERRING NON-FOREST COVER TO FOREST COVER LAND USING LANDSAT IMAGERIES

A. Karpov, PhD Intern; *ResearcherID: H-1915-2019,*
ORCID: https://orcid.org/0000-0002-9087-8399
B. Waske, Doctor of Geography, Prof.
Osnabrück University, Wachsbleiche 27, Osnabruck, 49090, Germany;
e-mail: lesnoy.monitoring@gmail.com

Satellite data becomes an important tool for monitoring global change in forest cover. Further development of remote sensing technologies creates opportunities for solving more complex problems requiring multi-time analysis of satellite data. Assessment of success reforestation after a disturbance in forest cover is such an important task. The traditional method of an assessment of successful reforestation is laying out the ground plots, which task requires significant time and resources. Fieldworks and transfer of land to forest cover land is carried out according to the method, which is developed by the Federal Agency for Forestry of Russia. This method has various criteria of success reforestation for every region. Arkhangelsk region, Vologda region and Republic of Karelia became the territories for research. Forest vegetation of this region belongs to the taiga zone and is divided into five groups: the area of pre-tundra forests and sparse taiga, northern taiga, middle taiga and south taiga. International forest classification relates this area to boreal forest. The task of transfer land to forest cover land can be optimized by using remote sensing data. This research shows analysis of recovery of the normalized difference vegetation index, the shortwave vegetation index and the normalized burn ratio in the framework of reforestation objects. Filed data was collected for every object and this data includes a number of young trees, average height and species composition. Processing of a considerable number of satellite imageries requires significant computing power because of the Google Earth Engine platform using for analysis data. The most suitable index was chosen in the analysis of the obtained data for the development of an automatic method for transfer land to forest cover land. The most suitable index for dividing lands on forest cover and non-forest cover lands is the shortwave vegetation index. Optimal threshold for transferring land is achievement of recovery index of 80 % from initial values before disturbance. The automatic method was developed using unsupervised classification and threshold values of recovery index.
For citation: Karpov A., Waske B. Method for Transferring Non-Forest Cover to Forest Cover Land Using Landsat Imageries. *Lesnoy Zhurnal* [Russian Forestry Journal], 2020, no. 3, pp. 83–92. DOI: 10.37482/0536-1036-2020-3-83-92
Funding: This research was undertaken as part of the project "Forest Monitoring in the Arkhangelsk Region, Using Multisensory Remote Sensing Data" funded by the Russian Ministry of Education and Science and the German Academic Exchange Service in the framework of the Michail Lomonosov Programme (project no. AAAA-A19-119020590052-2).

Keywords: land management, forest management, reforestation, Landsat.

Introduction

Land use change is the major driver of global environmental change resulting in loss of biological diversity, changing the global carbon cycle, affecting local climate and the hydrological cycle [15]. Forest cover change is particularly important, as forests can sequester atmospheric carbon and mitigate climate change. While the tropical domain experienced greater forest loss when compared to other climate domains [10], boreal forests store the largest amount of carbon of all global biomes [14]. Unfortunately, reliable statistics on boreal forest is not necessarily available and existing national scale forest statistics might be incomplete and inconsistent [14]. However, remote sensing systems have the potential to provide spatially distributed and temporally frequent data on forest cover, and offer great opportunities to better understand patterns, processes and underlying causes of forest cover change [1, 12].

Using of multitemporal analysis of the normalized difference vegetation index (NDVI), the shortwave vegetation index (SWVI), the normalized burn ratio (NBR) and components of Tasseled Cap transformations is usual for assessment vegetation cover, but the spectral index values depend on the phenology of vegetation and climatic conditions [6, 7]. Forest recovery after the disturbance has different periods for different climatic zones. This statement is true for boreal forest, which is located in some climatic zones. Achievement of 80 % of the initial value of the spectral index requires a different period for the extremely cold and cold temperature zones for the North American boreal forest region. Multitemporal analysis of several climatic zones requires a definition of a phenological period for each zone [13]. Analysis Tasseled Cap component shows that spectral indeces after disturbance can change for three decades in the territory of the North American boreal forest region. The region can be divided into eastern and western boreal forest shield, which has a different type of forest recovery. This fact is related to difference in precipitation, average temperatures and types of soils [5, 7, 12].

The burned severity is an important aspect of forest regeneration after forest fires. The extent of burned severity often divided into five classes: slight, low, medium, high, very high. This extent influences on the time of forest recovery. Therefore, spectral methods, based on difference or division of the values of the spectral indices before and after disturbance, are important for an assessment of the burned areas. For instance, Stand Regrowth Index (SRI) and Relative Regrowth Index (RRI) are based on after- and pre-disturbance of the NDVI values [8, 9, 18].

Method of unmixed spectral analysis is based on a statement that every pixel can include different fraction [11, 19]. These fractions are named endmembers. The endmembers can be vegetation with photosynthesis, vegetation without photosynthesis and bare soil. Fractional Vegetation Cover (FVC) and NDVI are based on correlation of differences of NDVI value of a pixel and average values of bare soil and vegetation [16, 18].

Using the spectral index requires field data for calibration indices for the assessment of reforestation and finding a relationship between a value of the index and real conditions of forest regeneration such as structure of recovered vegetation, number, and tree species per pixel and tree canopy. Comparison of the multitemporal Landsat data and airborne laser scanning (ALS) data defined pixel, which can be considered as a forest area using criteria of the Food and Agriculture Organization (FAO) if the pixel achieves 80 % of the NBR value before disturbance [2, 3, 17].

The practical issue of using satellite imageries for the assessment reforestation is finding the threshold for transfer cutting and burned areas to forest cover land.

Materials

The main research area is the North-Western region of Russia (Fig. 1). It is Arkhangelsk and Vologda regions and the Republic of Karelia. Forests are considered as northern taiga, moderate taiga and south taiga in this territory. The study region has an average forest cover of 60 % with predominant coniferous species, where major tree cover consists of mature and over-mature stands with low forest stock. Average species composition for the whole Arkhangelsk region is 70 % spruce, 20 % pine and 10 % birch with a small number of aspens. Most of the trial plots are located in Arkhangelsk region.

The studied regions are characterized by the development of the logging industry and large areas of mature and over-mature forest were cut down. Cutting of forest stands takes place in the form of clear and selective cutting.

Also, the north part of Arkhangelsk region belongs to the Arctic land area according to the Russian rules of the land division. According to the data of the State Forest Register of Russia dated on 2016, the Arctic land of Arkhangelsk region included 39,059 mln ha of land suitable for forest cultivation, and 29,765 mln ha or 76 % from land suitable for forest cultivation were cut down.

Main pattern of reforestation for all three regions is regrowth broadleaf species on cutting areas, which has low economical value for logging industry. Reforestation of coniferous species then occurs via change of species. The natural reforestation requires considerable time to restore coniferous forests.

The lack of natural regeneration on the part of cutting areas is caused by insufficient trees undergrowth, removing of trees undergrowth in the process of cutting, the absence of seed trees and adverse climatic conditions. Developed moss cover and forest litter prevent successful seed germination and rooting of seedlings.

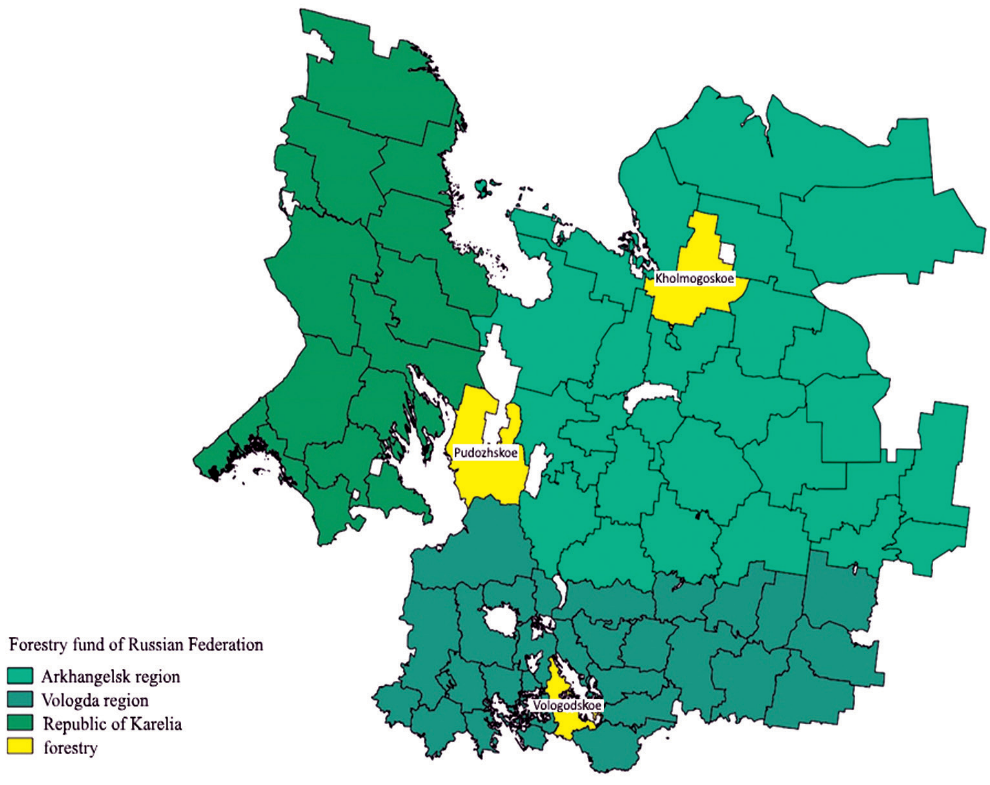

Fig. 1. Regions where trial areas were laid out

Ground plots were made in the period of 2015–2019 (Fig. 1) using spectral characteristic of forest recovery for the analysis. Fieldworks in 2016–2019 were carried out according to the Russian Temporary Procedure of the State Monitoring of Forest Regeneration in 2016 [4].

The ground plot has a square shape with sides equal to 20 m. The amount of young trees divided into groups according to their species and heights is taken into account inside the border of the ground plot. There is one ground plot per 10 ha of cutting area (Fig. 2).

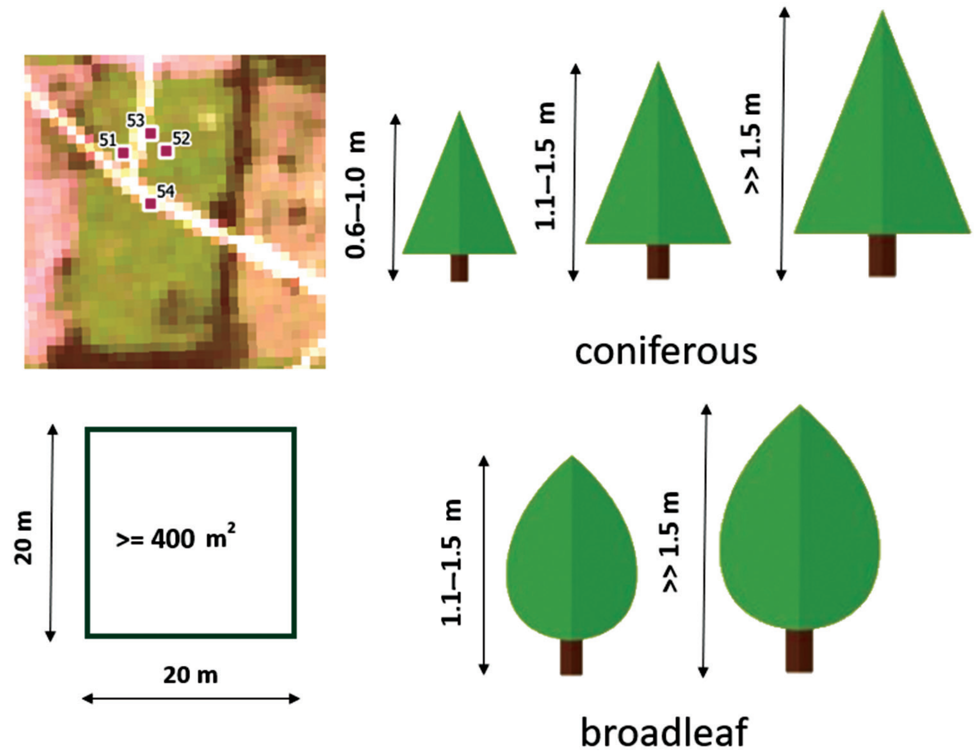

Fig. 2. Methods of creation of ground plots and groups of heights for different groups of tree species

Data of several ground plots on one cutting area are averaged and recorded in the report. The averaged data of the report is used to make a decision to transfer the non-forest cover land to the forest cover land. The procedure of state monitoring defines required conditions such as number, average height of trees and parameters of ground plots for transferring non-forest to forest land (Table).

Conditions for transferring non-forest land to forest land

Tree species	Trees, pcs/ha	Average height, m
Pine	1500	0.7
Spruce	1500	1.0
Birch, aspen, alder	2000	1.5

Almost all the objects on which the ground plots were made have reached the criteria of transfer to forest land during year fieldwork. The number of ground plots was equal to 57.

Satellite imageries of Landsat 5, 7, 8 are used for the analyses of spectral characteristics of the ground plots. These images had atmospheric correction, which was already done in the Google Earth Engine (GEE) collection.

The Global Forest Lost dataset for the period of 2000–2017 was used as a framework for unsupervised classification and tree cover datasets dated on 2000 [7].

High-resolution imageries of Google and Yandex services and Hansen's forest loss dataset were used for drawing the border of cuttings and burned areas.

Methods

The work under the project was divided into several parts: processing of field materials, drawing borders of research objects; analysis of spectral dynamic of NDVI, SWVI, NBR, detection of spectral recovery indices after disturbance (cutting, forest fire) at the moment of field observation; and developing a method for transferring non-forest land to forest land.

Collection of multitemporal values for research objects was carried out using the GEE platform. Research object is cutting or burned areas, where ground plots were done for field observation. Indices were calculated using middle resolution satellite imagery Landsat.

Algorithm for collection index values includes the following steps:

1. Research object is drawn using high resolution satellite imageries. This object can be a forest regeneration area after cutting or a forest fire with a high level of severity.

2. The search of all accessible satellite imageries for each research object. The search has some selection criteria: cloudiness of imagery less than 50 %, the time period of search only summer months (June, July and August). All selected imageries are included in the collection.

3. The boundary of the research object is increased by 1000 m. This area is used for detecting cloudiness pixels. The imagery is excluded from the collection if it has a cloudy pixel in this border.

4. The boundary of the research object is reduced by 30 m. This excludes pixels of forest edge and other objects, which do not belong to the cutting or burning areas.

5. Average values of NDVI, SWVI and NBR are calculated for each research object for each satellite imagery in the collection.

The script including all the steps is available here: https://code.earthengine.google.com/6ad67cf35ae901ead018832e4482c774. Average values of multi-time indices are downloaded on personal computer for processing.

Next step is finding the values of indices before disturbance, year of disturbance and field observations. Phenological differences have a significant influence on the values of the indices since the selected indices have to be dated by the close days of the year. The considerable number of research objects did not cover satellite imageries in the year of disturbance. Therefore, only pre-disturbance value and value at the time of the field observations were used in the analysis.

The charts of recovery of NDVI, SWVI and NBR were drawn for the analysis of reforestation on the areas of the research objects (Fig. 3).

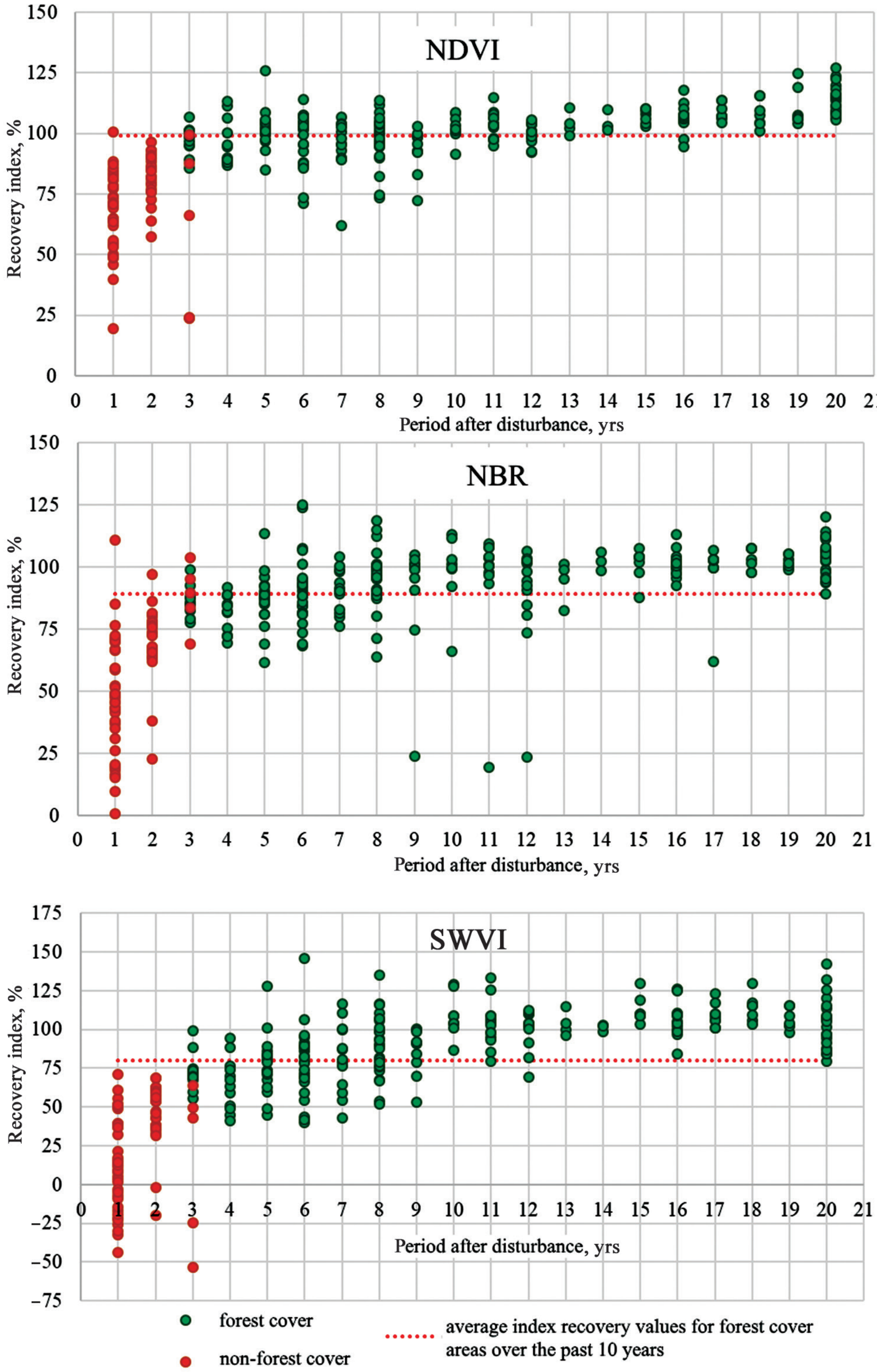

Fig. 3. NDVI, NBR and SWVI recovery indices for each research site

The calculated recovery indices based on NDVI, SWVI, and NBR are indirect measures of forest vegetation restoration and show the degree of reforestation at the studied sites. The indices are shown in Fig. 3, where green is land classified as forest cover land; orange is non-forest cover land. The average values of the recovery index for forest cover land for the past 10 years assigned are displayed as a red line.

We propose to calculate the degree of reforestation (recovery index) as a percentage according to the following formula:

$$R = \frac{I_{obs}}{I_{pre}},$$

where I_{obs} – index at the moment of field observation; I_{pre} – pre-disturbance index.

The recovery index based on NDVI does not show the degree of stand restoration and is not suitable for the land division onto forest cover and non-forest cover lands. Almost, all research objects have values of recovery index over 80 % including the objects with a short period of reforestation (from 1 to 4 years).

The recovery indices based on SWVI and NBR are the most promising, as they clearly show the degree of reforestation in the cutting and burned areas. All research objects in the figures with the recovery indices can be divided into 3 groups: non-forest cover land with the recovery index less than 80 %; forest cover land with the recovery index less than 80 %; forest cover land with the recovery index over 80 %.

Analysis of the chart of the SWVI recovery index shows that research objects have recovery over 80 % after 10 years. A part of the research objects have recovery index from 40 to 80 % in the period from 6 to 9 years. The objects were transferred into forest cover land. The objects, which were not transferred to forest cover land, had the recovery index less than 40 %.

Results

The SWVI recovery index was selected after the analysis of dynamic spectral indices as more suitable for the assessment of land reforestation. An automatic method for transferring non-forest cover to forest cover land was developed based on k-means method of non-supervised classification. Scheme for transfer non-forest to forest cover land is showed in Fig. 4.

The first step is the classification of satellite imagery on 15 clusters in the framework of the Hansen’s forest loss layer in the period from 2000 to 2014 [6]. Average SWVI values were calculated for each cluster.

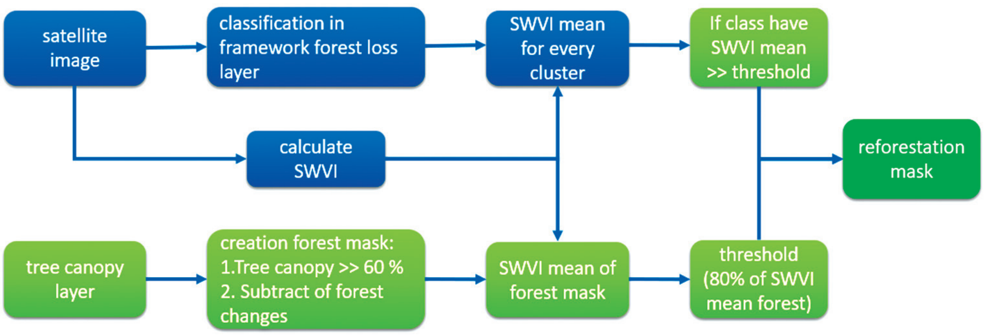

Fig. 4. Scheme for transferring land to forest cover land

The second step is creating forest mask, which includes mature and over-mature forests without disturbances. The forest mask is created using tree cover layer [10] and includes pixels that have canopy equal or more than 60 %. After that, the average SWVI value was calculated for the forest mask and threshold for transferring non-forest cover to forest cover land, which equals 80 % from the average forest mask value.

The third step is comparing the average SWVI value of each cluster with threshold for transferring to forest cover land.

Developed method was applied for imagery of the Landsat 8 satellite with ID: LC08_L1TP_181015_20180719_20180731_01_T1.

Conclusion

Analysis of research objects using remote sensing technology shows the possibility of creating methods for transfer non-forest to forest cover land. Optimal threshold values of recovery SWVI is over 80 % from the initial values before disturbance. Calculation of the initial index value for every pixel is a very difficult task, because initial value of forest was calculated using forest mask, which includes pixels mature and over-mature forest without disturbance.

REFERENCES

1. *Алешко Р.А., Алексеева А.А., Шошина К.В., Богданов А.П., Гурьев А.Т.* Разработка методики актуализации информации о лесном участке с использованием снимков со спутников и малых БПЛА // Современные проблемы дистанционного зондирования Земли из космоса. 2017. Т. 14. № 5. С. 87–99. [Aleshko R.A., Alekseeva A.A., Shoshina K.V., Bogdanov A.P., Guriev A.T. Development of the Methodology to Update the Information on a Forest Area Using Satellite Imagery and Small UAVs. *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa* [Current problems in remote sensing of the Earth from space], 2017, vol. 14, no. 5, pp. 87–99]. DOI: 10.21046/2070-7401-2017-14-5-87-99

2. *Алешко Р.А., Гурьев А.Т., Шошина К.В., Щеников В.С.* Разработка методики визуализации и обработки геопространственных данных // Научная визуализация. 2015. № 1. С. 20–29. [Aleshko R.A., Guriev A.T., Shoshina K.V., Schenikov V.S. Development of Methodology for Visualization and Processing of Geospatial Data. *Nauchnaya vizualizatsiya* [Scientific Visualization], 2015, no. 1, pp. 20–29].

3. *Богданов А.П., Карпов А.А., Демина Н.А., Алешко Р.А.* Совершенствование мониторинга лесов путем использования облачных технологий как элемента устойчивого лесоуправления // Современные проблемы дистанционного зондирования Земли из космоса. 2018. Т. 15, № 1. С. 89–100. [Bogdanov A.P., Karpov A.A., Demina N.A., Aleshko R.A. Improving Forest Monitoring by Using Cloud Technologies as an Element of Sustainable Forest Management. *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa* [Current problems in remote sensing of the Earth from space], 2018, vol. 15, no. 1, pp. 89–100]. DOI: 10.21046/2070-7401-2018-15-1-89-100

4. Приказ М-ва природных ресурсов и экологии Российской Федерации от 29 июня 2016 г. № 375 «Об утверждении Правил лесовосстановления»: Доступ из справ.-правовой системы «Консультант Плюс». [*Order of the Ministry of Natural Recourses and Ecology of the Russian Federation "On the Approval of the Rules of Reforestation" on June 29, 2016 no. 375*].

5. Aicardi I., Garbarino M., Lingua A., Lingua E., Marzano R., Piras M. Monitoring Post-Fire Forest Recovery Using Multi-Temporal Digital Surface Models Generated from Different Platforms. *EARSeL eProceedings*, 2016, vol. 15, no. 1, pp. 1–8.

6. Chu T., Guo X., Takeda K. Remote Sensing Approach to Detect Post-Fire Vegetation Regrowth in Siberian Boreal Larch Forest. *Ecological Indicators*, 2016, vol. 62, pp. 32–46. DOI: 10.1016/j.ecolind.2015.11.026

7. Frazier R.J., Coops N.C., Wulder M.A. Boreal Shield Forest Disturbance and Recovery Trends Using Landsat Time Series. *Remote Sensing of Environment*, 2015, vol. 170, pp. 317–327. DOI: 10.1016/j.rse.2015.09.015

8. Gauthier M.-M., Barrette M., Tremblay S. Commercial Thinning to Meet Wood Production Objectives and Develop Structural Heterogeneity: A Case Study in the Spruce-Fir Forest, Quebec, Canada. *Forests*, 2015, vol. 6(2), pp. 510–532. DOI: 10.3390/f6020510

9. Gradel A., Ammer C., Ganbaatar B., Nadaldorj O., Dovdondemberel B., Wagner S. On the Effect of Thinning on Tree Growth and Stand Structure of White Birch (*Betula platyphylla* Sukaczev) and Siberian Larch (*Larix sibirica* Ledeb.) in Mongolia. *Forests*, 2017, vol. 8(4), art. 105. DOI: 10.3390/f8040105

10. Hansen M.C., Potapov P.V., Moore R., Hancher M., Turubanova S.A., Tyukavina A. et al. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science*, 2013, vol. 342, iss. 6160, pp. 850–853. DOI: 10.1126/science.1244693

11. Keshava N., Mustard J.F. Spectral Unmixing. *IEEE Signal Processing Magazine*, 2002, vol. 19, iss. 1, pp. 44–57. DOI: 10.1109/79.974727

12. Pickell P.D., Andison D.W., Coops N.C. Characterizations of Anthropogenic Disturbance Patterns in the Mixedwood Boreal Forest of Alberta, Canada. *Forest Ecology and Management*, 2013, vol. 304, pp. 243–253. DOI: 10.1016/j.foreco.2013.04.031

13. Pickell P.D., Hermosilla T., Frazier R.J., Coops N.C., Wulder M.A. Forest Recovery Trends Derived from Landsat Time Series for North American Boreal Forests. *International Journal of Remote Sensing*, 2015, vol. 37, iss. 1, pp. 138–149. DOI: 10.1080/2150704X.2015.1126375

14. Potapov P., Turubanova S., Hansen M.C. Regional-Scale Boreal Forest Cover and Change Mapping Using Landsat Data Composites for European Russia. *Remote Sensing of Environment*, 2011, vol. 115, iss. 2, pp. 548–561. DOI: 10.1016/j.rse.2010.10.001

15. Turner B.L., Lambin E.F., Reenberg A. The Emergence of Land Change Science for Global Environmental Change and Sustainability. *PNAS*, 2007, vol. 104(52), pp. 20666–20671. DOI: 10.1073/pnas.0704119104

16. Vila J.P.S., Barbosa P. Post-Fire Vegetation Regrowth Detection in the Deiva Marina Region (Liguria-Italy) Using Landsat TM and ETM+ Data. *Ecological Modelling*, 2010, vol. 221, iss. 1, pp. 75–84. DOI: 10.1016/j.ecolmodel.2009.03.011

17. White J.C., Saarinen N., Kankare V., Wulder M.A., Hermosilla T., Coops N.C. et al. Confirmation of Post-Harvest Spectral Recovery from Landsat Time Series Using Measures of Forest Cover and Height Derived from Airborne Laser Scanning Data. *Remote Sensing of Environment*, 2013, vol. 216, pp. 262–275. DOI: 10.1016/j.rse.2018.07.004

18. Yi K., Tani H., Zhang J., Guo M., Wang X., Zhong G. Long-Term Satellite Detection of Post-Fire Vegetation Trends in Boreal Forests of China. *Remote Sensing*, 2013, vol. 5, iss. 12, pp. 6938–6957. DOI: 10.3390/rs5126938

19. Zhao F.R., Meng R., Huang C., Zhao M., Zhao F.A., Gong P., Yu L., Zhu Z. Long-Term Post-Disturbance Forest Recovery in the Greater Yellowstone Ecosystem Analyzed Using Landsat Time Series Stack. *Remote Sensing*, 2016, vol. 8(11), art. 898. DOI: 10.3390/rs8110898

МЕТОД ОТНЕСЕНИЯ ЗЕМЕЛЬ К ЗЕМЛЯМ, ЗАНЯТЫМ ЛЕСНОЙ РАСТИТЕЛЬНОСТЬЮ, ПО АЭРОКОСМИЧЕСКИМ СНИМКАМ LANDSAT

А. Карпов, *аспирант-стажер; ResearcherID: H-1915-2019,*
ORCID: https://orcid.org/0000-0002-9087-8399
Б. Васке, *д-р геогр. наук, проф.*
Оснабрюкский университет, ул. Ваксблайхе, д. 27, Оснабрюк, Германия, 49090;
e-mail: lesnoy.monitoring@gmail.com

Спутниковые данные становятся важным инструментом для мониторинга изменений, происходящих в лесном покрове. Дальнейшее развитие технологий дистанционного зондирования Земли создает возможности для решения более сложных задач, требующих многократного анализа спутниковых данных. Оценка успешности лесовосстановления после возникновения нарушений в лесном покрове является такой задачей. Традиционный метод оценки успешности лесовозобновления – закладка пробных площадей – требует значительных временных затрат и ресурсов. Полевые работы и отнесение земель к землям, занятым лесными насаждениями, через закладку пробных площадей производятся по методике, разработанной Федеральным агентством лесного хозяйства России. Данная методика имеет различные критерии успешного лесовозобновления для каждого региона. Территориями исследования стали Архангельская и Вологодская области, а также Республика Карелия. Растительность данного региона относится к таежной зоне и разделяется на пять групп: районы притундровых лесов и редкостойной тайги, северо-таежный, среднетаежный и южно-таежный районы. Международная классификация относит данные леса к группе бореальных. Использование спутниковых данных позволит оптимизировать мероприятия по отнесению лесных участков к землям, занятым лесными насаждениями. Проведен анализ индексов восстановления NDVI, SWVI и NBR на объектах лесовозобновления. На каждый исследуемый объект получены полевые данные о количестве подроста, средней высоте древостоя и породном составе. Обработка большого количества спутниковых снимков требует значительных вычислительных мощностей, поэтому для проведения анализа использовалась платформа Google Earth Engine. На основе полученных данных выбран наиболее пригодный для создания автоматической методики по переводу земель в лесопокрытую площадь индекс SWVI как наилучший спектральный индекс для разделения земель на достигшие и не достигшие критериев отнесения к землям, занятым лесными насаждениями. Оптимальным порогом для перевода земель стало достижение 80 % восстановления от первоначальных значений индекса до возникновения нарушений в лесном покрове. Использование метода *k*-средних и пороговых значений индекса для перевода позволило создать автоматизированную методику.

Для цитирования: Karpov A., Waske B. Method for Transferring Non-Forest Cover to Forest Cover Land Using Landsat Imageries // Изв. вузов. Лесн. журн. 2020. № 3. С. 83–92. DOI: 10.37482/0536-1036-2020-3-83-92

Финансирование: Данное исследование проведено в рамках проекта «Мониторинг лесов в Архангельской области с использованием данных мультисенсорного дистанционного зондирования», финансируемого Министерством образования и науки России и Германской службой академических обменов в рамках программы «Михаил Ломоносов» (проект № АААА-А19-119020590052-2).

Ключевые слова: землепользование, лесное хозяйство, лесовосстановление, Landsat.

Поступила 03.04.19 / Received on April 3, 2019