# AN ASSESSMENT OF EUROPEAN SPRUCE BARK BEETLE INFESTATION USING WORLDVIEW-2 SATELLITE DATA

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***ABSTRACT*** *- During the past three decades the spectral responses of declining forest health due to pest infestations as well as various methods for detection of trees' health status have been extensively studied. A set of narrow-band and broad-band Vegetation Indices (VIs) have been developed to assess the changes in the vegetation reflectance. The main objective of the study is to assess the damages caused by European Spruce Bark Beetle (Ips typographus L.) infestation in 'Bistrishko Branishte' UNESCO Man And Biosphere (MAB) reserve using WorldView-2 satellite data. The analysis was performed on Norway spruce (Picea abies) forest using the VIs indicative for forest stress: NDVI, SR, EVI, ARVI, CRI, CSc, and ARI. By applying density slice on the VIs, the main regions for stressed vegetation have been delineated. The CSc has been found to perform better in detecting the pattern of stressed spruce trees compared to ARI. The area affected by Ips typographus was determined by CSc index to 5.97% (0.373 km$^2$) of the study area.*

***Keywords:*** *area estimation, vegetation index, Ips typographus, WorldView-2, Norway spruce*

## INTRODUCTION

During the past three decades a lot of effort has been put toward studying the spectral effects of declining forest health [1]-[4] as well as developing various methods for detection the health status of trees [5]-[9]. Pests, such as the European Spruce Bark Beetle, are considered agents of stress in forests because they adversely affect the physiology and growth of trees. Some of the most widely spread insect infestations across the globe are those caused by Gypsy Moth (*Lymantria dispar*), Hemlock Woolly Adelgid (HWA) (*Adelges tsugae*) and Asian Longhorned Beetle (*Anoplophora glabripennis*) in North America [10], and European Spruce Bark Beetle (*Ips typographus L.*) in Europe and Asia [11]. The latter one attacks weakened and healthy trees, wind throws etc. It infests mainly lower and middle parts of stems. The difficulty with remote sensing monitoring of European spruce bark beetle is that it is common to observe green canopy of the trees, whereas the tree is without bark because of larval and woodpecker activity. At final stages of pest infestations the tree casts its needles and only dead tree bole lefts.

The decline of Normalized Difference Vegetation Index (NDVI), the shift of red-edge towards longer wavelengths, and the reduced absorption in chlorophyll absorption features in spectra are the main manifestations of the forest decline caused by insects or other diseases. Chlorophyll *a* (chl-*a*) displays maximum absorptions in the λ=410÷430 nm and λ=600÷690 nm regions, whereas chlorophyll *b* (chl-*b*) shows maximum absorptions in the λ=450÷470 nm range [12]. The mostly affected and visually perceptible output from stressed vegetation is its yellowing of leaves or needles, i.e. chlorosis. It is due to the reduced chlorophyll concentration in dispensing of the increased carotenoids and other pigments.

More than 150 vegetation indices (VIs) have been published in scientific literature, but only a small subset have substantial biophysical basis or have been systematically tested [13]. ITT VIS' software ENVI provides more than 27 VIs to use to detect the presence and relative abundance of pigments, water, and carbon as expressed in the solar-reflected optical spectrum (λ=400÷2500 nm).

A number of narrow band [3], [14], and broad band VIs [15]-[16] have been successfully used to assess changes in the reflectance due to the declining health status of the trees. A simple yet useful classification of broadband VIs into two categories, i.e. ratio based indices and linear based indices, is provided by [17]. According to the scheme the used VIs (NDVI, Simple Ratio (SR), Enhanced Vegetation Index (EVI), Anthocyanin Reflectance Index (ARI), and

Carotenoid Reflectance Index (CRI)) in present study pertain to the two categories. One of the simple ratios which is particularly good for detection and localization of stressed trees is the indicator of plant stress CSc – which is the ratio between λ=605 nm and λ=760 nm bands [18]. The index was initially developed for narrow-band hyperspectral specroradiometers, but in present study it is used as a basis for stress detection due to the additional bands of WorldView-2 satellite data. It utilizes the available 'yellow' band – with central wavelength at λ=605 nm and 'red edge' band with central wavelength at λ=725 nm. The 8th band of the WorldView-2 MultiSpectral (MS) satellite image has its central wavelength at λ=950 nm. It is also indicative for assessment and monitoring of crown condition [19]-[20].

Optical indices derived from the red-edge (the region of rapid shift between red and Near InfraRed (NIR) reflectance) are especially useful because they are sensitive to both chlorophyll content (chl *a*+*b*) and canopy structure [21]. Some investigators have related changes in chl *a*+*b* to a shift in position of the spectral red-edge [22]-[26], which has been associated with plant stress, forest decline, and leaf development [12].

The red-edge and chlorophyll content relationship was studied by Curran for slash pine. It was found that the mean value of red edge is around λ=713 nm when looking vertically, to around λ=716 nm when looking obliquely. The authors have not found any change in the red edge that was attributable to the azimuth of observation [27]. Later on, [2] found that reflectance at the λ=698 nm wavelength was significant in explaining needle reflectance response to southern pine beetle damage in *Pinus elliottii*, while [1] found reflectance at λ=700 nm to be an indicator of needle stress in lodgepole pine caused by mountain beetles. These examples show that there is still a need to precise the red edge position for particular coniferous tree species. The WorldView-2 data has the advantage of the additional band in the so-called red-edge reflectance part of the spectrum, but still it is a broadband one, i.e. λ=705-750 nm, and does not allow the investigator to detect the stress by simply using it as a stress detector. Although, the red-edge band could be used as a self-explanatory while a skilled observer is looking for a stress in a forest environment having *a priori* knowledge of the study area.

The study objective is to assess the damages caused by European Spruce Bark Beetle (*Ips typographus L.*) infestation in *Bistrishko Branishte* UNESCO Man and Biosphere (MAB) reserve using WorldView-2 satellite data. To achieve the objective a set of tasks were carried out:

- Calculating a set of VIs used for stress detection and monitoring;
- Performing visual interpretation of the classification results;
- Quantitative estimation of the level of damage caused by pest infestation.

**Study area**

The study area is situated in the upper part of *Bistrica* river basin in the *Vitosha* Mountain between 1430 and 2282 m a.s.l. Study area of *Bistrishko Branishte* was enlisted in the list of biosphere reserves of UNESCO-MAB Programme in 1977. At present the territory's protected area is 1061.6 ha [28], from which 52% are forests, and the rest part is covered with sub-alpine meadows, rocks, and screes, Figure 1. Dominant tree species is Norway Spruce (*Picea abies*), represented by 7 forms and varieties. Within the reserve are preserved 140-150 year old spruce trees, which Diameter Breast Height (DBH) is up to 1.30 m and 25 m height. On May 22, 2002, 13.6 per cent of the old growth Norway spruce trees (*Picea abies*) in the *Bistrishko braniste* reserve in *Vitosha* Mountain were destroyed [29]. In 2003 after a sudden outbreak of an *Ips typographus* infestation more than 30 ha from the reserve were devastated.

## MATERIALS AND METHODS

The satellite data used for the study is one WorldView-2 satellite MS and PAN tiled scene of the study area acquired on April 10, 2010. Its projection is Universal Transverse Mercator (UTM), datum World Geodetic System (WGS84), Zone 34 North. The software used is ENVI 4.5 (Academic license). Present study employs the methods of image analysis and visual image interpretation, such as calculating a set of VIs, such as NDVI, SR, EVI, ARVI, CRI, CSc, and ARI, which are indicative for forest stress. As it was outlined, ENVI provides workflow wizards for quick analysis for particular application field. The THOR tools and SPEAR Tools in present study were used for stress detection of vegetation, which is caused either by pests or other environmental factors. The additional added red-edge narrow band and two more bands in the NIR region provide for calculation not only of NDVI, and SR, but also for EVI, ARVI, CRI, and ARI. NDVI and SR are usually used to assess the vegetation vigour, whereas EVI and ARVI, has their potential to enhance the results of NDVI by taking into account atmospheric effects. GIS and Cartography methods are used for presentation of the results.

## RESULTS

The vegetation cover of the study area is presented on Figure 1. The fraction of the vegetation classes classified using SPEAR Tools in ENVI 4.5 is as follows: the 'No Vegetation' class covers 27.79% of the spatial subset (1.74 km²), 'Sparse Vegetation' class is (41.79%) of the entire territory (2.61 km²), the 'Moderate Vegetation' class is (27.82%) or (1.74 km²), and the smallest part belongs to 'Dense Vegetation' class with (2.59%) or (0.16 km²).

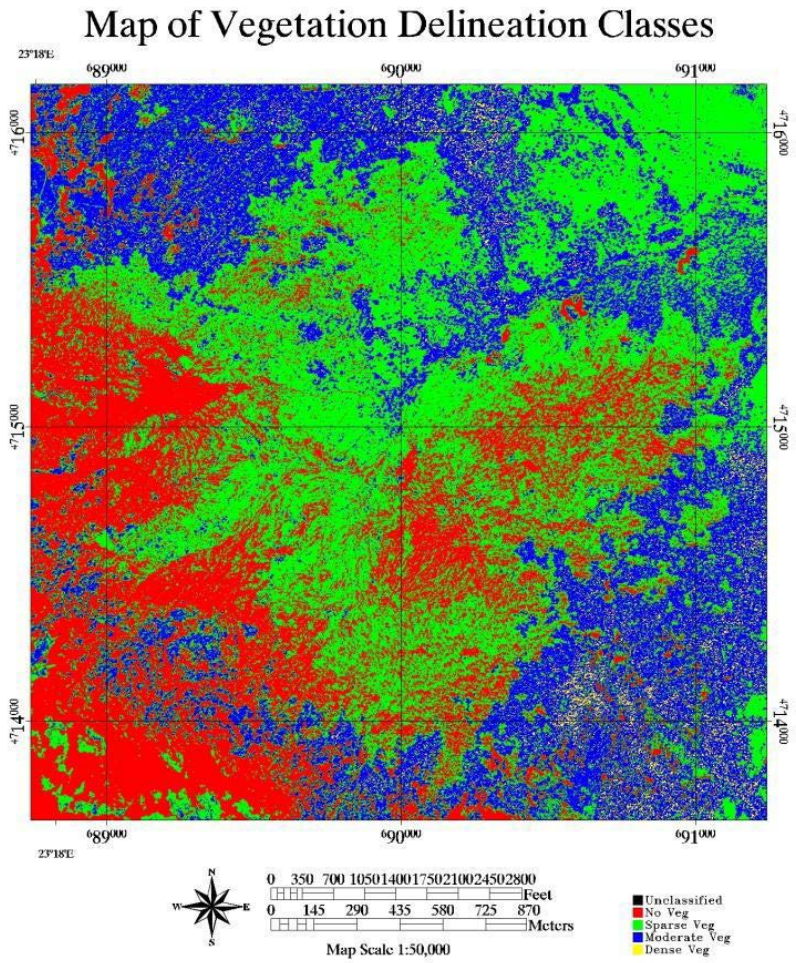
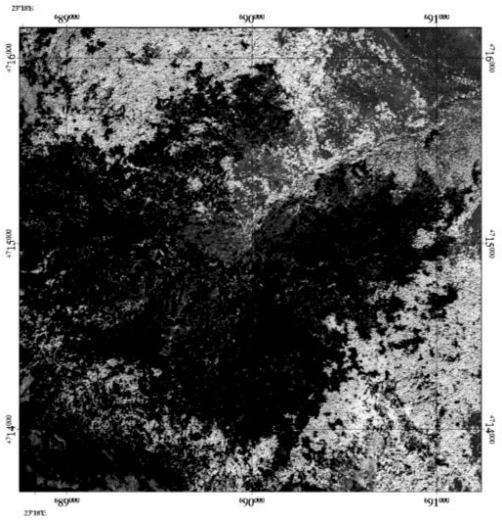
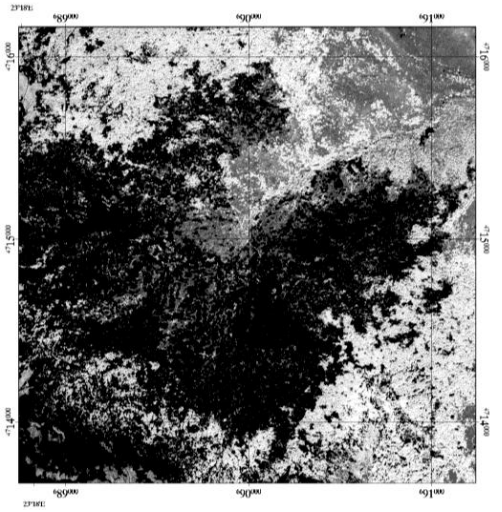



**Fig. 1.** Map of vegetation delineation classes.

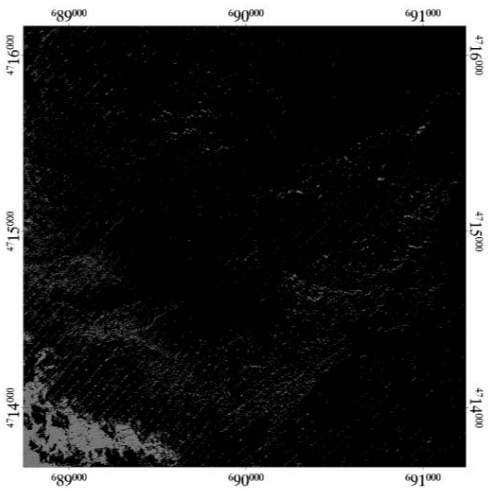
The results from the performed analysis shows that the WorldView-2 data of the *Bistrishko Branishte* UNESCO-MAB Biosphere reserve could be utilized by the embedded VIs in ENVI software. In order to perform these steps, a spatial subset from the WorldView-2 tiled image of 1 400 rows × 1 400 columns and a full range of the multispectral bands was used. The file header was edited by entering the start point and end point of band wavelengths. This was done in order to help the THOR Tools to handle the bands by their spectral metadata, and to calculate the VIs in a semiautomatic way. A vegetation mask was created using a NDVI image in order to mask out the non-vegetated areas. The mask was improved by applying clumping algorithms using 3 neighbouring pixels in a cross moving kernel, and sieving using 3 pixels as lower limit around the blob and 1 000 000 pixels blobs for upper limit. The provided WorldView-2 data has atmospheric and geometric corrections applied, and therefore, this pre-processing step from the data preparation stage was omitted. The resulting VIs from the THOR workflow were visually inspected in several test areas on the territory of reserve using an ancillary Hue Saturation Value (HSV) pan sharpened WorldView-2 subset Colour InfraRed (CIR) image for better visual interpretation. The VIs for stress detection are presented on Figure 2.



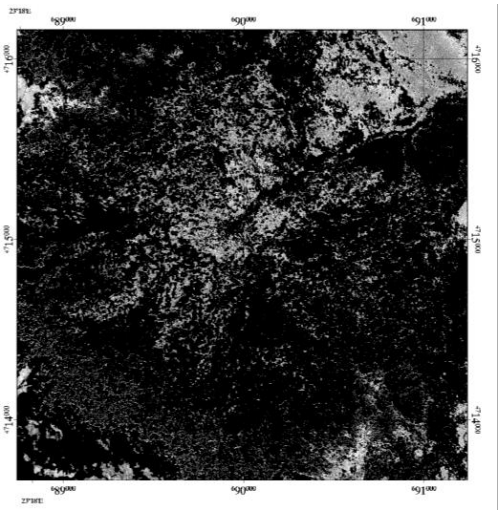
SR



NDVI



CSc stress index



ARVI

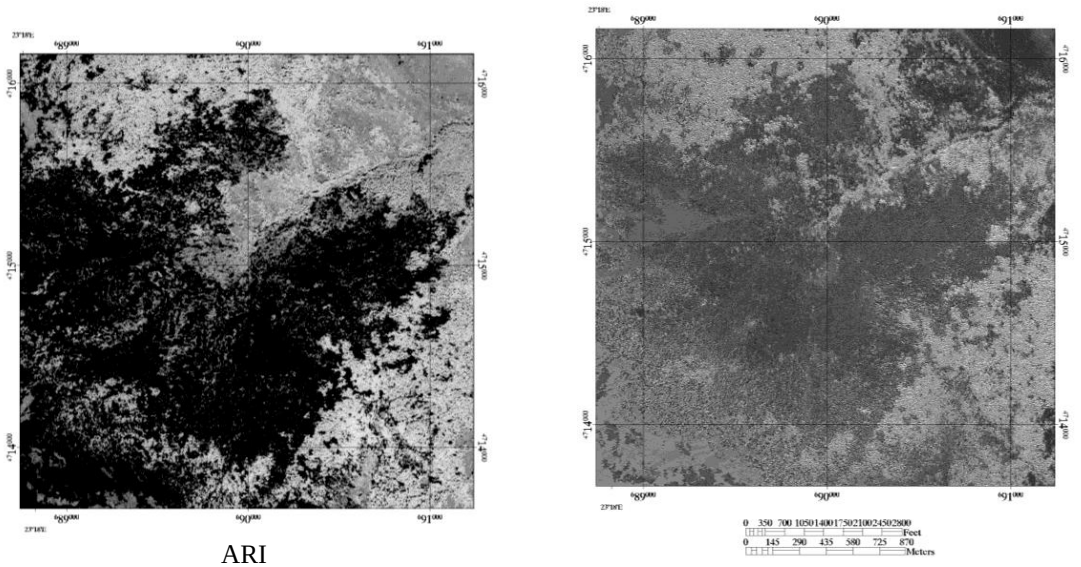



**Fig. 2.** Stress detection VIs for *Bistrishko Branishte* UNESCO-MAB biosphere reserve.

The greyscale colour ramp used for all VIs has their higher values in the lighter part of the ramp, where the lower values are associated with darker part of the ramp. Two of the VIs: EVI and ARVI were found to be not of sufficient quality in order to perform further analysis. For instance, EVI represent mostly binary output, which does not allow for classification of stressed vegetation. The ARI index was density sliced in 5 classes. The subtle variations of anthocyanin values ranging from 0 to 0.06 show that the midrange of 0.003 to 0.004 can be taken as the range at which the vegetation is still at its healthy stage. Below that value the coniferous become less distinctive on CRI and NDVI image. The ARVI values show sharper boundaries of the vegetation comparing to the understory of the forest. Its values for stressed vegetation are ranging from 0.55 to 0.90, where the lower values are close to the healthier vegetation. The classification result of density sliced image of ARI and CSc were compared on the basis of the level of spatial coverage of the damaged trees. It must be noted that CSc shows its potential mostly on detecting stress in living trees community, so its pattern differs from the ARI classification result. The territory covered with dry or senescent trees, or trees which are affected by *Ips typographus* according to the results of CSc index is about 5.97 % (0.373 $km^2$) of the territory, where some of the pixels identified as stressed could be arguably accepted as classification output due to systematic noise, which is apparent as diagonal striping on the image.

## DISCUSSIONS AND CONCLUSIONS

Present paper discusses the utilization of the VIs for WorldView-2 MS data for assessment of coniferous forest stress caused by pest infestation. Comparing to other MS sensors, the WorldView-2 data has its advantages in better spatial and radiometric resolution; also it is providing the ability to simulate the Bidirectional Reflectance Distribution Function (BRDF) of natural and man-made objects by using the built-in satellite agility and pointing mode of the sensor. The analysis of the results shows that the narrower the bands of the MS image give greater possibilities for particular applications fields. In the case of present study, WorldView-2 data was used to calculate several forest stress indices using THOR tools in ENVI 4.5. Due to its additional bands in red-edge region of the spectrum, and two NIR bands, the sensor is able to produce 3 more VI comparing to other MS radiometers, such as the 7-band Landsat ETM+.

The analyzed results from the VIs, show that the highest discrimination power have CRI and ARI. The only arguable point in interpreting the ARI is that its concentration is not only bound to stress situations, but also to seasonal changes within year. As it is seen from the image, there is still a snow cover in the highest parts of the reserve, so the temperature could be considered as a factor in lowered levels of anthocyanin. The most promising of the VIs is the CSc ratio, which provides further insight towards the senescent vegetation, and gives the missing part of the analysis, which aims at detection of stressed coniferous tree stands.

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