Bulgarian Journal of Agricultural Science, 30 (Suppl. 1) 2024
Agricultural Academy

An approach for studying changes in ecology: A beech forest case study from Pernik Province, Western Bulgaria

Borislav Grigorov[1*], Adam Rusinko[2] and Kiril Vassilev[3]

[1] *Sofia University "St. Kliment Ohridski", Faculty of Geology and Geography, Bulgaria*
[2] *Department of Physical Geography and Geoinformatics, Faculty of Natural Sciences, Comenius University, Bratislava, Slovakia*
[3] *Institute of Biodiversity and Ecosystem Research, Department of Plant and Fungal Diversity and Resources, Bulgarian Academy of Sciences, Sofia, Bulgaria*
[*]*Corresponding author:* borislav.g.grigorov@gmail.com

Abstract

Grigorov, B., Rusinko, A. & Vassilev, K. (2024). An approach for studying changes in ecology: A beech forest case study from Pernik Province, Western Bulgaria. *Bulg. J. Agric. Sci., 30 (Supplement 1)*, 90–96

The present study deals with the investigation of the beech forests of Pernik Province. It aims to test a methodological approach for determination of the condition of beech forests. The area of research is located in the western parts of Bulgaria. Forests represent an essential natural resource that impacts the quality of the environment and the population living in its vicinity. The processes of mapping and monitoring of tree habitats has a long tradition in dendrology. Landsat 8 data has been used for the calculation of the Normalized Difference Vegetation (NDVI) for the study area. Four months (May, June, July and November) have been studied with the available satellite data. The tested methodological approach shows promise when it comes to June and July, yet data regarding May and November is controversial.

Keywords: Landsat; remote sensing; vegetation index

Introduction

Forests are a significant natural resource that affects the quality of the environment and population (Touminen et al., 2009; Uvsh et al., 2020; Xiao & McPherson, 2005). Forests serve plenty of ecological functions like energy conservation, a habitat for wildlife, water catchment functioning, reduction of air pollution, have recreational, aesthetic and an economic dimension (Brown et al., 2000; Kramer et al., 2001; Xiao & McPherson, 2005). All these functions are influenced by tree health, i.e., forest condition. The condition of forests can serve as an indicator for global ecological change. Leaf size, leaf color and pigmentation, leaf moisture, and stem structure affect the health of vegetation. In addition, the characteristics of forests are connected to other factors, such as climate, land use, and other socio-economic factors (Chu et al., 2019). With the gradual development of technology and the pressure of the human population on global forests, their health is decreasing (Touminen et al., 2009; Zaitunah et al., 2018). Therefore, it is important to know the current forest condition and, based on the results, make decisions about their further management.

Mapping and monitoring of trees has a long tradition in dendrology (Wilford et al., 2005). However, this precise method requires field surveying and thus, it is expensive and not effective for big study areas (Alexander & Palmer, 1999; Xiao & McPherson, 2005). Moreover, the methods of field surveying are different among countries and/or have changed over time. So, data comparisons are complicated or impossible for some cases. On the other hand, satellite remote sensing data provides an appropriate tool to monitor landscape dynamics at different spatiotemporal scales (Chu et al., 2019). Therefore, satellite images are widely used in land use and land cover mapping (Alix-Garcia et al., 2016; Hietel et al., 2004; Hoyos et al., 2018), vegetation mapping (Potapov et al., 2015; Uvsh et al., 2020), or mapping of agricultural areas (Griffiths et al., 2013; Pazúr et al., 2020) but the rates and patterns of recent land changes remain unclear. Here we assess agricultural land change for the entire Carpathian ecoregion in Eastern Europe at 30 m spatial resolution with Landsat data and for two change periods, between 1985–2000 and 2000–2010. The early period is characterized by post-socialist transition processes, the late period by an increasing influence of EU politics in the region. For mapping and change detection, we use a machine learning approach (random forests.

Satellite technology has recorded significant technical progress since the launch of the World's first satellite mission – Sputnik in 1957. The most consecutive multi-spectral satellite images are provided by Landsat. The first mission of Landsat was launched in 1972. In 1984, spatial, geometrical, and radiometric resolutions were enhanced with Thematic Mapper sensor of Landsat-4. Current Landsat satellites are Landsat-8, launched in 2013 and Landsat-9, launched in 2020. Both have Operational Land Imager (OLI) optical sensor and Thermal Infrared Sensor (TIRS) (Hemati et al., 2021; Rogan & Chen, 2004)Landsat plays a key role in systematic monitoring of the Earth's surface, enabled by an extensive and free, radiometrically consistent, global archive of imagery. Governments and international organizations rely on Landsat time series for monitoring and deriving a systematic understanding of the dynamics of the Earth's surface at a spatial scale relevant to management, scientific inquiry, and policy development. In this study, we identify trends in Landsat-informed change detection studies by surveying 50 years of published applications, processing, and change detection methods. Specifically, a representative database was created resulting in 490 relevant journal articles derived from the Web of Science and Scopus. From these articles, we provide a review of recent developments, opportunities, and trends in Landsat change detection studies. The impact of the Landsat free and open data policy in 2008 is evident in the literature as a turning point in the number and nature of change detection studies. Based upon the search terms used and articles included, average number of Landsat images used in studies increased from 10 images before 2008 to 100,000 images in 2020. The 2008 opening of the Landsat archive resulted in a marked increase in the number of images used per study, typically providing the basis for the other trends in evidence. These key trends include an increase in automated processing, use of analysis-ready data (especially those with atmospheric correction. Besides Landsat, there are also other satellite images from different remote sensing missions. For example, CORONA, SPOT, Sentinel, MODIS, and also non-optical datasets, mainly from radar (SAR) missions: ASTER, SRTM etc. (Purnamasayangsukasih et al., 2016).

Satellite images contain a combination of bands with different wavelength. Using GIS, the composite images can be created and used for imagery analysis. The biggest advantage of multi-spectral satellite images is the fact that every specific combination of single bands can highlight particular objects on the Earth's surface including vegetation (Huang et al., 2021; Touminen et al., 2009). During the last decades, more than one hundred vegetation indices have been derived (Xue & Su, 2017)vigor, and growth dynamics, among other applications. These indices have been widely implemented within RS applications using different airborne and satellite platforms with recent advances using Unmanned Aerial Vehicles (UAV and are available for use in vegetation studies and forestry. One of the most well-known indices is the Normalized Difference Vegetation Index (NDVI) (Eastman et al., 2013; Huang et al., 2021; Touminen et al., 2009). The NDVI is derived from reflectance of sunlight in the visible red and near-infrared (NIR) wavelengths as a simple calculation: NIR minus red radiation divided by NIR plus red radiation (Tucker, 1979). The NDVI is sensitive to chlorophyll concentration, therefore, it is used as indicator of (healthy) vegetation. Likewise, the NDVI can be used for very quick delineation of vegetation from other land use / land cover classes. On the other hand, the NDVI is sensitive to phenological phases during the year. Thus, the NDVI measurements over different seasons can exhibit significant differences (Eastman et al., 2013). However, while the spatial and temporal scales are harmonized in datasets, the NDVI still provides an easily obtainable and high explanatory tool for vegetation mapping on wide areas.

Studies, that included NDVI, that have been carried out in the territory of Bulgaria include the ones of Bozhkov (2017), Stoyanova et al. (2018) and Ivanov and Tyufekchiev (2019). At the same time methodological studies (Nedkov et al., 2021) also play an important role for the present research.

We hypothesize that the application of NDVI will provide stable data for the summer months.

The aim of the present study is to test a methodological approach for determination of the condition of beech forests.

Materials and Methods

Case Study Area

The Pernik Province is located in South-West Bulgaria, and it is adjacent to the capital city of Sofia. The West and North borders of the study area overlap with the national border with the Republic of Serbia, which follows the main ridges of Karvav Kamak and Ruy Mountains (Figure 1). The North-East border follows the orientation of Zavalska, Viskyar, and Lyulin Mountains reaching the southwestern slopes of Vitosha Mountain. The East boundary follows the main crest of Vitosha Mountain from its highest peak – Cherni vrah (2290 m), to the Petrus peak (1454 m) from where it follows the periphery of Verila Mountain, encompassing the source area of Arkata river and its tributaries. In the south, the lower parts of Konyanvska Mountain separate Pernik Province from Kyustendil Province. The southwest border follows the foots of the Zemenska Mountain and the dividing ridge between the basins of Treklyanska and Yavor river, known as Penkyovska Mountain. Within these boundaries, the area of Pernik Province is 2396.8 km^2 or about 2.16 % of the total territory of Bulgaria.

Most of the mountains and ridges, as well as some of the river valleys, such as Konska reka, Svetlya, Yavor, and Treklyanska Rivers, are oriented from NW to SE (Figure 1). The highest point within the boundaries of the administrative unit is Cherni Vrah peak (2290 m) in Vitosha Mountain whereas, the Struma Valley near the town of Zemen is the point with the lowest elevation (about 560 m). A large portion of the study area (31.23%) is occupied by flood plains and river terraces, covering the extent of Pernik and Radomir graben valleys. The Radomir graben valley with its surrounding mountain slopes covers about 462.5 km^2, while the area of Pernik graben is significantly smaller – about 286.07 km^2 including the adjacent mountain slopes (Ivanov, 1960; 1961). The basin of Konska reka, known as Graovo, as well as the Tran Valley (Znepole) are also examples of relatively flat terrains with a low relief. At the same time, many mountains fall within the perimeter of Pernik Province, namely Ruy, Karvav Kamak, Erul, Strazha, Lubash, Cherna Gora, Golo Bardo, and Rudini Mountains, etc. which are considered to be part of the Kraishte physiographic region of Bulgaria. Mountains like Zavalska, Viskyar, Lyulin, Vitoha and Verila are a part of the Srednogorie Region. Due to this variety of landforms, the mean elevation of the study area is 874.8 m.

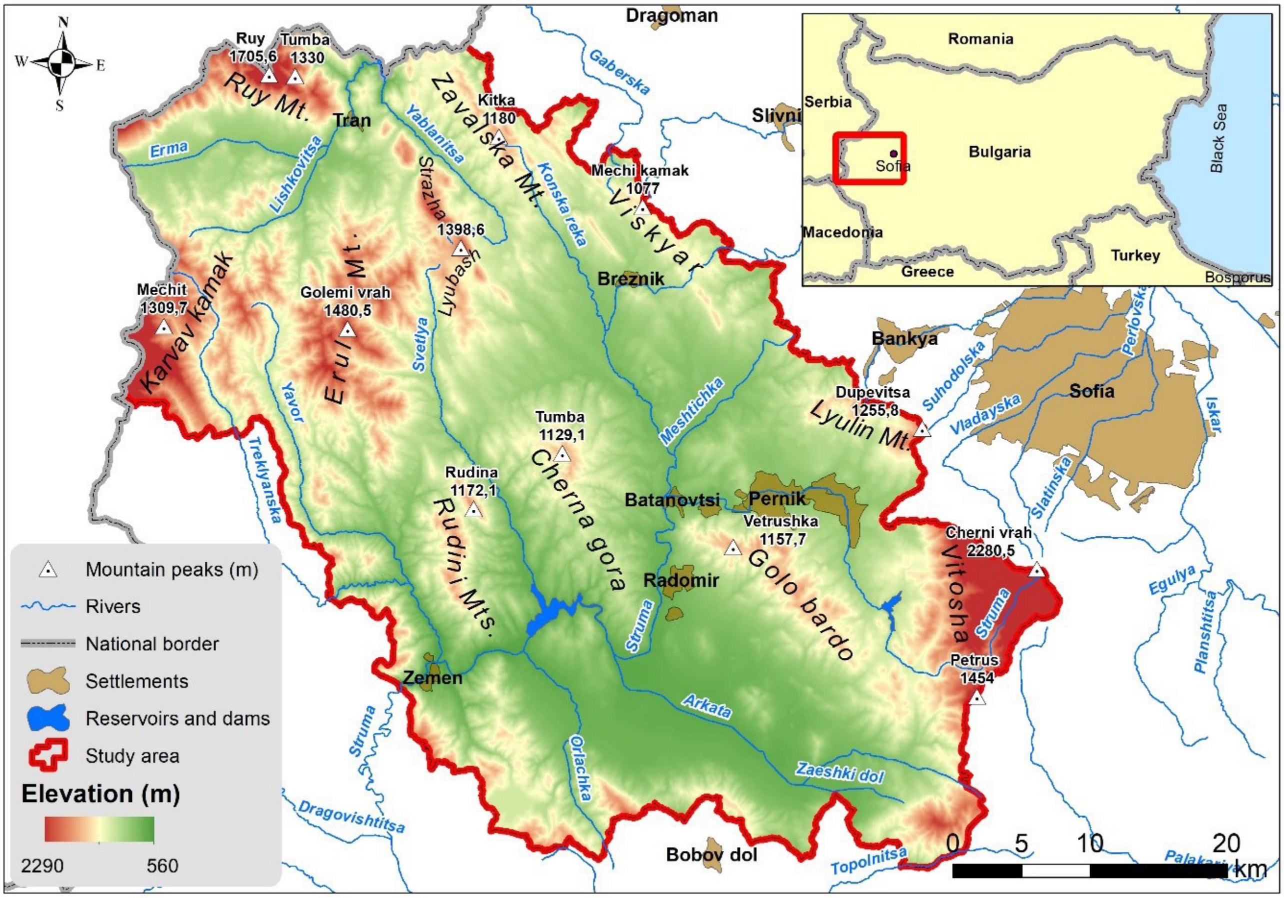

Fig. 1. Location of the study area of Pernik Province in the western part of Bulgaria

The predominant part of the study area (80.25%) has an elevation between 600 and 1000 m and the climate is temperate or mesothermal Cfb according to Köppen classification (Toplyiski, 2006) with no pronounced dry season and without significant precipitation difference between seasons. Terrains with an elevation between 1000 and 1600 m cover 18.53% of the study area, thus affecting the parameters of local climate by increasing annual precipitation sums and decreasing monthly air temperatures. These conditions are optimal for the development of different types of vegetation, mainly deciduous forests. Nevertheless, the record low temperature for Bulgaria (-38.3 °C) was measured at Tran in 1947 and temperature inversions are a common phenomenon in both the autumn and the winter months.

The variety of abiotic factors within the Pernik Province determine the vast diversity of landscapes, habitats, and its ecological conditions which reflect the dominant vegetation and the variability of soil cover. Significant areas such as Golo Bardo ridge and the south-west slopes of Vitosha Mountain are comprised of carbonate sediment rocks, mainly limestone and dolomites, which have been karstified. The presence of surface karst landforms prevents the formation of thick soil cover and the development of forest vegetation. Steep mountain slopes are prone to erosion which also affects the vegetation canopy. As a result of the continuous anthropogenization of the area due to agriculture and coal mining, the natural vegetation has been replaced by secondary communities in many places.

Theoretical Implications

Images from Landsat 8 (Landsat Collection 2 Level-2, Landsat 8-9 OLI/TIRS C2 L2) have been explored. Additional criteria have been applied to sort out and reduce the number of images with land cloud cover with values from 0 to 10. NDVI values have been calculated for all of them. In the end four months stood out. The months of May, June and July were picked due to the fact that the highest NDVI results that have been uncovered in them. November has also been chosen to get the lowest possible of the high NDVI values that could be used for a comparison. The months from December to April were excluded from the study due to intense snow cover. Composite bands were created to get the NDVI by using the Image analysis tool in ArcGIS 10.6.1. NDVI values have been used to reveal the condition of the beech forests in Pernik Province. Data, regarding forest distribution, has been provided by the National Forestry Inventory. The condition has been determined by the application of the following classes (https://eos.com/blog/ndvi-faq-all-you-need-to-know-about-ndvi/):

-1–0 Dead plants
0–0.33 Unhealthy plants
0.33–0.66 Moderately healthy plants
0.66–1 Very healthy plants

Results and Discussion

Four particular Landsat 8 images have used for the analysis (Table 1).

Table 1. Landsat 8 images that have provided the basis for the analysis

May	2021.05.13
June	2021.06.30
July	2021.07.16
November	2021.11.05

Figure 2 displays the NDVI values for *Fagus sylvatica* L. forests for the four months. High values are peaking in May (0.60). This may be explained by its physiological patterns (Berveiller & Damesin, 2008). They are the lowest in November when photosynthesis levels are very low.

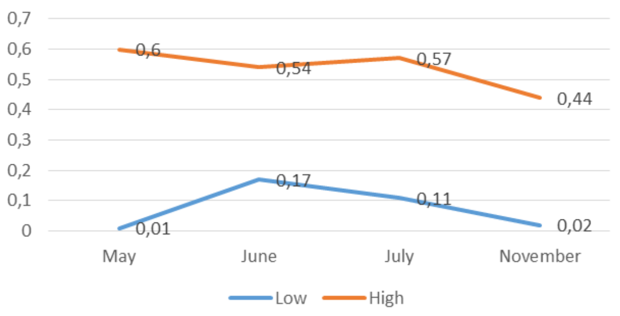

Fig. 2. NDVI values (high and low) for *Fagus sylvatica* L. forests in the territory of Pernik Province

Figures 3 and 4 are dealing with the condition of the forests that are dominated by *Fagus sylvatica* L. It is broadleaved and its forests are covering the largest territory of Pernik Province when it comes to deciduous forests cover. It is a typical species for the whole country and can be found throughout the whole Europe from the southern parts of the Scandinavian Peninsula to the shores of the Mediterranean Sea. An analysis on its condition in a part of Bulgaria could be useful from a continental point of view. Beach forests in Pernik Province (Figure 3 and Figure 4) are predominantly moderately healthy in May, June and July, while the numbers are the opposite in November when photosynthesis lacks. As for the month of May the moderately healthy individuals (121.5 km²) are almost twice, as much as the unhealthy plants (66.2 km²). The territories with unhealthy plants in May are located to the east of the village of Studena, and mainly between the villages of Strezimirovtsi and Penkyovtsi. They can also be found to the northwest and southeast of the town of Tran. Almost all *Fagus sylvatica* L. forests are falling within the category of the moderately healthy plants in the months of June and July, covering 185.31 km² and 186.1 km², respectively. Unhealthy plants in June are taking only 0.8 km² and can be located mainly to the north of the village of Penkyovtsi. The same category takes 0.01 km² in July, located mostly to the east of the village of Dren. The picture becomes quite different when we look into November. Unhealthy plants are taking up to 183.9 km². Moderately healthy plants are covering only 3.8 km². They are sparsely distributed mainly near the settlements of Strezimirovtsi, Tran and Penkyovtsi to the west and northwest and to the east of the villages of Studena and Dren.

Forests and their health with a focus on global change have been studied in the recent years and all of the above-mentioned data may support this type of research. Ayers & Lombardero (2000) and Trumbore et al., (2015) also emphasized on the importance of the definition of forest health, especially in the vicinity of climate change. They also focus on how essential is to detect the implication of different stress on forest ecology and the gravity of different types of disturbance. Additionally, Pravalie et al. (2014) used Landsat TM NDVI data for studying forest ecosystems in Southwestern Romania. Their study area is not that far away from the focus territory of the present investigation. Their data is from three distinct moments from 1990, 2000 and 2011 and it can be used for correlation. The scientists indicate the presence of a stable connection between thermal stress and forest degradation. A few years later García et al. (2020) conducted a study on forest regeneration and expansion in the face of ecological change. The authors emphasize on the need of evidence-based strategies, including pilot studies and long-term monitoring.

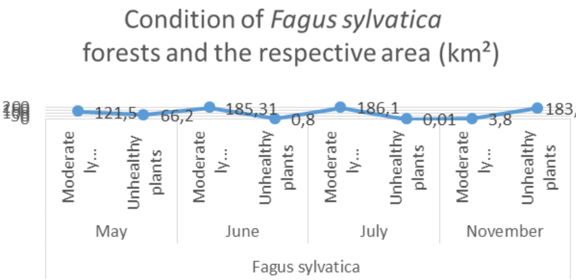

Fig. 3. The condition of *Fagus sylvatica* L. forests in Pernik Province and the respective area they cover

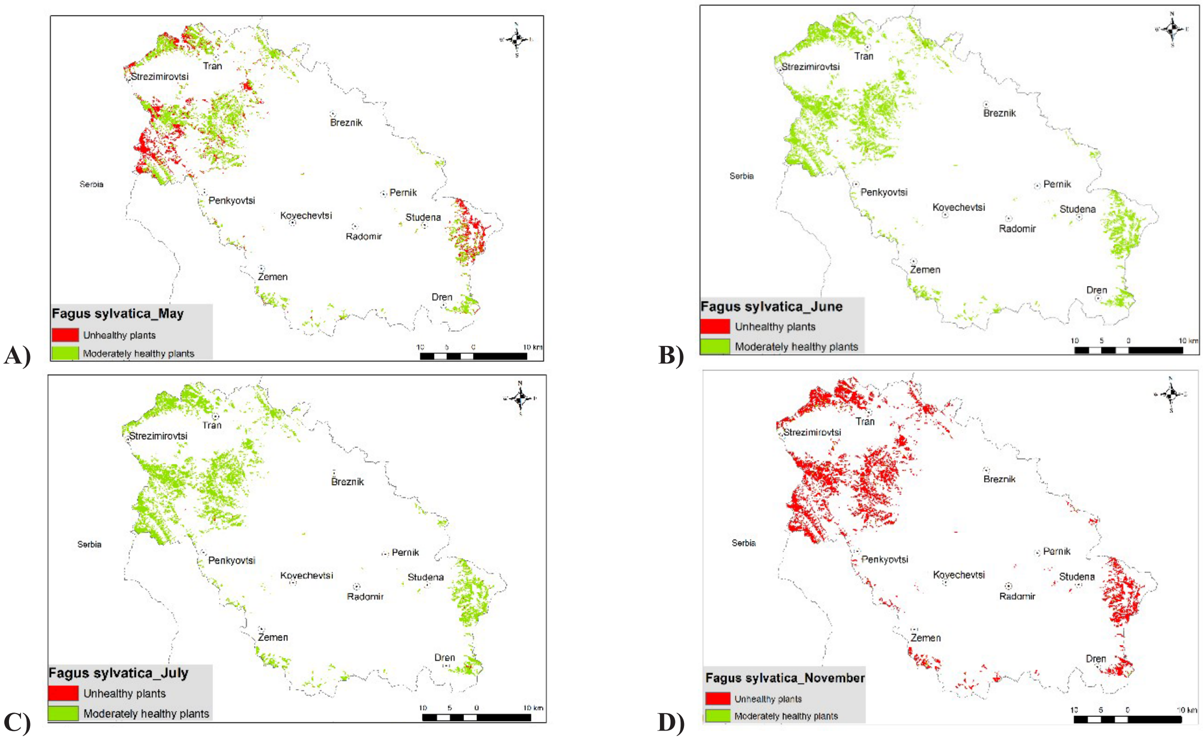

Fig. 4. The condition of *Fagus sylvatica* L. forests for the months of May (A), June (B), July (C) and November (D)

All of the abovementioned research may be used as a prove that changes in forest ecology are a matter of present day interest and different approach is needed. Overall, the proposed methodological approach in the present study adds more value in the study of forest ecology. It shows promise when it comes to the months of June and July, and it is controversial for the months of May and November, due to the presence of larger territories that include unhealthy plants. Beech forests have a well-developed leaf cover in June and July, therefore data about those of them that are falling within the "unhealthy plants" has to be considered valid. On the other side, the same individuals built up the forests in May and November when more territories fall within this category. This is mainly due to difference in photosynthetic levels so these individuals should not be regarded as unhealthy.

Conclusions

The present study provided data about the condition of the forests of Pernik Province, based upon the satellite data of Landsat 8 and the application of the Normalized Difference Vegetation Index (NDVI). The condition of *Fagus sylvatica* L. forests has been studied for four months. The tested methodological approach revealed that it can be applied only for the summer months of June and July, when beech forests are fully developed, which proved our hypothesis. At the same time data, regarding the two other months of May and November may be regarded as controversial. The successful results of the present research can be applied in similar studies throughout the country.

Acknowledgements

The study is supported by the project "Soil catenas and plant sites in the mountains of Rudini and Miloslavska" (contract 80-10-121/16.04.2024), financed by the budget of Sofia University "St. Kliment Ohridski" for scientific research in the year of 2024.

References

Alexander, S. & Palmer, C. (1999). Forest health monitoring in the United States: First four years. *Environmental Monitoring and Assessment*, *55*(2), 267–277. https://doi.org/10.1023/A:1005905310299.

Alix-Garcia, J., Munteanu, C., Zhao, N., Potapov, P., Prishchepov, A., Radeloff, V., Krylov, A. & Bragina, E. (2016). Drivers of forest cover change in Eastern Europe and European Russia, 1985–2012. *Land Use Policy*, *59*, 284–297. https://doi.org/10.1016/j.landusepol.2016.08.014

Ayeres, M. & Lombardero, M. (2000). Assessing the consequences of global change for forest disturbance from herbivores and pathogens. *Science of The Total Environment*, *262*(3), 263-286. https://doi.org/10.1016/S0048-9697(00)00528-3.

Berveiller, D. & Damesin, C. (2008). Carbon assimilation by tree stems: potential involvement of posphoenolpyruvate carboxylase. *Trees*, *22*(2), 149-157.

Bozhkov, P. (2017). Spatial and Temporal Analysis of Vegetation Canopy and their Relation with Slope Processes in Zemen Gorge (West Bulgaria). In: Proceedings of Seminar of Ecology – 2016 with international participation (21-22 April 2016), IBER–BAS, Sofia, Bulgaria, 223–229.

Brown, D., Pijanowski, B. & Duh, J. (2000). Modeling the relationships between land use and land cover on private lands in the Upper Midwest, USA. *Journal of Environmental Management*, *59*(4), 247–263. https://doi.org/10.1006/jema.2000.0369.

Chu, H., Venevsky, S., Wu, C. & Wang, M. (2019). NDVI-based vegetation dynamics and its response to climate changes at Amur-Heilongjiang River Basin from 1982 to 2015. *Science of the Total Environment*, *650*, 2051–2062. https://doi.org/10.1016/j.scitotenv.2018.09.115.

Eastman, J., Sangermano, F., Machado, E., Rogan, J. & Anyamba, A. (2013). Global trends in seasonality of Normalized Difference Vegetation Index (NDVI), 1982-2011. *Remote Sensing*, *5*(10), 4799–4818. https://doi.org/10.3390/rs5104799.

García, C., Espelta, J. & Hampe, A. (2020). Managing forest regeneration and expansion at a time of unprecedented global change. *J. Appl Ecol.*, *57*, 2310–2315. DOI: 10.1111/1365-2664.13797.

Griffiths, P., Müller, D, Kuemmerle, T. & Hostert, P. (2013). Agricultural land change in the Carpathian ecoregion after the breakdown of socialism and expansion of the European Union. *Environmental Research Letters*, *8*(4). https://doi.org/10.1088/1748-9326/8/4/045024.

Hemati, M., Hasanlou, M., Mahdianpari, M. & Mohammadimanesh, F. (2021). A systematic review of landsat data for change detection applications: 50 years of monitoring the earth. *Remote Sensing*, *13*(15). https://doi.org/10.3390/rs13152869.

Hietel, E., Waldahrdt, R. & Otte, A. (2004). Analysing land-cover changes in relation to environmental variables in Hesse, Germany. *Landscape Ecology*, *19*(5), 473–489. https://doi.org/10.1023/B:LAND.0000036138.82213.80.

Hoyos, L., Cabido, M. & Cingolani, A. (2018). A Multivariate Approach to Study Drivers of Land-Cover Changes through Remote Sensing in the Dry Chaco of Argentina. *ISPRS International Journal of Geo-Information*, *7*(5). https://doi.org/10.3390/ijgi7050170.

Huang, S., Tang, L., Hupy, J., Wang, Y. & Shao, G. (2021). A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. *Journal of Forestry Research*, *32*(1), 1–6. https://doi.org/10.1007/s11676-020-01155-1.

Ivanov, I. (1960). Géomorphologie du bassin de Dimitrovo. *Ann. Univ. Sofia*, *53*(3) – Géog., 1-48 (Bg).

Ivanov, I. (1961). Géomorphologie du bassin de Radomir. *Ann. Univ. Sofia, 54*(3) – Géog., 1-44 (Bg).

Ivanov, M. & Tyufekchiev, K. (2019). Remote Sensing Based Vegetation Analysis in Parangalitsa Reserved Area. *Ecologia Balkanica*, *Special Edition*, *2*, 187-197.

Kramer, M., Hansen, A., Taper, M. & Kissinger, E. (2001). Abiotic Controls on Long-Term Windthrow Disturbance and Temperate Rain Forest Dynamics in Southeast Alaska. *Ecology 82*(10), 2749–2768. https://doi.org/http://dx.doi.org/10.2307/2679958.

Nedkov, S., Borissova, B., Nikolova, M., Zhiyanski, M., Dimitrov, S., Mitova, R., Koulov, B., Hristova, D., Prodanova, H., Semerdzhieva, L., Dodev, Y., Ihtimanski, I. & Stoyanova, V. (2021). A methodological framework for mapping and assessment of ecosystem services provided by the natural heritage in Bulgaria. *Journal of the Bulgarian Geographical Society*, *45*, 7-18. https://doi.org/10.3897/jbgs.e78680.

Pazúr, R., Lieskovsky, J., Burgi, M., Müller, D., Lieskovsky, T., Zhang, Z. & Prischepov, A. (2020). Abandonment and recultivation of agricultural lands in Slovakia-patterns and determinants from the past to the future. *Land*, *9*(9). https://doi.org/10.3390/LAND9090316.

Potapov, P., Turubanova, S., Tyukavina, A., Krylov, A., Mccarty, J., Radeloff, V. & Hansen, M. (2015). Eastern Europe's forest cover dynamics from 1985 to 2012 quantified from the full Landsat archive. *Remote Sensing of Environment*, *159*, 28–43. https://doi.org/10.1016/j.rse.2014.11.027.

Pravalie, R., Sîrodoev, I. & Peptenatu, D. (2014). Detecting climate change effects on forest ecosystems in Southwestern Romania using Landsat TM NDVI data. *J. Geogr. Sci.*, *24*, 815–832. https://doi.org/10.1007/s11442-014-1122-2.

Purnamasayangsukasih, P., Norizah, K., Ismail, A. & Shamsudin, I. (2016). A review of uses of satellite imagery in monitoring mangrove forests. In: IOP Conference Series: *Earth and Environmental Science*, *37*(1). https://doi.org/10.1088/1755-1315/37/1/012034.

Rogan, J. & Chen, D. (2004). Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning*, *61*(4), 301–325. https://doi.org/10.1016/S0305-9006(03)00066-7.

Stoyanova, M., Kandilarov, A., Koutev, V., Nitcheva, O. & Dobreva, P. (2018). Potential of multispectral imaging technology for assessment of coniferous forests bitten by bark beetle in Central Bulgaria. *MATEC Web of Conferences*, *145*, 01005. https://doi.org/10.1051/matecconf/201814501005.

Toplyiski, D. (2006). Climate of Bulgaria. Foundation AMSTELS (Bg).

Touminen, J., Lipping, T., Kuosmanen, V. & Haapanen, R. (2009). Remote Sensing of Forest Health. In: *Geoscience and Remote Sensing INTECH*, *Gee, P. & Ho, P.* (Eds.), 29–52. https://doi.org/10.5772/8283.

Trumbore, S., Brando, P. & Hartmann, H. (2015). Forest Health and Global Change. *Science*, *349*, 6250, 814-818. https://doi.org/10.1126/science.aac6759.

Tucker, C. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, *8*(2), 127–150. https://doi.org/10.1016/0034-4257(79)90013-0.

Uvsh, D., Gehlbach, S., Potapov, P., Munteanu, C., Bragina, E. & Radeloff, V. (2020). Correlates of forest-cover change in European Russia, 1989–2012. *Land Use Policy*, *96*, 104648. https://doi.org/10.1016/j.landusepol.2020.104648.

Wilford, D., Cherubini, P. & Sakals, M. (2005). Dendroecology: A Guide for Using Trees to Date Geomorphic and Hydrologic Events. B.C. Min. For., Res. Br., Victoria B.C. Land Manage. Handb. No. 58. https://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh58.htm.

Xiao, Q. & Mcpherson, E. (2005). Tree health mapping with multispectral remote sensing data at UC Davis, California. *Urban Ecosystems*, *8*(3–4), 349–361. https://doi.org/10.1007/s11252-005-4867-7.

Xue, J. & Su, B. (2017). Significant remote sensing vegetation indices: A review of developments and applications. *Journal of Sensors*. https://doi.org/10.1155/2017/1353691.

Zaitunah, A., Samsuri, S., Ahmad, A. & Safitri, R. (2018). Normalized difference vegetation index (ndvi) analysis for land cover types using landsat 8 oli in besitang watershed, Indonesia. In: *IOP Conference Series: Earth and Environmental Science*, *126*(1). https://doi.org/10.1088/1755-1315/126/1/012112.

https://eos.com/blog/ndvi-faq-all-you-need-to-know-about-ndvi/

Received: **October, 09, 2024**; *Approved*: **October, 14, 2024;** *Published:* **December, 2024**