Advancing Urban Ecology Research with UAV: A Study on NDVI and Individual Tree Vitality Assessment in Species-rich Parks

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Abstract: The study compares the NDVI index with visual assessment of vitality using the Roloff method in species-rich parks. To evaluate the NDVI, a UAV with a multispectral camera has been used in two terms, in early June and in August. In total, 523 trees were analysed in two objects, at the same time with an extensive on-ground survey. The results show a dependency of the NDVI on the vitality classes in the second part of the growing season, significant inter-species variations in the NDVI values, and a difficult prediction of vitality classes.

Keywords: UAV, remote sensing, park, NDVI, species-rich

1 Introduction

Current scientific knowledge (Huma, Lin & Hyder 2021, Nowak et al. 2017) focusing on the benefits arising from the presence of trees in urban environments concurs that ensuring of a stable population of trees in cities, gardens and parks is a societal concern. Trees represent an essential compositional element for landscape architecture and constitute the actual essence of its objects, whether they are alleys, gardens and parks, historical objects, or urban greenery in general. Trees play an irreplaceable role also in related planning of sustainable green infrastructure of our cities (Navarrete-Hernandez & Laffan 2019). To allow for conceptual work with the trees and tree stands, one must know their characteristics. In order to ensure the required functions of trees, the decisive parameter is to know their qualitative condition, in the context of this paper mainly the physiological vitality. Physiological vitality of trees affects their basic functions (it can be ecosystem services and benefits, aesthetic and compositional value, degree of impact on structural integrity and site safety, etc.).

For landscape architects, planners and site managers, knowledge of the real qualitative condition of trees is very important as it is closely associated with the possibility and accuracy of prediction of the future development and the perspective of the trees and tree stands. This is essential for planning maintenance procedures or recovery and development measures. If further research and development of this topic allowed site and greenery managers to quickly collect relevant and accurate data on the qualitative state of trees using UAV (interpretation of NDVI values, i. e. dead trees, withering trees, local changes in quality, etc.) up to the level of individual trees or groups, it would be possible to quickly plan and implement the required interventions.

The use of remote sensing in planning and monitoring is a promising way of achieving better informedness throughout the process. In case of remote sensing planning, there are several levels of detail as per the GSD (ground sample distance) – high resolution (UAV) in centi-

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metre accuracy, medium resolution in 2–25 cm accuracy (aerial photography) or 10 m accuracy in case of satellite images from Landsat or Sentinel or centimetre resolution from commercial suppliers lake Planet. As per vegetation, remote sensing delivers both quantitative data of the dimensions of objects on the surface and qualitative data based on capturing different wavelengths. The evaluation of the quantitative state of urban greenery in most of the cases issues from vegetation indexes that combine separate bands of reflected radiation. The most used bands are Near-infrared or Red Edge. A versatile and simple parameter for measuring the vitality of vegetation is the NDVI vegetation index (ROUSE et al. 1974). While in forestry or agriculture it has already become standard (e. g. ELTNER et al. 2022), in green infrastructure planning it is applied at the level of cities or urban districts (WELLMANN et al. 2020).

In case of smaller areas such as parks or alleys the assessment gets to the level of an individual tree. Urban greenery, unlike forestry or agriculture, does not work with monocultures but with a wide range of species and varieties with different morphological and physiological manifestations that complicate automated evaluation. In order to be able to evaluate the physiological vitality of an individual tree, it is necessary to go down to individual level (KLOSTERMAN et al. 2018). Some authors study the correlation between phenophases and individual species upon series of flight missions (FAWCETT, BENNIE & ANDERSON 2021). In this, there is space for researching the possibility to predict vitality of individual trees based on the NDVI index with high resolution, but compared to the monoculture stands it is much more complicated.

The research question is to what degree can the evaluation of an individual's physiological vitality be predicted based on high-resolution multispectral images from UAV, and defining of obstacles to the development of this method with regards to the specific issues of landscape architecture.

The paper describes the use of SFM photogrammetric method with multispectral imaging, utilizing split bands of reflected visible radiation and near infrared spectrums of radiation (NIR), and then applying the NDVI index to identify the correlation between the NDVI and the physiological vitality classes according to ROLOFF (2016). In the second step, it tests the possibilities of prediction to identify vitality scores based on NDVI and vice versa. The paper verifies the comparison of the two types of survey on typologically different areas of greenery, with the aim to combine both methods.

2 Materials and Methods

2.1 Study Site

The data is processed based on a survey of two model sites. The model sites were chosen in order to include objects diverse in terms of species and age: an intensively managed park and a non-intensive countryside park area. The basic characteristics and localisation are summarised in the table 1.

2.2 Drone Data Acquisition and Processing

Acquisition of data using a drone and on-ground survey took place over two terms, in late June and late August 2023. At the end of June, the trees are in full foliage and the NDVI index does not rise any higher (FAWCETT, BENNIE & ANDERSON 2021). The August term was chosen in order to observe seasonal changes in vitality. Although there might be multiple factors contributing to reduction in qualitative state (climate, drought, climate changes, etc.), it was not the purpose of this paper to identify these causes. The aim of the paper was to compare the mutual relation between two methods (terrestrial and remote) of qualitative assessment of trees (NDVI, physiological vitality, respectively).

Table 1: Characteristic of the model areas. Area (measured as a Convex Hull Bounding Box in hectares; Above Ground Level describes flight altitude in meters

Name of the Study site	Localisation (coordinates, elevation, annual rainfall total)	Area	No of trees	Date of Acquisition	Above Ground Level (m)
Dataset 1: Rybniční zámeček	48.7838475N, 16.7957642E, 178 m a.s.l., 480 mm	2.33 ha	110	27. 6. 2023 15. 8. 2023	80
Dataset 2: Zámecký park	48.7997119N, 16.8074103E, 170 m a.s.l., 480 mm	10.04 ha	413	27. 6. 2023 15. 8. 2023	60

The data was acquired using Parrot Sequioa multispectral camera mounted on UAV Matrice 210. Parrot Sequioa scans 4 separate bands: red (RED, wavelength 660 nm, bandwidth 40 nm), green (GREEN, wavelength 550 nm, bandwidth 40 nm), near-infrared spectrum (NIR, wavelength 790 nm, bandwidth 40 nm), and the so-called Red Edge band (wavelength 735 nm, bandwidth 10 nm). Parallel with the multispectral images, images in visible spectrum were acquired too, using DJI X4S camera. The scanning was done from flight level 80 and 60 m AGL (Above Ground Level), respectively, in a GRID type mission. The difference in flight level was determined by the Civil Aviation Authority. Automated flight was assisted using the DJI GS Pro application.

Data processing was performed using the Structure from Motion method. It is a technique that deploys sets of 2D images to 3D surface reconstruction through a software-specific algorithm (Jones and Church 2020), in Pix4D software. The data was rectified using six ground control points (GCP) per each of the study areas. The output was resampled for same resolution grid with 3 cm ground surface distance (GSD) resolution for the NDVI index and a digital surface model (DSM). The NDVI is calculated according to the formula:

$$NDVI = \frac{\rho NIR - \rho RED}{\rho NIR + \rho RED}$$

The identification of the tree crowns was done using the Inverse Watershed Delineation method and the results were manually corrected in QGIS. The Inverse Watershed method is widely used especially for dense forest canopies where it delivers satisfactory results. Manual correction was also applied to check whether the individual trees assessed in the field correspond with the trees identified on the aerial images. Individual trees that could not be clearly identified were removed from the study. This for instance applied to specimens growing under other trees or young specimens with small crowns that the selected method did not capture.

The NDVI calculation for the individual tree crowns was done using Zonal Statististic method in QGIS, where average NDVI value of the whole crown diameter was calculated. For one dataset we compared the average of the NDVI values with the average of 20 percent of the brightest pixels per the Berra method (BERRA, GAULTON & BARR 2017) to get closer to the Roloff method.

The data was processed further in R software and evaluated using ANOVA analysis and mixed regression model.

2.3 Field Survey Method and Data Acquisition

Physiological vitality (Vitality Score) of a tree expresses the degree of possible reduction or threat to viability of the tree due to physiological reasons. It is determined visually by the character of the tree's foliage and character of branching on the periphery of the crown (different ratio between long and short shoots, for more detail see (KOLAŘÍK 2018, 14; PEJCHAL & ŠIMEK 2018, ROLOFF 2016).

The following scale of physical vitality has been used (for more detail, see Fig. 1):

- 1 – optimal (exploration phase by ROLOFF 2016), vigorous trees with top part of their crown in the stage of exploration. Long shoots develop from terminal buds and from almost all lateral buds;
- 2 – slightly reduced (degeneration phase by ROLOFF 2016), slightly weakened trees with top part of their crown in the stage of degeneration. Long shoots develop from the terminal buds, but almost all the lateral buds produce only short shoots;
- 3 – moderately reduced (stagnation phase by ROLOFF 2016), severely weakened trees with the top part of their crown in the stage of stagnation. Terminal buds produce only short shoots and shortened lateral shoots do not continue to branch out;
- 4 – severely reduced (resignation phase by ROLOFF 2016), severely weakened trees and dying trees, with the top part of their crown in the stage of resignation. Only short shoots are produced, and only in parts of the crown. These shoots often break and fall or dry out;
- 5 – none, dry dead tree without any signs of physical vitality (without living shoots), not in the Fig. 1.

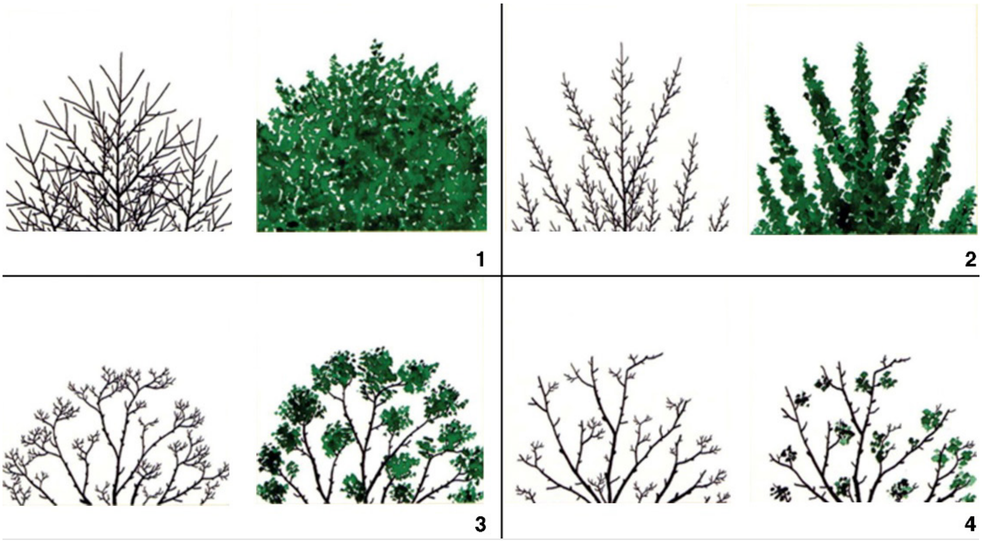

Fig. 1: Legend: physiological vitality phases, figure adapted from ROLOFF (2016), modified. The following physiological vitality scale was applied during field survey: 1 – optimal (= exploration phase), 2 – slightly reduced (degeneration phase), 3 – moderately reduced (stagnation phase); 4 – severely (resignation phase).

Data acquisition took place over two terms, the same as for the data acquisition using a drone. For all the trees in the model areas, a field dendrological survey was carried out in line with standard methodological procedures (PEJCHAL & ŠIMEK 2018). The basic dendrometric data was measured and recorded per each tree, taxon was determined (species), age class (scale applied: 1 – new planting; 2 – established young planting; 3 – maturing tree; 4 – mature tree; 5 – veteran tree) and physiological vitality was assessed.

3 Results

3.1 Datasets Characteristics

The subjects of the analysis are two datasets containing data from both days. Dataset 1 (Rybnicni) contains a total of 110 evaluated trees (Fig. 2); Dataset 2 (Zamek) contains 413 evaluated trees (Fig. 3). Trees in the undergrowth or trees for which it was not possible to determine the size of the crown were left out from the assessment. Both the datasets refer to managed park areas; unlike forest stands they are highly diverse in terms of deciduous and coniferous species. In Dataset 1 there are 35 species among overall 110 items (trees), in Dataset 2 it is 110 species among overall 413 items.

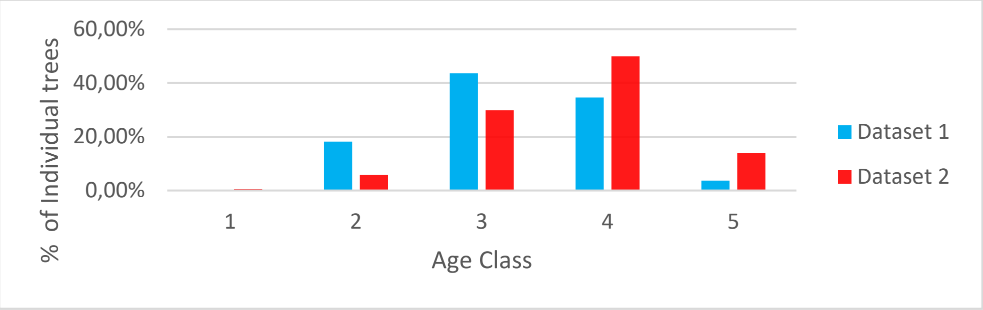

Fig. 2: Representation of age classes in the datasets 1 – new planting; 2 – established young planting; 3 – maturing tree; 4 – mature tree; 5 – veteran tree

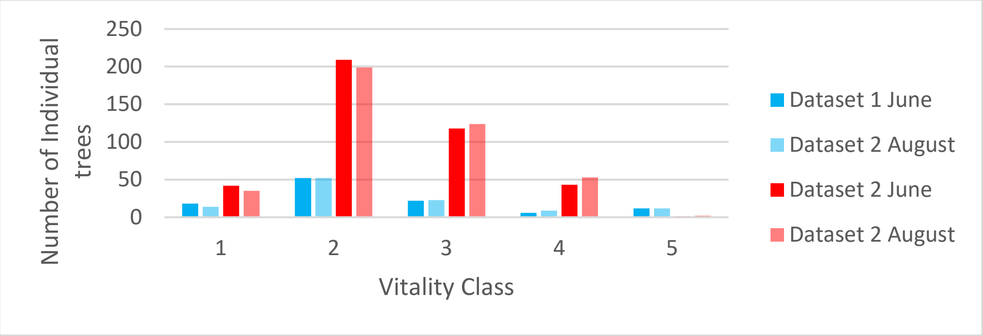

Fig. 3: Representation of physiological vitality classes in the datasets from field observation. The figure renders the shift between vitality classes during the vegetation season. The shift is apparent in dataset 2. Number of items in vitality class 1 and 2 decrease whereas the number of items in lower vitality classes.

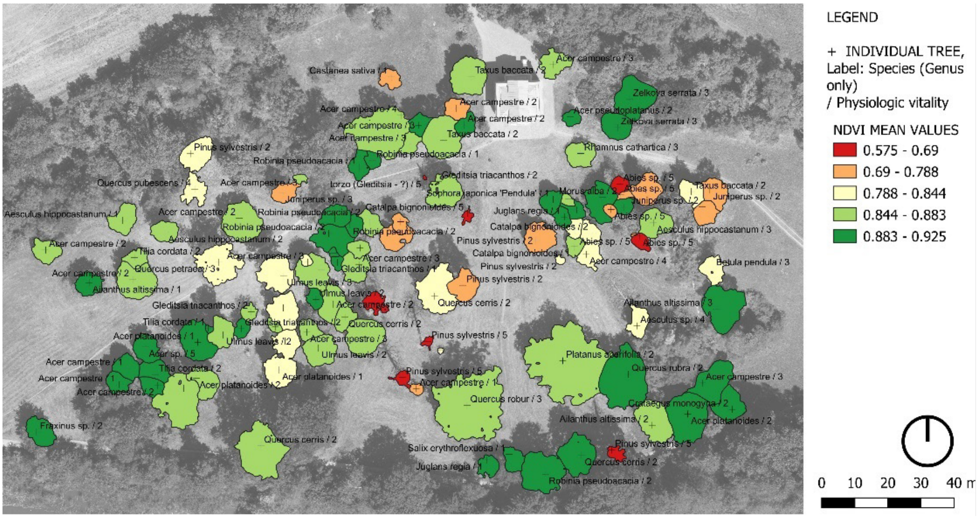

Fig. 4: Dataset 1 (Rybnicni) Mean NDVI values projected onto individual tree crowns

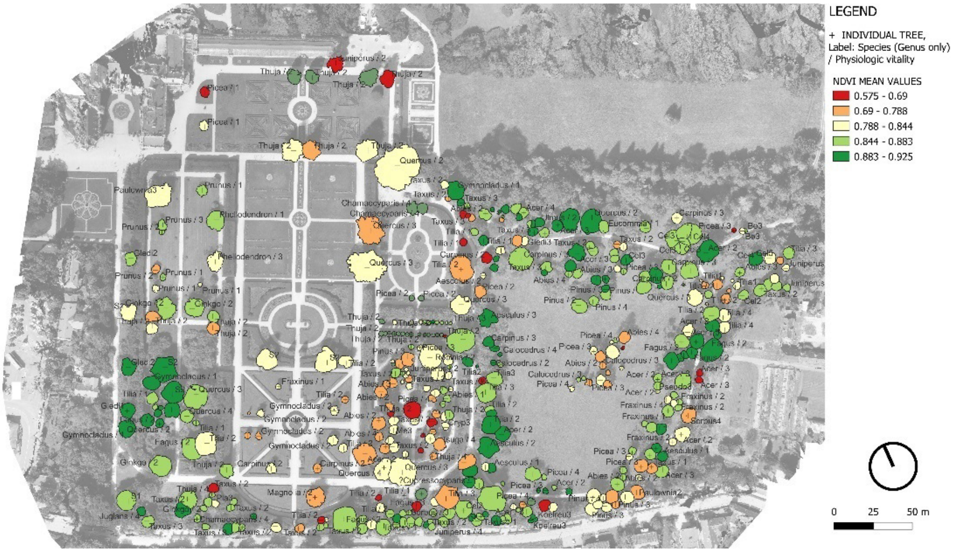

Fig. 5: Dataset 2 (Zamek) Mean NDVI values projected onto individual tree crowns

3.2 NDVI and Vitality Class Comparison

Average NDVI values were calculated for the individual trees and their crowns (see Fig. 4 and Fig. 5). These were then compared against the vitality scores observed in the field. The vitality classes are categorical data, therefore the ANOVA method was used for testing to check investigate the correlation between the vitality classes and NDVI (see Table 2). One-way ANOVA revealed that there was a statistically significant difference in mean exam score between NDVI and Vitality Class in all the examined datasets and dates ($p \leq 0.05$) see table

2. In Dataset 1 from 2 June the difference was at the lowest (p =0.02), but the correlation was confirmed. Average values show the lowest variability in subjects with physiological vitality, while physiological vitality values reach the highest variance. The NDVI values in relation to the observed physiological vitality are shown on Figure 6 and Figure 7. From the Figure 6 is apparent that the variance of the NDVI values is significant within the fifth vitality class.

Table 2: Descriptive statistics table for NDVI Values in all datasets and ANOVA results

					95% Confidence Interval for Mean				**ANOVA**	
	N	**Mean**	**Std. Deviation**	**Std. Error**	**Lower Bound**	**Upper Bound**	**Mini-mum**	**Maxi-mum**	**F Value**	**p**
Dataset 1 June	110	0.846	0.077	0.007	0.831	0.860	0.498	0.929	20.690	0.000
Dataset 1 August	110	0.815	0.092	0.009	0.797	0.832	0.431	0.910	31.950	0.000
Dataset 2 June	413	0.806	0.120	0.006	0.794	0.818	0.225	0.914	2.994	0.019
Dataset 2 August	413	0.806	0.070	0.003	0.800	0.813	0.476	0.917	15.620	0.000

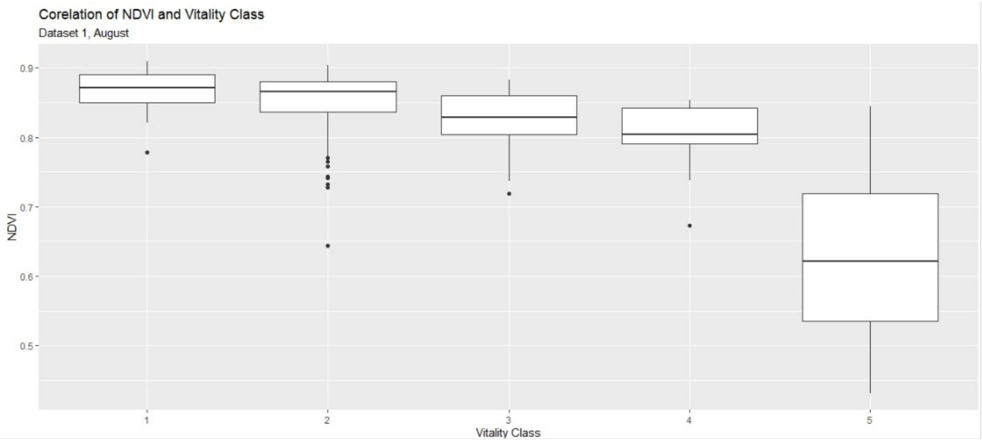

Fig. 6: Correlation of physiological vitality (Vitality Class) and NDVI values applied for whole dataset without species selected in Dataset 1 in August

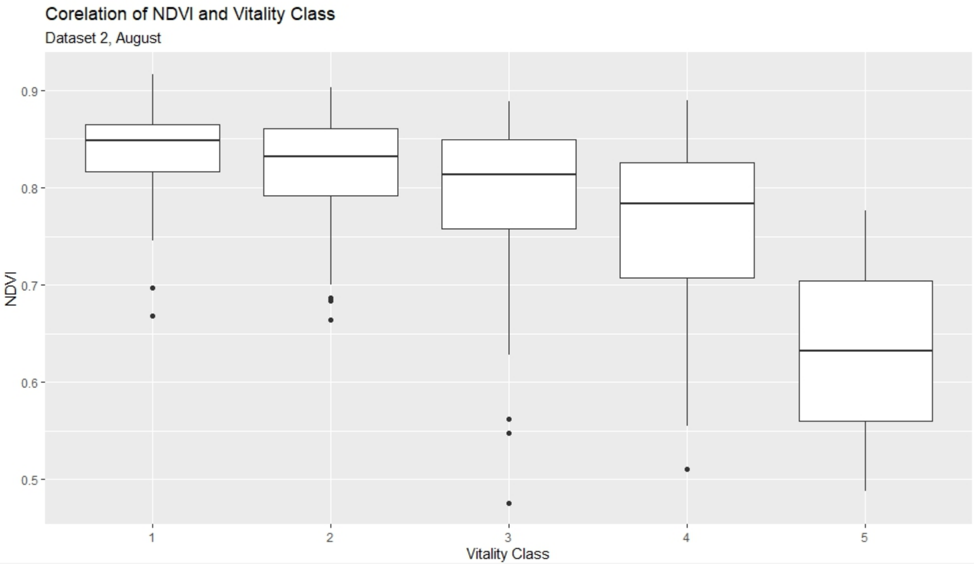

Fig 7: Correlation of physiological vitality (Vitality Class) and NDVI values applied for whole dataset without species selected in Dataset 2 in August

3.3 Prediction Model

The next step was to investigate the possibility of predicting vitality classes based on NDVI. Linear regression model, specifically the linear mixed model was used for the testing. Simple linear regression was used to test if NDVI significantly predicted Vitality Class. To obtain a better fit, individual trees were grouped by species (Genus, more precisely).

The coefficient of determination for prediction of NDVI based on vitality class was R2 = 77% (83% in June). This outcome indicates relatively good fit and prediction, since the perfect fit is R =100%.

However, for the purposes of tree vitality evaluation, Vitality Classes were used (ROLOFF 2016), whereby the model for prediction of the vitality class was used (Fig. 8). The determinant of correlation was significantly lower, R = 48 % which does not explain the variability in the extent required for individual tree evaluations.

Fig. 8: Mixed model fit for prediction of NDVI based on Vitality Class. Coefficient of determination is 77 %. Value 100% indicates that the regression predictions fit the data perfectly. The difference between the individual curves confirms differences in the NDVI values based on the tree genera. For Acer, the model predicts the highest NDVI values in all classes, whereas the Quercus genus received the lowest prediction.

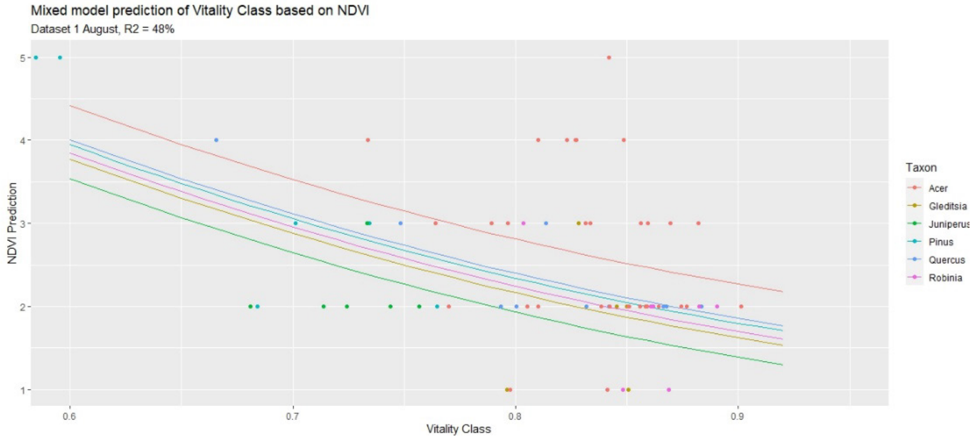

Fig. 9: Mixed model fit for prediction of NDVI based on Vitality Class. Coefficient of determination is 48 %. Value 100% indicates that the regression predictions fit the data perfectly. The difference between the individual curves confirms differences in the NDVI values based on the tree genera. The highest values are those for Acer, the lowest for Juniperus.

From the above, the following important conclusions emerge:

- The ANOVA statistical test confirmed the correlation between vitality measured using the Roloff method and the NDVI index measured using a multispectral camera from a low-flying UAV in both measurements (Fig. 6, Fig. 7).
- Prediction of the NDVI value using linear regression model based on vitality class explains the correlation at 77 % if the species are fitted separately (Fig. 8). But for the purposes of health assessment, the opposite prediction is required – vitality class based on NDVI.
- Prediction of vitality class by the NDVI value reaches only 48 % of determination coefficient (Fig. 8, Fig. 9). In order to predict the physiological vitality class, it is not possible to apply the linear regression model, and the solution tends to another regression method capable of classification based on multiple factors (e. g. Random Forest).
- The genus of the trees has a significant effect on the NDVI index value (Fig. 8, Fig. 9, curves for each species gain different values). A greater difference in the NDVI index between the individual vitality classes was recorded in the second half of the growing season.

4 Conclusion and Outlook

The development of the issue allowed the site and greenery managers to quickly source relevant and accurate data about the qualitative state of the trees by means of UAV and through interpretation of NDVI values. Based on this data it is possible to quickly plan the necessary management interventions such as:

- targeted complementary field research, implementation of maintenance interventions,
- additional watering of young trees, felling and removal of withering trees,
- early identification of outbreaks of diseases or pest infestations,
- potential recommendations for a change of species composition,
- modification of the tree stand structure.

Anyway, in the case of multi-species park areas the aggregated data without identification of the species is very difficult to use and cannot be utilised for supporting a reliable prediction. The application of UAV tends to use where species are identified based on field survey and physiological vitality is only monitored on a year-to-year basis. These applications presume a sufficiently robust prediction model (R2 >85 %), see (CAMPBELL et al. 2023, MAO et al. 2023), similarly as in prediction models that estimate quantitative parameters of trees (height, volume). The starting point is a sufficiently large digitized library of trees and seasonal NDVI manifestations, ideally during the growing season, allowing for a sufficient training of the model. The basis is a database of quality on-ground tree database with identified species, which allows for comparison with the remote survey. UAV surveying is time-consuming and is suitable for scanning individual objects or lower tens of objects per year. It is highly probable that this database will be created once satellite images are available (compare with BERRA, GAULTON & BARR 2017) an allow sourcing data units of higher order.

This application can be important in case of larger greenery objects where standard field research requires very long outdoor surveys and often exceeds the possibilities of the respective site managers. This includes larger landscape complexes, designed landscapes, parks, urban forests or various recreational greenery areas, but also tree alleys in the countryside, insulating green strips bound to highways, railways, etc.

The potential of UAV in near future, with regards to higher resolution than that of satellite images, lies in quick remote checks of the condition of newly planted tree stands, mainly associated with the need of additional watering. At a time of an ongoing climate change, the efforts of greenery managers and the need for ensuring a new stable generation of trees, this topic is becoming increasingly important.

In the future, with better resolution and availability of satellite data, knowledge gained through using methods based on UAV will allow for quicker deployment of methods of monitoring vegetation health in the everyday practice of landscape architects and greenery managers.

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