MONITORING *TOUMEYELLA PARVICORNIS* (COCKERELL) (HEMIPTERA: COCCIDAE) INFESTATION ON COASTAL AND URBAN *PINUS PINEA* L. STANDS THROUGH INTEGRATION OF REMOTE SENSING AND *IN SITU* DATA

Valentina Falanga, Saverio Francini, Francesco Parisi, Bruno Lasserre, Gherardo Chirici, Marco Ottaviano, Marco Marchetti

Abstract: Urban forests are particularly significant as they enhance quality of life by fostering social connections and improving physical and mental health. They also reduce pollution, lower heating and cooling costs, increase real estate values, and help mitigate climate change. Effective management and maintenance of urban forests are crucial to ensure these benefits continue. Consequently, the management of urban green areas is even more important, increasingly subjected to external pressure, yet they represent the few remaining comfortable areas in the city and guarantee the maintenance of urban biodiversity. There are numerous potential disturbances that can jeopardise the existence of urban green areas. This study focuses on the urban area of the city of Rome, where the *Pinus pinea* population is attacked by the scale insect *Toumeyella parvicornis*, which is undermining its existence. This research studies PlanetScope images from 2019 to 2023 with the objective of evaluating the effectiveness of remote sensing in studying this phenomenon.

Keywords: Pests, Urban forests, Monitoring, PlanetScope

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Introduction

Based on CORINE Land Cover plus (CLC+) Backbone 2018, a geospatial component of the CLC+, (EEA, 2022), the Italian area occupied by needle-leaved trees is approximately 1 650 000 hectares. Of these, about 240 559 hectares are classified as Mediterranean pine forests, divided between *Pinus pinaster Aiton* forests (64 701 ha), *Pinus pinea L.* forests (48 123 ha), and *Pinus halepensis Mill.* (114 713 ha), according to the 2015 INFC inventory (INFC2015) Throughout the Mediterranean area stone pine forests *P. pinea* are distributed in a fragmented manner, covering approximately 650 000 hectares and ranging from sea level to an altitude of 1000 meters. *P. pinea* is particularly concentrated on the Iberian Peninsula, as well as the coasts of France and Italy [1]. Maritime *P. pinea* forests (the ones located in coastal areas) are often found near heavily developed areas. This is due to historical factors that encouraged the planting of pine forests near marshy areas to enhance their soils and protect inland crops [2]. Additionally, the greater concentration of land consumption and human activities along coastal areas also contributes to this phenomenon [3]. Pine forests, mainly the ones in coastal areas, are threatened by several factors, anthropic (tourism, infrastructure and building activities), biotic (parasite attacks, nutrient unavailability) [4] [5] and abiotic (fire, drought, structural problems). In Rome, *P. pinea* forests are under threat from the *Toumeyella parvicornis* (Cockerell) (Hemiptera: Coccidae). The origins of this scale species are from North America and then it expanded to the Caribbean region and Europe [6]. It was first detected in Italy in 2014 (specifically in the regions of Abruzzo, Campania, Lazio and Apulia) and is under the official control of the EFSA Panel on Plant Health. The alien pest produces sticky honeydew related to feeding activity, this causes the development of sooty moulds that cover branches and needles. Attacked plants suffer yellowing, reduced growth, phylloptosis, decline and death [7]. In addition to the spread of this alien species across Europe due to globalized world trade, global warming contributes to its proliferation [8]. At the end of 2014, the tortoise pine scale *T. parvicornis* was recorded in Italy (Naples) for the first time [9]. In 2018, *T. parvicornis* was also reported in Rome and led to the decay and death of many plants around central and south Italy [10]. In this study, PlanetScope imagery was trialed for urban forest monitoring due to its ability to offer reliable, detailed images, which higher resolution satellites like Sentinel-2 could not provide due to mixed pixel effects.

The aim of this study is: i) to test the investigation sheet employed in the ground surveys; ii) to evaluate the effectiveness of the PlanetScope satellite constellation images to monitor damages caused by the attack of *Toumeyella parvicornis* on *Pinus pinea* in Rome; iii) to identify the advantages and criticalities of monitoring with high resolution satellite images forest disturbances occurring in urban areas.

Materials and method

The municipality of Rome is the area where the study is being conducted. It has a public space incidence of 3.7 %, approximately 48 km^2 [11], allocated among equipped green areas, historical archaeological parks, and large urban parks.

Moreover, Protected Natural Areas and Nature Reserves fall partially within the municipal territory. A preliminary analysis revealed that the large historic villas had the highest concentration of *Pinus pinea*. However, some public parks and other green areas were also included in the study: in these green spaces more uniform coverage of the same arboreal species can be found. Considered areas were chosen to cover different quadrants of urban territory, and they also respond to different characteristics: the density of crown coverage, homogeneity of species, and the dimension of crown coverage. Sites for analysis are selected inside the area delimited by Ring Road A90, more densely populated and urbanized.

Figure 1 – Sites for surveys chosen inside the area delimited by Ring Road A90.

Surveys were conducted between June and August 2023 at the selected sites. Each inspection entailed, using the Qfield app (Figure 2), the georeference and completion of the identification sheet for each individual plant.

In this study the method used for assessing tree condition is a qualitative method: the variables were evaluated on a scale ranging from ‘not degraded’, 'little degraded', ‘moderately degraded’, ‘very degraded’ to ‘completely degraded' but transposed numerically in percentage of degradation to facilitate subsequent analysis. The form includes five variables: two related to sooty mold (presence and quantity), two related to tree crown (desiccation and density), and one related to the overall vitality of the plant. The first four parameters were evaluated in percentage intervals of 0 %÷20 %, 20 %÷40 %, 40 %÷60 %, 60 %÷80 %, 80 %÷100 %; the last one, which pertains to the overall evaluation of the plant’s health, was rated with a score ranging from 1 to 5.

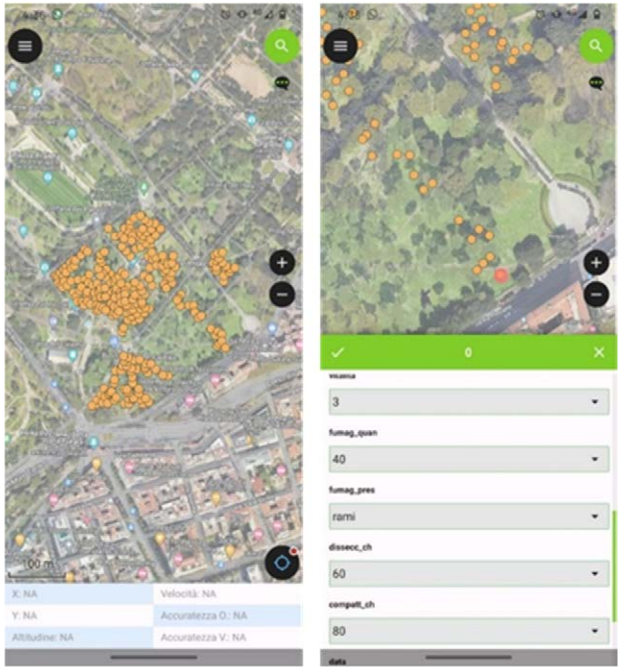

Figure 2 – Qfield app screen through which it was possible to georeference each point and fill in the corresponding evaluation form.

AREA:			DATE:	
Overall plant vitality:				
1	2	3	4	5
notes:				
Sooty mold presence:			rami	tronco
Sooty mold quantity:				
20%	40%	60%	80%	100%
notes:				
Tree crown desiccation:				
20%	40%	60%	80%	100%
notes:				
Tree crown density:				
20%	40%	60%	80%	100%
notes:				

Figure 3 – Evaluation sheet used for surveys. This sheet was digitalised and filled through the app Qfield

Table 1 – A list of the areas visited, accompanied by dates of surveys and plants surveyed within each area.

Name of area	Number of surveyed trees	Surface	Date of survey
Parco degli acquedotti	130	240 ha	16-29/06/2023
Villa Ada	30	160 ha	21/06/2023
Parco Don G. Alberione	16	0.7 ha	23/06/2023
Villa Borghese	340	80 ha	21/06 - 29/07 - 27/08/2023
Area verde via D. Campana	10	2.4 ha	07/06/2023
Via delle Terme di Caracalla	106	600 m	17/06/2023
Parco G. Sbragia	47	4 ha	23/06/2023
Parco E. Corizza	16	4.2 ha	06/06/2023
Villa Glori	202	23 ha	21/06 - 22/07/2023
Villa Lazzaroni	37	6.5 ha	18/06/2023
Parco Papacci	49	11 ha	10/06/2023
Villa Pamphili	574	185 ha	27/06 - 11/07 - 23/07 - 28/07 - 10/08/2023
Parco Petroselli	19	13 ha	07/06/2023
Parco Don Giovanni Scorza	40	1 ha	16/06/2023
Pineta Sacchetti	331	5 ha	27/06 – 08/08/2023
Trees along the road in the Saxa Rubra area	41	220 m	10/06/2023
Giardino Aldo Tozzetti	7	2.5 ha	07/06/2023
Parco Tor Tre Teste	28	54 ha	07/06/2023

The fully digital data recording methodology enables direct use of these data on specific software (Qgis and Google Earth Engine). As can be seen in Table 1 the number of plants in selected areas is variable, as is the surface of each area.

As the insect has infested all green areas of Rome, a control area was established outside the city in a section of the San Rossore pine forest, that had not yet been attacked by the insect.

In this study, we used PlanetScope nano-satellite images acquired between 2019-07-15 and 2023-07-15 and including 12 bands: four spectral bands (3 m spatial resolution) and eight quality bands. These images derive from the second generation of PlanetScope satellites (PS2.SD), available from 2019. The four spectral bands are:

Blue	464 ÷ 517 nm
Green	547 ÷ 585 nm
Red	650 ÷ 682 nm
NIR	846 ÷ 888 nm

The height quality bands were used to mask out clouds and noise from the images. Specifically, the height quality bands include the following information: “Band 1: clear mask; Band 2: snow mask; Band 3: shadow mask; Band 4: light haze mask; Band 5: heavy haze mask; Band 6: cloud mask; Band 7: confidence; Band 8: unusable data mask” [12]. Images were coregistered using the PlanetScope coregistration tool, which allows for spatial alignment of a series of images in a specified time series. The order, and thus the coregistration, the clipping, and the downloading of the imagery was performed in sequence for the 21 different study areas (Figure 1). This was important as to properly apply the coregistration tool there must be a consistent overlapping between different PlanetScope scenes and thus small study areas are needed. The final resulting number of downloaded coregistered and clipped imagery was 30 481.

A selection of areas, for subsequent analysis, was made based on the number of plants present in each area to ensure a sufficient sample size for defining area characteristics. The threshold for selection was 40 plants. For a preliminary study three areas were considered to test the process, calculated between August 2021 to August 2022. Once the band values had been obtained for each point surveyed, the vegetation indices were calculated. The results were aggregated by area, in order to have a single value for each site. First, a comparison was made between some of the most commonly used indices for detecting vegetation disturbances, based on the availability of the bands provided by PlanetScope [12]. The following indices were calculated: NDVI ($(Nir - R) / (Nir + R)$); RDVI ($(Nir - R) / (Nir + R)^{0.5}$); SAVI ($(1 + L) x (Nir - R) / (Nir + R + L)$ where L=0.5); and SIPI ($(Nir – B) / (Nir + B)$).

Although all the indices showed the same trends (except for SIPI), RDVI was the most effective in highlighting differences between chosen areas. Therefore, it was chosen for successive analyses. For the definitive study, the RDVI was calculated for the longest possible period permitted by PlanetScope images, spanning from July 2019 to July 2023, across all selected areas.

The index's behavior over time was analysed by aggregating the data monthly, averaging the monthly values of all the plants belonging to the area considered. This level of aggregation was chosen in order to allow a more immediate comprehension of the index trend. When aggregating at a daily level, making the daily average for each plant belonging to the area, the data oscillation is too high, making it more complex to visualise the trend.

Figure 4 – Images of some areas: a) medium health status (Villa Borghese), b) bad health status (Pineta Sacchetti), c) branch with *T. parvicornis*

Results

The graphs below show the results of the preliminary study in which 3 areas were analysed over a 12-month period. As mentioned above, the use of RDVI was chosen because of its ability to better discriminate the differences between the areas.

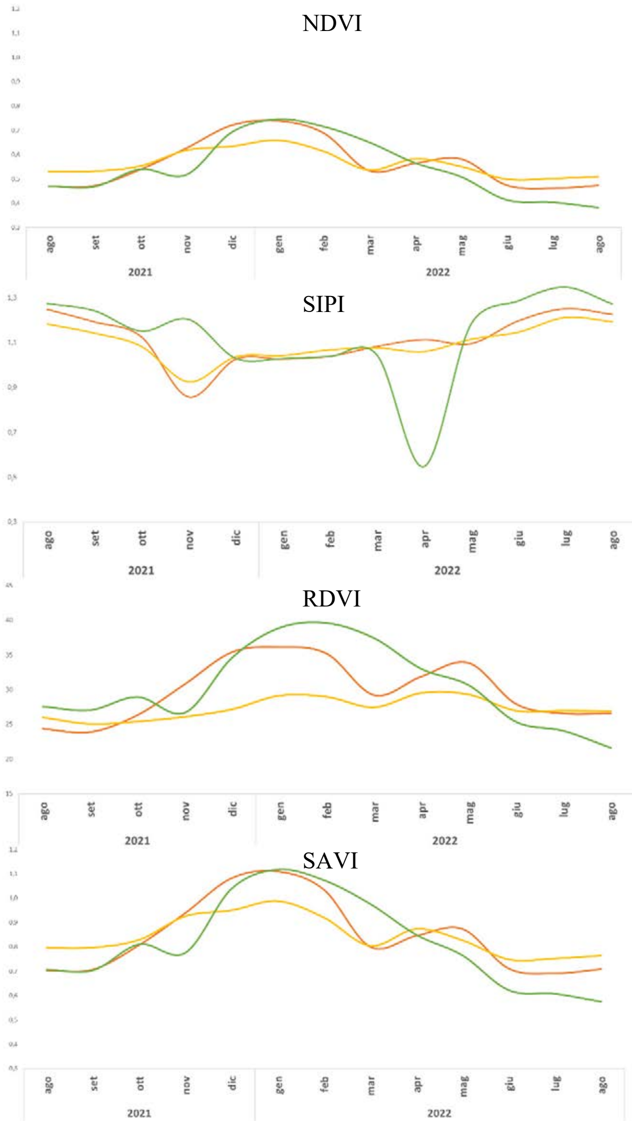

Figure 5 – Preliminary study on three areas to test the effectiveness of indexes: Pineta Sacchetti (green), Villa Glori (yellow) and Villa Borgese (orange). The evaluation period is 12 months (August 2021 – August 2022).

In the second phase of the study, the index was analysed across all areas surveyed. Figure 6 illustrates the average value for all areas, treated as a single zone, which declines during the spring-summer period each year.

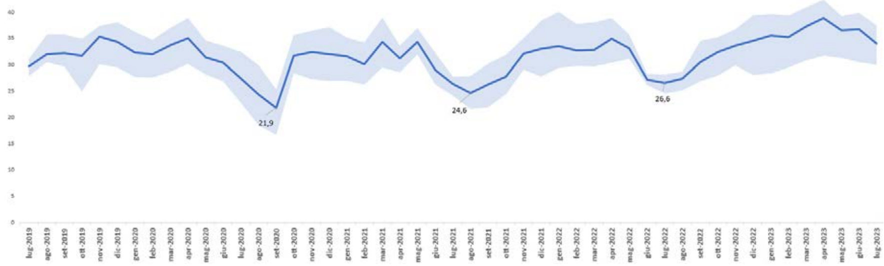

Figure 6 – Average RDVI of visited areas (gray part: range of maximum and minimum values assumed by the index)

The development (Figure 7) of the individual areas (shown in grey) and the selected control area were also examined. It is evident that the index trend of the control area differs from that of the areas attacked by *Toumeyella*; it does not exhibit a pronounced decline during the summer months, maintaining a relatively consistent level of activity. Over the considered period, numerous felling operations have been carried out, particularly of dead trees. This is due to the risk that trees in urban areas represent to public safety [13]. In the surveyed areas, a total of approximately 250 dead and cut trees were counted. These situations were, however, excluded from the analysis, to ensure that the described trend is not influenced by them.

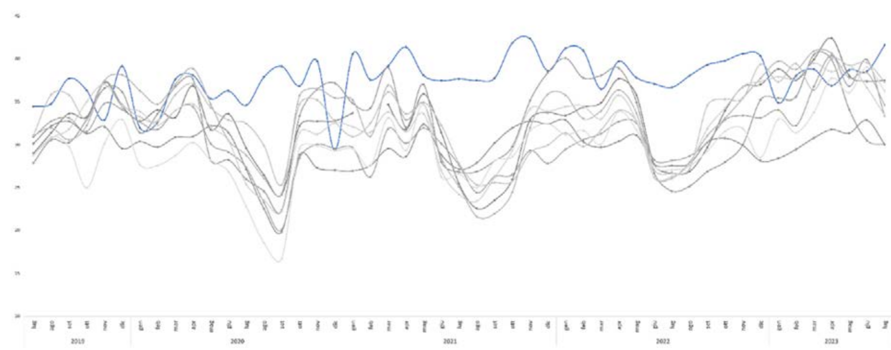

Figure 7 – Average RDVI of each visited area (gray) and control area (blue).

Discussion

In order to gain insight into the trend of the RDVI index of the attacked areas, it is essential to consider the ovideposition periods of *Toumeyella parvicornis*. As Garonna P. observe, three ovideposition cycles occur, the first between the second half of April and May, the second between July and early August, and the last between September and November. Between late spring and early autumn, the pathogen attack is continuous and debilitating for the plant, which has no time to recover. This can be observed in the trend of the RDVI, which shows a dramatic drop between May and September in all the visited areas. The efficiency of remote sensing, as shown in previous studies [14,15], is proved by the evidence of data, that shows the consistent damage inflicted on plants during the aforementioned period. Extracting data from remotely sensed PlanetScope imagery, allowed the calculation of vegetation indices to assess plant health over a long period of time, as shown by D'Amico et al., Dalponte et al., Shi et al. [10,16,17]. Comparing healthy areas with areas attacked by the insect (an approach also used by Wulder [18]), it was found that the values in the first one, do not decrease over the period indicated but remain relatively stable throughout the time period analysed. This provides to accentuate the periods of decline in the attacked areas with greater clarity.

It can be observed even that the deterioration tends to gradually decrease over time. A comprehensive analysis of the data reveals that the index reached a value of 21.9 in 2020, 24.6 in 2021, and a minimum peak of 26.6 in 2022 (Figure 6). It is possible that this trend of lower peaks is due to the implementation of a massive endotherapic treatment campaign throughout the municipality of Rome since the autumn of 2020 [19]. Unfortunately, no information on the endotherapy cycles was available for this study, (including the type of products used and the timing of treatments). This information will be essential in order to better understand the results in more detail. It would also be beneficial to reflect on the observation period. It is recommended that the observations be extended to encompass the years preceding and following the attack, in order to facilitate a more accurate assessment of the dynamics. This final point is directly related to the necessity of identifying high resolution images that extend back in time to a sufficient extent.

Conclusions

This research was conducted to test the use of remote sensing in the monitoring of *T. parivcornis* in an urban area. It is, indeed, the first study on urban green areas in the city of Rome (if we exclude the ones on the Castelfusano pinewood) affected by the parasite, investigated through very-high-resolution satellite images. The study demonstrates the efficacy of vegetation indices to clarify the impact of *Toumeyella* on *Pinus pinea*. This was achieved through the utilisation of high resolution PlanetScope images, which enable the analysis of highly detailed data across 4 spectral bands. Additionally, the research underscores the significance of direct field assessment and the subsequent generation of a ground-truth layer, which serves as a pivotal foundation for the following remote sensing phase.

In order to effectively counteract the invasion of *Toumeyella parvicornis*, further studies in this direction are still required. As future developments, it would be interesting to develop a technique for identifying markers that allow for intervention before plant death occurs. The sharing by stakeholders of additional information about the plants' health prior to the attack and the timing of treatment cycles could enhance the interpretation of the phenomenon's dynamics. Moreover, continuing ground surveys annually will increase the database and knowledge of the current state of the plants, which is fundamental for refining remote sensing work and obtaining more accurate results.

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