IMPROVING URBAN TREE SPECIES CLASSIFICATION WITH HIGH RESOLUTION SATELLITE IMAGERY AND MACHINE LEARNING

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ABSTRACT

In the context of climate change, reducing heatwave and air pollution are major challenges by using nature-based solutions. Urban greening helps to limit heat islands and promote resilience and trees also offer many other advantages in terms of making our cities more sustainable. This study explores the potential of multi-resolution imagery (Pléiades, PlanetScope and Sentinel-2) to map urban tree species in the Strasbourg Urban Area, France. We propose two object-oriented approach, one based on theorical crown buffer and the other on a watershed segmentation using a Random Forest algorithm to map the ten most representative tree species. Our results showed promising improvements in the overall accuracy and F1-Score of urban tree species classification using very high resolution imagery (Pleiades), high spatial resolution time series (PlanetScope and Sentinel). The method also successfully demonstrated a logical distribution of errors based on the trees intrinsic characteristics (species, distribution pattern, location) and the effect of data pre-processing. All these findings underscore the complexity of tree species classification in urban environments and suggest areas for future methodological enhancements.

***Index Terms*—** tree species, machine learning, PlanetScope, Pléiades, Sentinel-2, urban forestry

1. INTRODUCTION

Urban trees provide multiple ecosystem services such as pollutant filtering, local climate cooling, well-being enhancement through aesthetic qualities, and biodiversity support [1]. These provided benefits, however, depend on their species, planting methods, and geographical placement [2]. Identifying the species and locations of these trees then appears crucial to maximize this ecological contribution and understand how much trees are helping to improve our environment [3]. Providing such knowledge also helps urban planners and managers to update their local databases. Hence, it is really important to propose simple and robust methodological ways to figure out to achieve this purpose. To date, the majority of studies focus on the classification of tree species in forest areas rather than those within urban areas [4]. Indeed, the study of intra-urban trees can prove to be complex due to the highly heterogeneous nature of cities in terms of materials and surface reflectance. Trees also have very specific spatial organizations: they can be grouped in irregular spatial patterns, as well as being isolated [5]. Finally, due to local policies that can vary depending on the city, trees are subject to uneven pressure from their management (maintenance, pruning), which makes their identification and their monitoring even more complex [4].

With the increasing number of Earth Observation satellite missions, the availability of multi-resolution, multi-temporal, and multi-spectral imagery presents new opportunities for the classification of tree species. For now, most of the studies use high spatial resolution imagery (e.g. Sentinel-2 and/or Landsat) [6] to detect tree species over forest areas and very high spatial resolution imagery (e.g. Worldview, Pléiades and/or aerial imagery) [7] for urban tree species. Object-based approach has been used for individual tree classification in urban areas. In literature, this approach uses two mains machine learning algorithms: Support Vector Machine (SVM) and Random Forest (RF) [8]. The latter has proven his robustness for this task in many studies over the years.

In this paper, we explore the use of multi-resolution and time series imagery to classify urban tree species. Thus, we make the hypothesis that (1) the temporal and spectral depth of high-resolution imagery enhances classification results and that (2) an object-based approach using theoretical crowns is as effective as segmentation for urban tree species mapping. The findings will also provide additional insights related to the species and spatial organisation of our trees. To our knowledge, this study is the first one combining PlanetScope (Planet), Sentinel-2 and Pléiades imagery for tree species classification.

2. METHODOLOGY

2.1. Study Area and Datasets

The research was carried out in the metropolitan area of Strasbourg (Figure 1), located in northeastern France near the border with Germany. Local authorities have carried out very precise inventories of urban trees freely available

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through a tree database in the public domain (*Patrimoine arboré 2022 ©OpenDataStrasbourg*) with numerous attributes (e.g., crown size, species, planting date, etc.). It contains about 85,000 trees spread over the urban area. We choose to classify the 10 most representative species available, which represent more than 40% of the entire dataset (i.e. about 500 species).

First, we used images from the Sentinel-2 mission, a part of the European Space Agency's Copernicus program, that are freely accessible every five days. Sentinel-2A and 2B contain 13 spectral bands from the blue to the short-infrared spectrum. The spatial resolution of these images ranges from 10 to 60 meters based on the spectral band. We selected a single tile (T32UMU) covering the city and only kept the 10 high resolution spectral bands (10m and 20m). Throughout 2022, we had access to 22 cloud-free images of the study area.

PlanetScope imagery, managed by Planet Labs, originates from an extensive network of over 400 small CubeSats. These images are typically available daily with a spatial resolution of 3.125 meters. Our study employed the radiometrically and geometrically corrected Ortho Tile products from PlanetScope, which are readily obtainable via PlanetScope's data delivery API. We specifically gathered images from the most advanced SuperDove (PSB.SD) satellites, chosen for their spectral compatibility with Sentinel-2, as evidenced by their closely matched and correlated surface reflectance. The 4-band products were considered suitable for our analysis. In the year 2022, we compiled 53 cloud-free images over our study area. Both datasets were processed to reflect top of atmosphere correction levels.

Four high-resolution Pleiades satellite images were utilized, captured on January 12, April 18, June 30, and August 7, 2022. Each of these acquisitions presents very high spatial resolution imagery at 50 cm. The dataset comprises both panchromatic and multispectral images, offering detailed spectral information across multiple bands. We performed pan-sharpening to fuse multispectral bands with the panchromatic band at 50cm spatial resolution.

2.2. Object-Based Classification Framework

In our study, two distinct approaches were implemented to prepare the data for the Random Forest classification. The first approach is only based on the theoretical crown buffer. Here we assumed that the size of the crown in the database reflects the actual canopy size on the ground, allowing us to create a buffer zone around each tree with this value. The second is based on watershed segmentation. This technique involved delineating the extent of each tree canopy by analyzing the spatial patterns and gradients within the very high resolution satellite imagery. This segmentation was performed over the Pléiades summer acquisition of 30 June 2022 with a depth threshold parameter set to 0.0001 and the flood level parameter set to 0.001 to have multiple segments of each tree

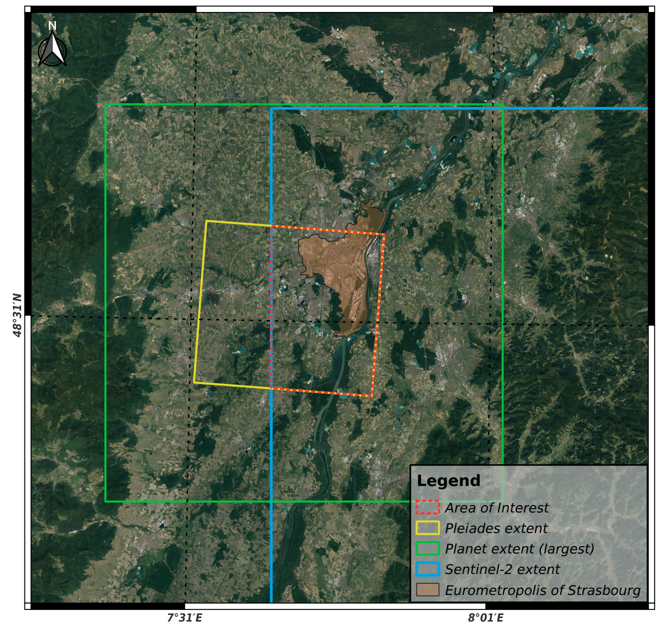

Fig. 1. Study area and satellites extent (Coordinates in WGS84).

and ensure that the crown is correctly segmented. These parameters have been set after several tests. Then, we intersect these segments with the buffered theorical crowns (based on the crown diameter defined in the tree database) to get the segments of each individual trees.

For the classification of urban tree species, we employed a Random Forest (RF) algorithm, renowned for its robustness and efficacy in handling complex datasets like those derived from remote sensing imagery. A Random Forest consists of a multitude of decision trees, each constructed on a random subset of the training data, and outputs the mode of the classes as the prediction. This ensemble approach not only improves prediction accuracy but also controls overfitting, making it ideal for our analysis.

Our implementation of the Random Forest algorithm involved 1000 estimators, which is a significant number that helps in capturing the complexity and diversity of the data while still maintaining computational feasibility. The algorithm was applied to the zonal statistics of our dataset, extracted from two distinct methodological approaches: the theoretical crown buffer and the watershed segmentation approach.

In calculating the zonal statistics, we chose to use only the median value. The median is less sensitive to outliers compared to the mean and is particularly adept at mitigating the influence of non-tree elements within the zone, such as roads or buildings, which can have significantly different reflectance values. By focusing on the median, we aimed to capture the central tendency of the reflectance values that are most representative of the trees themselves, thus enhancing the likelihood that the RF model would learn to recognize the spectral signatures characteristic of different tree species.

2.3. Test protocol and quantitative evaluation

To assess the performance of both approaches (Table 1), six test scenarios (*Seg1* to *Seg8* for *watershed* segmentation and *TC1* to *TC8* for theoretical crown buffer approach) were devised, incorporating different combinations of sensor data (10 bands at 10m for Sentinel-2 and the four spectral bands for Pléiades and PlanetScope) and spectral indices (NDVI for all images) or exogenous data such DSM, *Digital Surface Model*, calculated with DSM-OPT[9] from tri-stereoscopic Pléiades imagery.

The classification results (Table 2) have been assessed through *precision*, *recall*, and *F1-Score* metrics. In this paper, we only reported the *F1-Score*. Other metrics are available through our research project webpage[1].

Table 1. Overview of test protocol for Urban Tree Species Classification

Scenario	Sensors Used			NDVI/DSM	
	S2	Pléiades	Planet	NDVI	DSM
1 (Seg1, TC1)	✓	✓	✓	✓	✓
2 (Seg2, TC2)	✓	✓		✓	✓
3 (Seg3, TC3)		✓	✓	✓	✓
4 (Seg4, TC4)		✓		✓	✓
5 (Seg5, TC5)	✓			✓	
6 (Seg6, TC6)			✓	✓	
7 (Seg7, TC7)	✓	✓	✓		
8 (Seg8, TC8)	✓		✓		

3. RESULTS

The watershed segmentation approach (Seg1 to Seg8), while effective, demonstrated the inherent complexities of segmenting individual trees in the heterogeneous urban fabric. The highest F1-Scores (Table 2) were observed for Platanus acerifolia (0.8966) using watershed segmentation and the same species also showed strong performance with the theoretical crown approach (0.9013). These results reflect the adaptability of Random Forest algorithms to the structured data provided by both segmentation and crown buffer approaches.

In the theoretical crown buffer approach (TC1 to TC8), the classification accuracy (0.7296) and weighted F1-Score (0.7235) marginally surpassed those obtained from watershed segmentation (Table 2). This suggests that when precise tree databases are available, as is the case with the data provided by the Strasbourg urban area, the need for preliminary segmentation can be bypassed, thereby streamlining the classification process. The F1-Scores provide a nuanced picture, especially when considering the close performance between certain tests such as Seg5/TC5 using Sentinel-2 imagery and Seg6/TC6 using PlanetScope imagery. This suggests that in the absence of accurate tree databases, as is the case with the data provided by the Strasbourg urban area, preliminary segmentation can produce a similar result. This eliminates the need for tedious and costly fieldwork, while streamlining the classification process. In private areas, where there is often no validation data, segmentation could prove even more useful. The F1-Scores provide a nuanced picture, especially when considering the close performance between certain tests such as Seg5/TC5 using Sentinel-2 imagery and Seg6/TC6 using PlanetScope imagery. Sentinel-2's spatial resolution of 10 to 20 meters, compared to PlanetScope's finer 3-meter resolution, suggests that higher spatial resolution does not automatically translate to significantly better classification outcomes in this context. It should be noted that this conclusion is reached ignoring the heterogeneity of PlanetScope acquisitions in terms of view and solar angles. For instance, the F1-Scores for watershed segmentation (Seg5) and theoretical crown buffer (TC5) using Sentinel-2 data yielded results that are in close range to those obtained from PlanetScope data in Seg6 and TC6 scenarios. This is noteworthy, as one might expect the finer spatial resolution of PlanetScope imagery to outperform the coarser Sentinel-2 data, yet the results are strikingly similar. One explanation for this phenomenon could be the spectral depth offered by Sentinel-2 imagery, which includes 10 bands and particularly emphasizes the near-infrared spectrum, a critical component for vegetation analysis. This spectral richness likely compensates for its coarser spatial resolution by providing more detailed spectral information which is essential for species-level differentiation.

4. CONCLUSION

Our research has demonstrated the value of combining multiresolution and multi-temporal data for mapping tree species. In this study we show that if tree data is available, it is sufficient to use it to implement a method for classifying tree species on an urban scale. However, the watershed segmentation method still holds substantial value, particularly for its potential applicability to other cities or private areas where similar detailed tree databases may not be available. This method can be utilized to infer models based on the spatial organization and spectral signatures of urban trees, allowing for the extrapolation of the classification model to other urban settings.

Overall, our findings illustrate that the choice of classification approach should be guided by the availability and quality of data. The use of a theoretical crown buffer approach where detailed data exists can yield high classification accuracy, while watershed segmentation remains a robust alternative for broader applicability across different urban landscapes, even if the calculation time could be slightly higher.

[1] http://romainwenger.fr/treesML/index.html

Table 2. F1-Score for tree species classification using a *watershed* segmentation (Seg$n$) and theoretical crown (TCn)

Tree Species	**Seg1**	**Seg2**	**Seg3**	**Seg4**	**Seg5**	**Seg6**	**Seg7**	**Seg8**
Aesculus hippocastanum	0.8280	0.7993	**0.8339**	0.7577	0.7308	0.7905	0.8041	0.7834
Acer pseudoplatanus	**0.6532**	0.6502	0.6454	0.5359	0.5923	0.6011	0.6325	0.6146
Tilia cordata green spire	**0.6429**	0.6387	0.6061	0.4706	0.6209	0.5586	0.6246	0.6087
Tilia x euchlora	**0.7015**	0.7006	0.6897	0.6417	0.6708	0.6585	0.6916	0.6811
Platanus x acerifolia	**0.8966**	0.8908	0.8867	0.8541	0.8278	0.8552	0.8903	0.8697
Tilia cordata	**0.5844**	0.5841	0.5256	0.4258	0.5390	0.4637	**0.5844**	**0.5844**
Acer platanoides	0.5613	**0.5842**	0.5541	0.4527	0.5007	0.4987	0.5442	0.5344
Fraxinus excelsior	**0.6855**	0.6790	0.6781	0.5167	0.6552	0.6475	0.6952	0.6847
Prunus avium	0.6258	**0.6538**	0.5724	0.4800	0.5667	0.5443	0.5948	0.5948
Acer campestre	0.6434	**0.6578**	0.6319	0.4762	0.6507	0.6281	0.6324	0.6307
Accuracy	**0.7249**	0.7236	0.7119	0.6307	0.6769	0.6772	0.7140	0.7012
Weighted F1-Score	**0.7192**	0.7185	0.7051	0.6192	0.6675	0.6679	0.7074	0.6940

Tree Species	**TC1**	**TC2**	**TC3**	**TC4**	**TC5**	**TC6**	**TC7**	**TC8**
Aesculus hippocastanum	**0.8459**	0.8268	0.8454	0.7524	0.7553	0.8014	0.8176	0.8205
Acer pseudoplatanus	**0.6335**	0.6167	0.6184	0.5283	0.5479	0.5745	0.6127	0.6015
Tilia cordata green spire	0.6214	**0.6458**	0.5505	0.3875	0.6273	0.5411	0.6258	0.6286
Tilia x euchlora	0.7086	**0.7102**	0.7002	0.6379	0.6615	0.6680	0.6999	0.6824
Platanus x acerifolia	**0.9013**	0.8919	0.8982	0.8461	0.8280	0.8774	0.8902	0.8692
Tilia cordata	0.6187	**0.6328**	0.5714	0.5266	0.5786	0.5034	0.6220	0.6095
Acer platanoides	**0.5499**	0.5247	0.5306	0.4499	0.5068	0.5069	0.5337	0.5455
Fraxinus excelsior	0.6817	0.6391	0.5858	**0.6877**	0.5891	0.6584	0.6574	0.6442
Prunus avium	0.6540	0.6332	0.6254	0.5016	0.5897	0.5890	0.6538	**0.6555**
Acer campestre	0.6898	0.6720	0.6559	0.4873	0.6613	0.6356	**0.6938**	0.6774
Accuracy	**0.7296**	0.7185	0.7165	0.6366	0.6715	0.6870	0.7178	0.7080
Weighted F1-Score	**0.7235**	0.7115	0.7083	0.6234	0.6613	0.6771	0.7113	0.7011

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