Assessment of the health status of tree stands based on Sentinel – 2B remote sensing materials and the short-wave vegetation index SWVI

A Alekseev* and D Chernikhovskii

Department of forest inventory, management and GIS, Saint-Petersburg State Forest Technical University, 5 Institutsky Lane, St. Petersburg 194021, Russian Federation

*Corresponding email: a_s_alekseev@mail.ru

Abstract. The article presents the results of a study of the possibilities of using the short-wave vegetation index SWVI to assess the state of stands. As test objects, we used the trial areas laid down according to the ICP-Forests method in 2019, as well as additional areas with mainly heavily damaged, dying and dead plantings. To determine the short-wave vegetation index of SWVI, the 8th (NIR) and 11th (SWIR) spectral channels of Sentinel-2B images were used. Data from ground-based stand surveys and remote sensing data were combined and processed in the QGIS geographic information system. The study of the interdependencies of the state of tree stands and the values of the short-wave vegetation index was carried out in the STATGRAPHICS 18.0 application software package using variance and regression analysis. It is shown that the short-wave vegetation index SWVI statistically reliably reflects the state of vegetation and can be used to organize monitoring of the state of forests in a continuous mode.

1. Introduction

The purpose of this work was to study the possibilities of using open remote sensing materials to assess the state of stands based on the application of the short-wave vegetation index SWVI. The relevance of such research lies in the fact that at present there is a need to know the current state of stands on sufficiently large territories, which can change quite quickly under the influence of a combination of natural and anthropogenic factors and therefore requires constant monitoring. The study of the possibilities of using vegetation indices to assess the characteristics and condition of forest ecosystems is one of the most popular areas of remote methods.

The development of this area is promoted by the growing requirements for remote sensing results in various fields, as well as significant technological progress in recent decades, associated with an increase in the number of satellites, improving the characteristics of survey materials, increasing the availability of remote sensing materials, improving software and processing algorithms.

The basic principles of determining and interpreting vegetation indices are described in a number of textbooks and monographs [1-10]. Tools for determining and studying vegetation indices based on remote sensing materials can be programs for processing remote sensing materials, geoinformation systems, and special applications [11-15]. The article [11] is devoted to a brief review of 27 vegetation indices determined by ENVI (Band Math tool). It is noted that the main advantage of vegetation indices is the ease of obtaining them and a wide range of tasks solved with their help. The indices are grouped into seven categories according to the vegetation properties that they characterize (indices of "greenness", light efficiency, nitrogen content, carbon content, pigment content, indices for assessing
the moisture content in the vegetation cover). The initial spectral channels used for calculations are indicated. The regularities taken into account when using vegetation indices are noted. Thus, for specific natural conditions and various tasks, some indexes from the group can give more accurate results than others. The index that most accurately reflects the property under study is selected by comparing the results of the index calculations with the field data. It is also noted that any vegetation indices give only relative estimates of the properties of the vegetation cover, which can be interpreted and converted into absolute values using field data. The values of the indices are influenced by the sensor characteristics and shooting conditions [11].

The tasks solved by means of vegetation indices in the study of forests are quite diverse, and the number of published research results is large. In [10], the physical basis for calculating a number of vegetation indices is considered in detail, and the results of in-depth studies of the use of vegetation indices for solving various tasks for assessing vegetation cover (satellite mapping of agricultural land, assessing the current state and dynamics of vegetation cover in Russia, monitoring vegetation cover) are presented. Examples of the use of vegetation indices for solving practical problems in agriculture and forestry are also discussed in the monograph [16].

A number of studies demonstrate the use of vegetation indices for the classification of vegetation cover [17-22]. A significant number of studies are devoted to the study of dynamic processes of vegetation change using time series of remote sensing materials and the calculation of vegetation indices [5, 10, 12, 23, 24]. A number of publications are related to the use of vegetation indices to study the processes of vegetation restoration after burning, deforestation and other violations of forest cover [25-31], the classification of certain categories of land [28, 31] and groups of plantings [17].

Many studies are devoted to solving the problems of identifying and studying the relationships between vegetation indices and forest characteristics. Examples are the study of the influence of forest cover variability of Siberian larch stands in high-altitude forests on vegetation indices [32], the relationship of vegetation indices with leaf indices, the growth and productivity of fir forests of the Pacific coast of the United States [33], the development of a methodology for monitoring and predicting pyrogenic forest loss based on satellite observations [34].

The purpose of this work was to study the possibilities of using open remote sensing materials to assess the state of stands based on the application of the short-wave vegetation index SWVI.

2. Methods and Materials
During the summer field season of 2019 the state of forest tree stands in the border zone of Russia and Finland was assessed. The objects of the study were the sample plots regularly laid out under the ICP-Forests methodology on the territory of the Vyborg district of the Leningrad Region. The method of conducting field work is described in detail in [15-17]. Stands of all species in these sample areas are either healthy (Norway spruce, Birch) or weakened (Scots pine), hardwoods are in better condition than coniferous, Scots pine stands are most damaged. In general, the condition of stands in the border zone of Russia and Finland on the Russian side, in the Vyborg district of the Leningrad region, can be assessed as good: 56 trial areas were assessed as completely healthy and 43 as weakened. There were no strongly weakened, dying and dead tree stands on the surveyed sample plots.

To increase the representation of the tree stands with bad health status forest allotments with severe damaged, dying and dead tree stands were added to the ground based data. The materials of forest management were used from the standard geoinformation databases of the North-Western forest management district. With the help of the WinGIS and PLP-2015 programs needed tree stands were selected for which the degree of damage was indicated during the forest survey of 2019 as severe damaged, drying as well as dead tree stands. In further studies, 153 sample areas were used.

This study used a Sentinel-2B image (date of shooting July 31, 2018). The original images were processed at Level-1C, so they needed to perform atmospheric correction (DOS1 correction) and
convert the brightness values to decimal values, which were performed using the SAC module in the QGIS.

The possibility of assessing the state of forest stands using the short-wave vegetation index SWVI was studied:

\[ \text{SWVI} = \frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}} \]  

(1)

Here, NIR is the reflection of vegetation cover in the near-infrared part of the spectrum with a range of 0.76-0.9 microns; SWIR is the reflection of vegetation cover in the mid-infrared part of the spectrum with a range of 1.55-1.75 microns.

The vegetation indices were calculated using the Raster Calculator menu in QGIS (Raster – Raster Calculator). To determine the SWVI index, a formula for calculating the index was entered in the Raster Calculator Expression window using the 8th (NIR) and 11th (SWIR) Sentinel – 2B channels.

The relationship between the damage classes of tree stands and the value of the short-wave vegetation index SWVI was studied by mathematical statistics methods using variance and regression analysis with the help of STATGRAPHICS 18.0 software.

3. Results and Discussion

The preliminary analysis showed that there is statistically reliable relationship between tree stands damage classes and vegetation index SWVI (see table 1 and figure 1).

Table 1. ANOVA table for vegetation index SWVI by 5 damage classes.

| Variability source          | Sum of Squares | Degree of freedom | Mean square | F-ratio | P-value |
|----------------------------|----------------|-------------------|-------------|---------|---------|
| Between damage classes     | 1.633          | 4                 | 0.408251    | 44.53   | 0.000   |
| Within damage classes      | 1.35677        | 148               | 0.009167    |         |         |
| Total                      | 2.98977        | 152               |             |         |         |

The ANOVA table decomposes the variance of vegetation index SWVI into two components: a between-group (damage classes) component and a within-group component.

Figure 1. Mean values of vegetation index SWVI and 95% confidence intervals for tree stands 5 damage classes.

The F-ratio (Fisher criteria), which in this case equals 44.53, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is less than 0.05, there is a statistically significant difference between the mean vegetation indexes SWVI from one level of damage class to another at the 95% significance level.

The vegetation index SWVI shows a significant dependence on the classes of damage to stands, the average value of the index varies from 0.08 for dead stands to 0.34 for healthy ones, that is, more than 4 times. Thus, the SWVI index is sensitive to changes in the state of stands. But healthy and slightly damaged tree stands practically do not differ from each other in terms of the SWVI index as well as moderately and severely damaged (see figure 1). The shape of the curve statistically reliable
describing the relationship between vegetation index SWVI and tree stands mean damage classes is shown on figure 2 and illustrated the uncertainty in determining neighboring damage classes by the value of index.

![Figure 2](image_url)

**Figure 2.** Relationship between vegetation index SWVI and tree stands mean damage classes ($R^2 = 83.5\%$).

The curve on figure 2 clearly demonstrate a reasonability to aggregate the tree stands damage classes in order to increase the resolution of damage class determination by the value of vegetation index SWVI. To realize this enlarged, aggregated 3 classes of damage to stands were formed according to the following rule: the first aggregated class included healthy and slightly damaged stands corresponding to points 0 and 1, the second included moderately damaged and severely damaged stands corresponding to points 2 and 3, and the third - dead stands corresponding to points 4. Table 2 demonstrates the analysis of variance results if vegetation index SWVI related with aggregated damage classes and figure 3 mean values of vegetation index SWVI and 95% confidence intervals for tree stands 3 damage classes.

Tabl**e 2.** ANOVA table for vegetation index SWVI by 3 aggregated damage classes.

| Variability source          | Sum of Squares | Degree of freedom | Mean square | F-ratio | P-value |
|----------------------------|----------------|-------------------|-------------|---------|---------|
| Between damage classes     | 1.56663        | 4                 | 0.7833      | 82.56   | 0.000   |
| Within damage classes      | 1.42314        | 148               | 0.0095      |         |         |
| Total                      | 2.98977        | 152               |             |         |         |

The F-ratio (Fisher criteria), which in this case equals 82.56 and almost twice more than in table 1 (44.53), demonstrates significantly more strong relationship of vegetation index SWVI and 3 aggregated damage classes. It may be seen on figure 3 that the 95% confidence intervals for mean values of vegetation index SWVI calculated for 3 aggregated damage classes haven’t interceptions and may be used for damage class determination on higher level of confidence.

Relationship for damage class calculation using the vegetation index SWVI as an explaining variable in this case of aggregated classes is linear with high coefficient of determination:

$$\text{Aggregated damage class} = 3.753 - 8.453*\text{SWVI}, \ R^2 = 89.4\%.$$  

Last equation may be used for thematic maps development for visualization of forest health state on the areas of interest in the terms of aggregated damage classes on the base of Sentinel – 2B images using NIR and SWIR spectral channels in form of vegetation index SWVI.
4. Conclusion

As a result of this study was obtained the interesting result consist in high sensitivity of short-wave vegetation index SWVI on tree stands health state as it reflected by its mean damage class. The value of SWVI varies as much as 4 times for healthy and dead tree stands, the more index value the better tree stands health state. If in analysis use the 3 aggregated damage classes instead of 5 initial usually used the resolution ability of vegetation index SWVI elevates as much as twice and relationship between index value and aggregated damage classes became linear with high determination coefficient. Last may be successively used for thematic maps development by application of proper GIS technology to visualization and analysis of forest health state on the areas of interest. Especially such an approach may be of help for study of forest health state on remote areas damaged for example by such a natural factors as forest fires, pest and diseases, unfavorable weather conditions as well as by manmade influence. Thematic maps that reflect the state of plantings can be interesting and in demand by various interested organizations and groups of citizens, such as state forestry management bodies, environmental organizations, groups of gardeners, hunters, fishermen and other recreational workers.

Generally such a method based on the use of vegetation index SWVI can be recommended for solving many problems of forestry related to monitoring the state of forests. In particular, it can be used to organize continuous monitoring of the health status of forests on the basis of obtaining up-to-date materials of remote sensing of the Earth for constantly informing interested groups of the population about the results.

Acknowledgements

This study was carried out with the financial support of the project No 21-16-00065 “The role of insects and pathogens in the weakening and death of coniferous stands in the North-West of the Russian Federation: quantification and monitoring” funded by the Russian Science Foundation.

5. References

[1] Franklin S 2001 Remote Sensing for Sustainable Forest Management (Lewis publishers) p 425
[2] Chandra A and Ghosh S 2008 Remote Sensing and Geographical Information System (Moscow: Technosphere) p 312
[3] Tokareva O 2010 Processing and Interpretation of Remote Sensing Data (Tomsk: Tomsk Polytechnic University Press) p 148
[4] Schowengerdt R 2010 Remote Sensing. Models and Methods for Image Processing (Moscow: Technosphere) p 560
[5] Ramachandran B 2011 Land Remote Sensing and Global Environmental Change NASA's Earth
Observing System and the Science of ASTER and MODIS vol 11 ed B Ramachandran, C O Justice and M J Abrams (Springer) p 894

[6] Malysheva N 2012 Automated Interpretation of Aerospace Imageries of Forest Stands (Moscow: Moscow State Forest University Press) p 151

[7] Tolstokhatko V and Penkov V 2013 Lecture Notes for the Course «Photogrammetry and Remote Sensing». Module 2: Remote Sensing (Kharkiv: Kharkiv National Academy of Urban Economy) p 113

[8] Kurbanov E, Vorobiev O and Lezhnin S 2015 Thematic Mapping of Vegetation Cover from Satellite Imagery: Validation and Accuracy Assessment (Yoshkar-Ola: Volga State University of Technology) p 132

[9] Lillesand T 2015 Remote Sensing and Image Interpretation. Seventh Edition ed T M Lillesand, et al (Wiley) p 770

[10] Bartalev S, Egorov V, Zharko V, Loputin E, Plotnikov D, Khvostikov S and Shabanov N 2016 Land Cover Mapping over Russia Using Earth Observation Data (Moscow: Russian Academy of Sciences’ Space Research Institute) p 208

[11] Cherepanov A and Druzhinina E 2009 Spectral Properties of Vegetation and Vegetation Indexes Geomatica 3 pp 28-32

[12] Yifang B 2016 Multitemporal Remote Sensing: Methods and Applications vol 20 ed B Yifang (Springer International Publishing) p 448

[13] Eklundh L and Jönsson P 2017 Timesat 3.3 with Seasonal Trend Decomposition and Parallel Processing Software Manual p 92 Available at: http://web.nateko.lu.se/timesat/docs/TIMESAT33_SoftwareManual.pdf

[14] Fisher R, Hobgen S, Mandaya I, Kahlo N and Zulkarnain N 2017 Satellite Image Analysis and Terrain Modelling - A Practical Manual for Natural Resource Management, Disaster Risk and Development Planning using Free Geospatial Data and Software. Version 2. SAGA GIS 4 p 150 available at: https://sagatutorials.wordpress.com/

[15] Congedo L 2020 Semi-Automatic Classification Plugin Documentation Release 7.0.0.1. 197 p available at: DOI: http://dx.doi.org/10.13140/RG.2.2.25480.65286/1

[16] Baghdadi N, Mallet C and Zribi M 2018 QGIS and Applications in Agriculture and Forest vol 2 ed N Baghdadi et al (London: ISTE Ltd) p 353

[17] Ivanov A, Butorina E and Baldina E 2012 Long-Term Dynamics of Primary Spruce Forests (Southern Taiga) in the Kologriv Forest Natural Reserve Moscow University Bulletin. Series 5. Geography 3 pp 74-79

[18] Neshataev M and Neshataev V 2012 Combination Method for Mapping Vegetation (on the Example of the Lapland Nature Reserve) «Izvestia Sankt-Peterburgskoj Lesotehniceskoj Akademii» 201 pp 29-40

[19] Sharikalov A and Yakutin M 2014 The Analysis of Taiga Ecosystems Condition Applying Automatic Decoding Method «Izvestiya of Altai State University». Earth sciences 3-1(83) pp 123-127

[20] Adamovich T and Ashimikhina T 2017 Study of the Dynamics of Forest Cover on the Territory of the «Nurgush» Reserve Based on Satellite Data Prospects of Science – 2017: Collection of Materials of the VI International Correspondence Competition of Scientific Research Works ed A V Gumerov pp 359-364

[21] Soromotin A and Brodt A 2018 Monitoring of Vegetation Cover During the Development of Oil and Gas Fields According to the Landsat Multispectral Survey Data Tyumen State University Bulletin. Ecology and nature management 4(1) pp 37-49

[22] Ali M, Vorobyev O and Kurbanov E 2020 Decision Tree Algorithm for Forest Classification of Syrian Arab Republic with the Use of Sentinel-2 Image Bulletin of the Volga State Technological University. Series: Forest. Ecology. Nature management 1(45) pp 5-30

[23] Vorobyev O, Kurbanov E, Demisheva E, Menshikov S, Ali M, Smirnova L and Tarasova L 2019 Remote monitoring of forest stands sustainability ed E A Kurbanov (Yoshkar-Ola:
[24] Vorobyev O, Kurbanov E, Demisheva E, Menshikov S and Smirnova L 2019 Algorithm for Reviling the Phenological Parameters of Forest Cover on the Base of Time Series of Satellite Data *Bulletin of the Volga State Technological University. Series: Forest. Ecology. Nature management* 1(41) pp 5-20

[25] Vorobyev O, Kurbanov E, Gubayev A, Leznin S and Polevshikova Y 2012 Remote Monitoring of Forest Burnt Areas in Mari Zavolzhje *Bulletin of the Volga State Technological University* 1 pp 12-22

[26] Kurbanov E, Vorobyev O, Polevshikova Y and Leznin S 2012 Solution for remote sensing monitoring of postfire areas using ENVI 4.8 and ARCGIS 10.0 system *Geomatics* 4 pp 82-92

[27] Kurbanov E, Vorobyev O, Leznin S and Polevshikova Y 2013 Assessment of Burnt-Out Forest of Chuvashia by Remote Sensing Method «Vestnik IrGSHA» 54 pp 80-87

[28] Belova E and Ershov D 2015 Assessing reforestation on clear cuts based on Landsat time series *Russian Journal of Forest Science (Lesovedenie)* 5 pp 339-345

[29] Vorobyev O, Kurbanov E, Polevshikova Y and Leznin S 2016 Assessment of dynamics and disturbance of forest cover in the Middle Povolzhje by Landsat images *Current problems in remote sensing of the Earth from space* 13(4) pp 124-134

[30] Vorobyev O and Kurbanov E 2017 Remote monitoring of vegetation regeneration dynamics on burnt areas of Mari Zavolzhje forests *Current problems in remote sensing of the Earth from space* 14(2) pp 84-97

[31] Belova E and Ershov D 2019 Using Landsat Time Series for Assessing Reforestation on Clear Cuts in Bryansk Region *Forest Science Issues* 2 (4) pp 1-20

[32] Loranty M, Davydov S, Kropp H, Alexander H, Mack M, Natali S and Zimov N 2018 Vegetation Indices Do Not Capture Forest Cover Variation in Upland Siberian Larch Forests *Remote Sens.* 10 1686

[33] Waring R, Milner K, Jolly W, Phillips L and McWethy D 2006 Assessment of site index and forest growth capacity across the Pacific and Inland Northwest U.S.A. with a MODIS satellite-derived vegetation index *Forest Ecology and Management* 228(1–3) pp 285–291

[34] Bartalev S, Stytsenko F, Khvostikov S and Loupian E 2017 Methodology of Post-Fire Tree Mortality Monitoring and Prediction Using Remote Sensing Data *Current problems in remote sensing of the Earth from space* 14(6) pp 176-193