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THE USE OF A FIELD SPECTROMETER AND SATELLITE IMAGERY FOR IDENTIFYING STRESSED VEGETATION IN BUCHAREST, ROMANIA

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Abstract

Chlorophyll is the basic pigment for photosynthesis. Vegetation senescence can be accelerated if this process is hampered by external factors. Remote sensing tools contribute to vegetation stress detection. Previous studies correlated chlorophyll values with vegetation indices and red-edge shoulder position. This paper explored the applicability of multi- and hyperspectral satellite images and in-situ spectrometry data for identifying healthy and stressed vegetation in four parks within Bucharest, the capital city of Romania. It integrated data from Sentinel-2 MSI, EO-1 Hyperion and STS-VIS spectrometer from Ocean Optics. Overview of vegetation health is delivered by spaceborne sensors, using vegetation index values. MTVI indicates that vegetation in Unirii Park is the most affected, whilst Herăstrău Park and Tei Park are better managed. Furthermore, red-edge position analysis using leaf reflectance of three species (ash tree, linden tree, pine) confirmed the findings from satellite images. All analysed species Unirii Park and Păcii Park showed signs of high stress, resulting in a red shift of the red-edge position. Ash tree in Herăstrău Park is rather healthy. All species in Tei Park seemed to record a normal senescence rhythm.

***Keywords**: Urban Vegetation; Spectrometry; Red-edge; REIP; MTVI*

Introduction

Urban environmental factors, such as high temperatures and drought due to heat island effect and air pollutants due to traffic, have a negative effect on vegetation. They can lead to loss of nutrients or water deficit [1, 2].

Remote sensing tools offer reliable and low-cost solutions for vegetation health monitoring. Previous studies correlated vegetation indices with biochemical and biophysical properties, such as chlorophyll [3, 4], water [5], nitrogen [1], foliar structure [6], evapotranspiration [7]. Moreover, narrowband indices deliver more accurate information than broadband ones [8]. Modified Triangular Vegetation Index (MTVI) is an indicator used in predicting LAI as it captures the changes in leaf and canopy structures [9].

A more detailed approach to study vegetation health is based on red-edge position [10]. Red-edge refers to the spectral region characterised by a rapid increase of reflectance values from red at around 680 nm to NIR at around 730 nm [11]. The red edge position is a second generation of vegetation indices and spectral traits are positively correlated to pigments and

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nutrients, mainly chlorophyll and leaf nitrogen [12, 13]. Techniques for analysing the red-edge position include computation of Red-Edge Inflection Point (REIP) [14]. REIP is an indicator for vegetation health as it is based on bands which indicate maximum chlorophyll absorption and maximum reflectance in NIR [15]. Also, the background effects are minimized [1].

However, there is a research gap for investigating urban vegetation health with spectrometry and remote sensing, as most studies are focused on crops or forest [12], [16]. Other studies focused on field observations of anatomical tree parameters in natural forests [17].

The main objective of this paper is to investigate and quantify the differences in spectral response of healthy/stressed urban vegetation. The study is based on four parks in Bucharest, Romania and three tree species: ash tree, linden tree and pine. The methodology is based two complementary reflectance analysis: vegetation index computed from satellite imagery and leaf reflectance data using a field spectrometer.

Methodology

Study area

Bucharest is the capital city of Romania. It is characterized by high population density (8,260/km^2), variability of micro-climate (northern part is the least affected by the urban heat island effect), existence of pollution sources and environment degradation (especially in the southern and south-eastern parts) [18]. Thus, vegetation in Bucharest is at risk of being affected by external factors and delivery of ecosystem services could be reduced [19].

Field spectrometry data

Field reflectance data was acquired using a field spectrometer STS-VIS from Ocean Optics, in the range 350 – 820nm. Thus, it covers the visible and the red edge spectrum. It is characterized by ~0.5nm spectral resolution (full-width-at-half-maximum, FWHM) and 1024 continuous bands [20].

Field measurements campaigns were conducted in four selected parks: Herăstrău Park (HER), Tei Park (TEI), Unirii Park (UNI), Păcii Park (PAC), in August and September 2016. Leaf reflectance was measured for two sensible tree species to pollutants: ***pine*** (*Pinus nigra*) and ***ash tree*** (*Fraxinus excelsior*) and one specie tolerant to pollutants: ***linden tree*** (*Tilia cordata*) [21]. These species are also the most common ones in the parks in Bucharest. Number of trees is different for each park, according to Table 1. Campaigns' dates were chosen according to Sentinel-2's and Hyperion's overpasses and the time was around midday, considering that the best time for field spectral campaigns is 12:00(±2 hours). No cloud coverage was observed.

Table 1. Number of trees for which reflectance was recorded

Tree | Park	HER	TEI	UNI	PAC
Fraxinus excelsior	9	15	9	7
Tilia cordata	12	10	8	9
Pinus negra	7	7	7	6

Satellite imagery

Two images acquired on similar dates from Sentinel-2 MSI (30.07.2016) and EO-1 Hyperion (4.08.2016) was included in the study.

Sentinel-2 sensors (S2A & S2B) acquire data in 13 spectral bands. These multispectral sensors deliver important information for vegetation studies due to the bands in the visible spectrum and the three narrow bands in the red-edge spectrum [22]. After radiometric correction and geometric resampling procedures, the surface reflectance product had a resolution of 10m.

Hyperion is a hyperspectral sensor mounted on EO-1 satellite. It has a spatial resolution of 30m and it acquires data in 242 spectral bands with a spectral resolution of ~10nm, in the visible, near and short-wave infrared. It is necessary to mention that some spectral bands are not calibrated or are severely affected by noise due to water absorption from atmosphere [23]. These bands were eliminated from analysis. Surface reflectance values were extracted after radiometric corrections were applied.

Vegetation Indices and reflectance profiles

Two approaches were undertaken: analysis at the canopy level, depicted from spaceborne sensors and analysis at the leaf level, based on field spectral data. The two approaches could not be correlated because of the difference in sensors' characteristics and they were analysed as complementary information.

MTVI was calculated using the narrow bands of Sentinel-2 MSI and Hyperion. Due to the narrow width of Hyperion scene, data could not be computed for PAC. Also, for this study, mixed pixels containing other than tree coverage were excluded. MTVI was calculated based on the Equation (1)

$$MTVI = 1.2 * [1.2 * (\rho 800 - p550) - 2.5 * (\rho 670 - \rho 550)] \qquad (1)$$

Where: ρ - represents the reflectance recorded at indicated wavelength [9].

Reflectance profiles were computed from leaves' reflectance data and the red-edge region was analysed. The red shift in the reflectance profiles of *healthy* vs. *stressed* vegetation can be explained by differences in leaf structure and biochemical parameters. This process can be accelerated by external factors, resulting in stressed vegetation.

Moreover, the red-edge was exploited using REIP, calculated based on field reflectance data using Formula (2). As the plant is affected by senescence, REIP records lower values because it positively correlated with chlorophyll content [24].

$$REIP = 700 + 40\left(\frac{\left[\frac{\rho 670 + \rho 780}{2}\right] - \rho 700}{\rho 740 - \rho 700}\right) \qquad (2)$$

where: ρ - represents the reflectance recorded at indicated wavelength [14].

Results and Discussion

At the canopy level, MTVI computed from Sentinel-2 and Hyperion revealed a good agreement for the selected sites despite the different spatial resolution (Fig. 1).

Results showed greater values of MTVI for Herăstrău Park and Tei Park than for Unirii Park, which recorded values < 0.3 from both datasets. Low values could be correlated with poor foliar structure. Unirii Park is located in the city centre and it receives high pressure from traffic-related pollutants and high temperatures [24], which could be responsible for early defoliation. This result was in agreement with other studies, which reported drought stress leading to de-colouring of the leaves and opening up of the tree canopy [26,27]. Correlated

MTVI values revealed that Hyperion was a valuable source of urban information despite the lower spatial resolution and thanks to high spectral resolution.

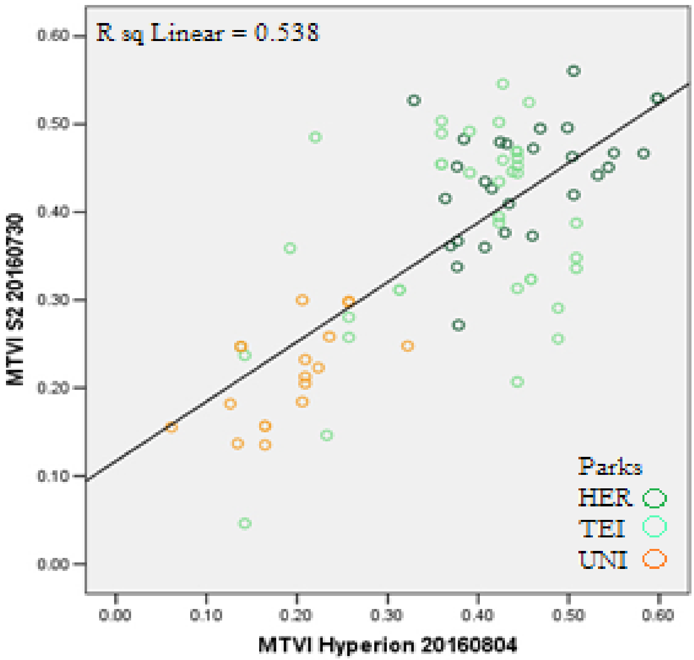

Fig. 1. Correlation between MTVI from Sentinel-2 MSI and EO-1 Hyperion

To our knowledge, this is the first attempt to investigate vegetation health in Bucharest using spectrometry. The major finding of this study is the recorded spectra for the three tree species. Thus, at the leaf level, vegetation could be further analysed. Figure 2 represents the spectra of tree's reflectance per species and per park, in a range from 350 to 820nm, from 2 campaigns (August and September). In both datasets, spectral profiles of trees in Păcii Park and Unirii Park revealed the lowest reflectance values in visible and NIR spectrum for *Fraxinus excelsior*, *Pinus nigra* and *Tilia cordata*, indicating here a higher impact of stressors than in Herăstrău Park or Tei Park.

REIP computed from the field data shows differences in the spectral response, as shown in Figure 3. A great difference in REIP could be correlated with a high rate of senescence, as it is explained by a significant change in leaf pigments and structure. This senescence was due to the natural vegetative cycle, but it was also accelerated by stressing external factors. Thus, Păcii Park and Unirii Park need close monitoring because all species recorded the lowest values. Păcii Park and Unirii Park are small parks and small parks more exposed to stress factors than larger parks are [27, 28], such as Herăstrău Park. Also, Păcii Park and Unirii Park don't have an irrigation system to decrease drought stress and they are located in areas affected by traffic and high temperatures [27]. In Herăstrău Park, only *Fraxinus excelsior* recorded signs of accelerated senescence. Tei Park revealed a regular senescence rhythm for all species, as this park is usually better managed than the others.

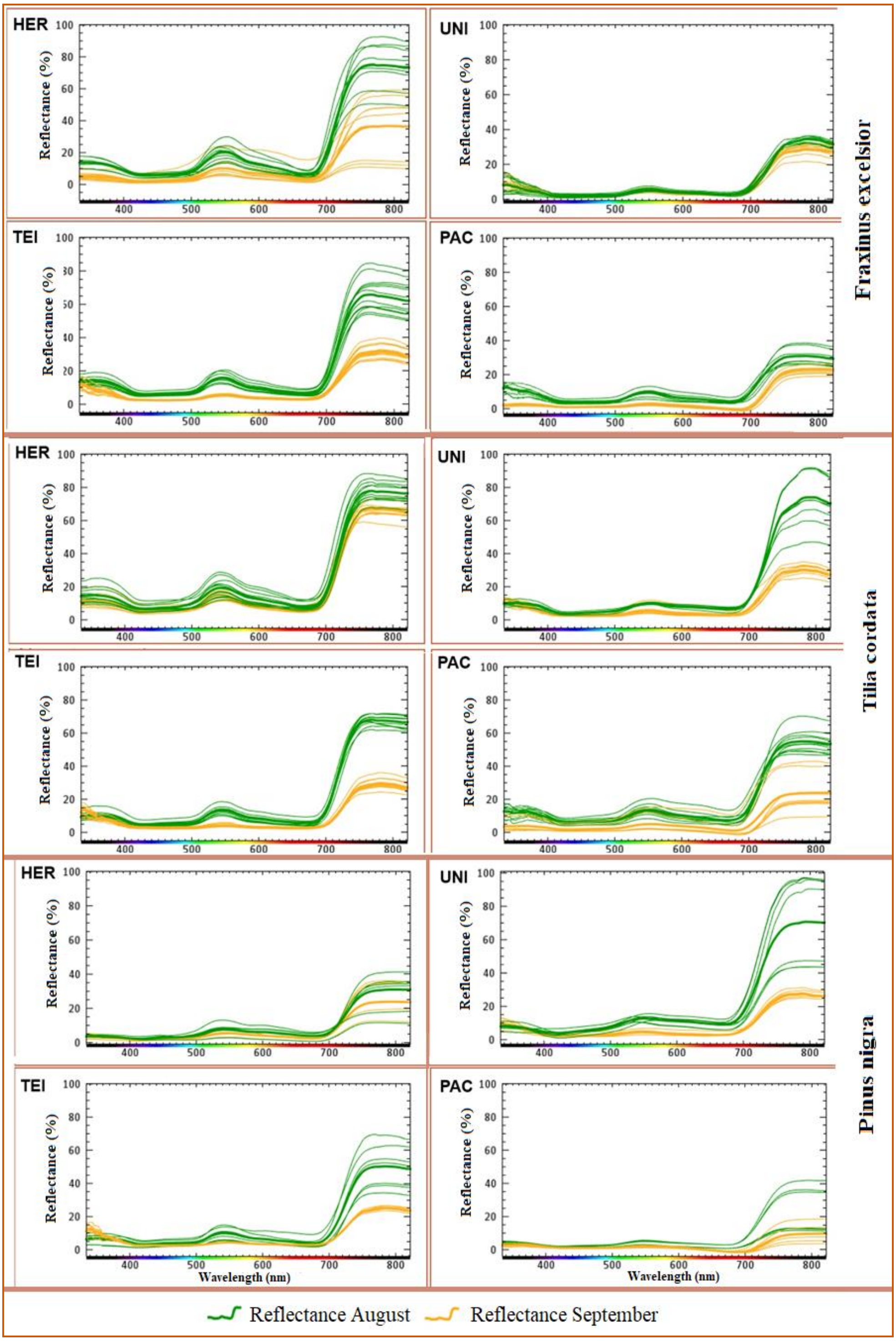

Fig. 2. Spectral profiles for three tree species in four parks in Bucharest, acquired in August and September 2016

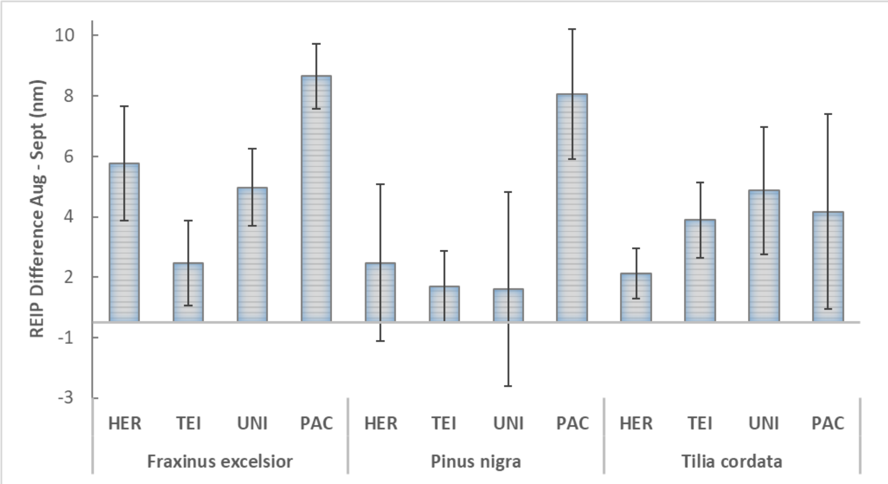

Fig. 3. REIP difference between the two campaigns: August and September, 2016

Conclusions

Early vegetation senescence, which in urban areas can be accounted mainly by pollutants and high temperatures, can be identified using satellite imagery and/ or field spectrometry. This study integrated spaceborne sensors (Sentinel-2 MSI, EO-1 Hyperion) and reflectance data measured with a field spectrometer (STS-VIS from Ocean Optics) for assessing vegetation health in four parks in Bucharest and three species (*Fraxinus excelsior*, *Pinus nigra* and *Tilia cordata*). Results showed the lowest MTVI values for Unirii Park, a small park located in the city centre. Here, plant defoliation started earlier than in other parks. Also, results showed a red shift of the red-edge position, in case of stressed vegetation. Păcii Park and Unirii Park parks revealed stressed vegetation across all species: *Fraxinus excelsior*, *Pinus nigra* and *Tilia cordata*, as here the senescence process was the most accelerated one. Herăstrău Park showed that only *Fraxinus excelsior* indicated signs of early senescence. Tei Park had better management solutions for vegetation and its vegetation is less affected by stressors.

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