

Early Detection of Decline in Tree Health. Could the Pace of Stem Water Be an Effective Indicator? [†]

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Abstract: The health and vitality assessment of each single tree is one of the most important actions for an optimal urban forest management program. The development of new technology able to continuously monitor the tree vitality and underlying trends, could help reduce the frequency of the monitoring assessment and help overcome problems related to the rapid decline in tree health. Our aim was to test the suitability of point dendrometers in evaluating the tree vitality trend through high resolution stem cycle analyses. To achieve this objective, we installed point dendrometers on twelve *Pinus radiata* each currently in one of three defined vitality classes (alive, compromised, and dead) growing in an urban area. The stem cycle analysis approach was used to synchronize dendrometer signals with the stem water status and temperature. Our results showed that both, the trend of stem growth (GRO) and the time lag between the occurrence of the minimum temperature and the onset of the stem shrinkage, are all promising indicators of tree vitality in *Pinus radiata*. These parameters could be integrated in network systems able to send “early alerts” to experts. It could allow them to keep multiple trees under continuous monitor and control simultaneously, and reduce costs due to the reduced monitoring visits.

Keywords: tree stability; dendrometers; stem radial growth; urban forestry; VTA; *Pinus radiata*

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1. Introduction

Urban trees grow under the pressure of recurrent biotic and abiotic stressors and their vitality assessment represents one of the most important proxies of their stability. In accordance with the visual tree assessment (VTA) procedure, after an inspection visit, the experts release a report where each tree is assigned to a risk class. The risk class determines the frequency of the future monitoring visits [1]. Such “calendar approach” to define the frequencies could induce performing visits not really necessary or suggest visit intervals that are not adequate for detecting a sudden drop in tree vitality mostly for the vulnerable tree species, which are expected to suffer due to the fast microclimate warming and the pest diseases increasing in urban areas. In this frame, the development of a non-destructive technology able to follow remotely and in continuous the tree vitality trend, would be desirable [2].

The cell water status is the most important parameter driving cell division and expansion [3] and the hydraulic failure of the xylem is thought as the main mechanism leading a tree to death [4]. In the last years, the urban visual vitality index was significant related to the leaf water status in *Elms* hybrids [5], oaks species [6,7], and *Platanus × acerifolia* [8], whilst tree vitality declining was positively related to the increasing xylem

embolism events in holm oak [9]. These results show that tree vitality could be usefully monitored through high resolution analyses of the tree water status.

Point dendrometers have been widely used to monitor stem growth and phenology in forestry, as well as to drive irrigation scheduling in woody crops [10–14]. Such instruments provide, by daily high time resolution dendro data recording, a typical bell-shaped pattern (reversible changes). The stem shrinkage phase (i.e., decrease of the stem radius) occurring during daylight shall be borne by the mirroring water loss occurring within storage compartments (bark and phloem) to support the increased water demand due to the crown transpiration rate. The stem swelling (i.e., increase of the stem radius) is rather mainly driven by the refilling processes of the stem water reserves occurring during nighttime. In the last years, a few algorithms, based on stem cycle analyses, were developed with the aim to extrapolate the amplitude and duration of “dendro phases” as shrinkage and swelling from each diurnal cycle [15]. Synchronization of “dendro phases”, with the temperature and tree water status has allowed correlating the amplitude and timing of stem shrinkage with a sap flow and canopy transpiration in olive [12], and poplar [14,16]. These results highlighted the strength of “dendro phases” as reliable proxies of the stem water status in these species.

In this context, a general question arises: Can the diurnal stem variation represent a suitable proxy of the tree vitality? To address the question, we installed point dendrometers on mature *Pinus radiata* trees growing in urban areas and assigned them to a contrasting vitality class. The dendrometer outputs were analyzed by a stem cycle analyses approach in order to find the relationship among the trend of stem growth, tree vitality and “dendro phases” features (amplitude and duration). We assumed that in compromised up to dead trees, a progressive decline of the hydraulic system efficiency determining a progressive decrease of stem radial and axial water fluxes is in place, as well as canopy transpiration. Following this decline gradient, the stem radius variation would arrive in dead trees, to be guided only by environmental rather than physiological signals.

In this frame, we would like to verify the above hypothesis, i.e., that the duration and amplitude of “dendro phases” in trees belonging to compromised and dead classes, are mainly induced by the physic effects of wood temperature variation rather by the radial water fluxes.

The point dendrometers, especially in urban contexts, can be easily integrated in wireless systems enabling remote control. Therefore, they can ideally be used in complex monitoring networks able to setup a simultaneous monitoring of several trees reducing the necessity of *post* VTA monitoring visits frequency and, in general, the overall management costs of urban forests.

2. Materials and Methods

2.1. Site Description and Environmental Data

The experiment was carried out in the area of relevance of the Italian National Research Council (CNR) of Montelibretti (Central Italy). The site is a suburban area where the trees are mainly arranged in rows along the streets. Twelve *Pinus radiata* trees (40 years old) were selected for their size uniformity (tree height range 8–12 m, dbh average 52 ± 7 cm), and visually assigned to three vitality classes (alive, compromised, dead) following the crown transparency procedure described elsewhere [1]. No significant differences for dbh were highlighted among the vitality classes ($P = 0.4$). The air temperature (T , °C), relative humidity (RH, %), wind speed, and precipitation (P , mm) were recorded each 15 min by the modular weather station belonging to the Institute of Atmospheric Pollution Research (IIA—CNR), and located less than 200 m from the trees. The vapor pressure deficit (D , KPa) was calculated as reported already elsewhere [14].

2.2. Dendrometer

Stem radius variation was detected using high-resolution automatic point dendrometers, as already described elsewhere [11]. Before the installation of the dendrometers, each stem was scanned by a sonic tomography (Arbotom technology) to check wood defects or anomalies. After the check, the dendrometers were positioned at breast height on the north side of each stem. The raw data were averaged every 15 min. The irreversible stem expansion (SR) and the reversible stem shrinkage induced by the tree water deficit (TWD) were determined using the Treenetproc R software [17]. Diurnal stem cycles were analyzed using the DendrometerR software [18], and the timing, duration, and amplitude of each dendro phase were calculated accordingly. The sensitivity of each dendro phase to the temperature variation was assessed considering the time lag between the occurrence of the daily minimum temperature and the onset of stem shrinkage. A graphical representation of the procedure followed in order to assess the time lag, as reported in Figure 1.

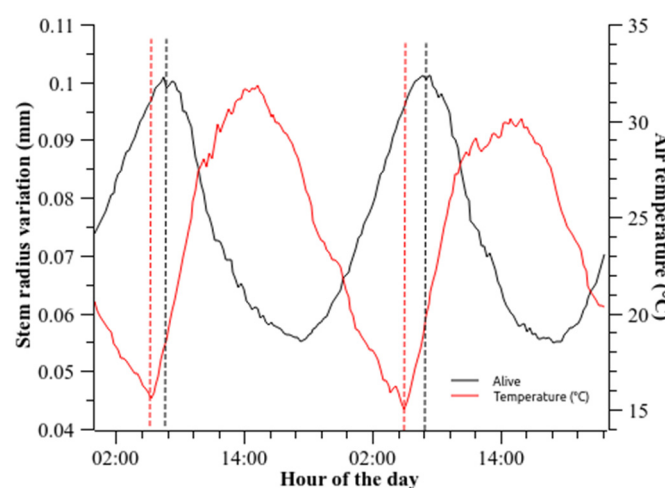


Figure 1. Graphical representation of the time lag assessment in *Pinus radiata* trees. The time lag was assessed as the difference between the occurrence of the daily minimum temperature and the onset of the stem shrinkage. Data were recorded each fifteen minutes during 14–15 July 2020 in alive trees. The solid lines represent the stem radial variation (black, mm) and temperature (red, °C) respectively. The dashed lines represent the hour of the day at which the maximum stem radius (black) and the daily minimum temperature (red) occurred.

2.3. Statistical Analyses

The statistical unit was the individual tree. Data were checked for normal distribution (Shapiro test) and the effect of the vitality class on dendro phases was assessed by the Welch test ($P < 0.05$).

3. Results and Discussion

During the experiment, the mean temperature was 25.9 ± 5.6 °C ranging between 15 and 36.9 °C without rainy events. The daily mean D ranged from 2.2 and 0.85 KPa but the hourly maximum D exceeded 4 KPa from 24 to 26 July (data not shown). Although the increase of the evaporative demand (high D values) and the lack of precipitation induced a water deficit condition in this area, the stem radius of the alive trees gradually increased ($GRO = 169.1 \pm 132$ μm), whilst it decreased in compromised and dead ones (Figure 2). The slope of the daily growth rate was double in alive trees (1.2 ± 0.2 $\mu\text{m h}^{-1}$ $n = 20$) than the compromised (0.5 ± 0.06 $\mu\text{m h}^{-1}$ $n = 8$) and dead ones (0.6 ± 0.08 $\mu\text{m h}^{-1}$ $n = 3$). These results showed that biomass accumulation (i.e., carbon gain) occurred only in the alive trees during summer and GRO can be an useful proxy of the tree vitality in *Pinus radiata*.

trees. The irreversible stem radius increase (i.e., stem growth) is considered the most suitable proxy of tree productivity and structural carbon allocation in forest trees [17,19].

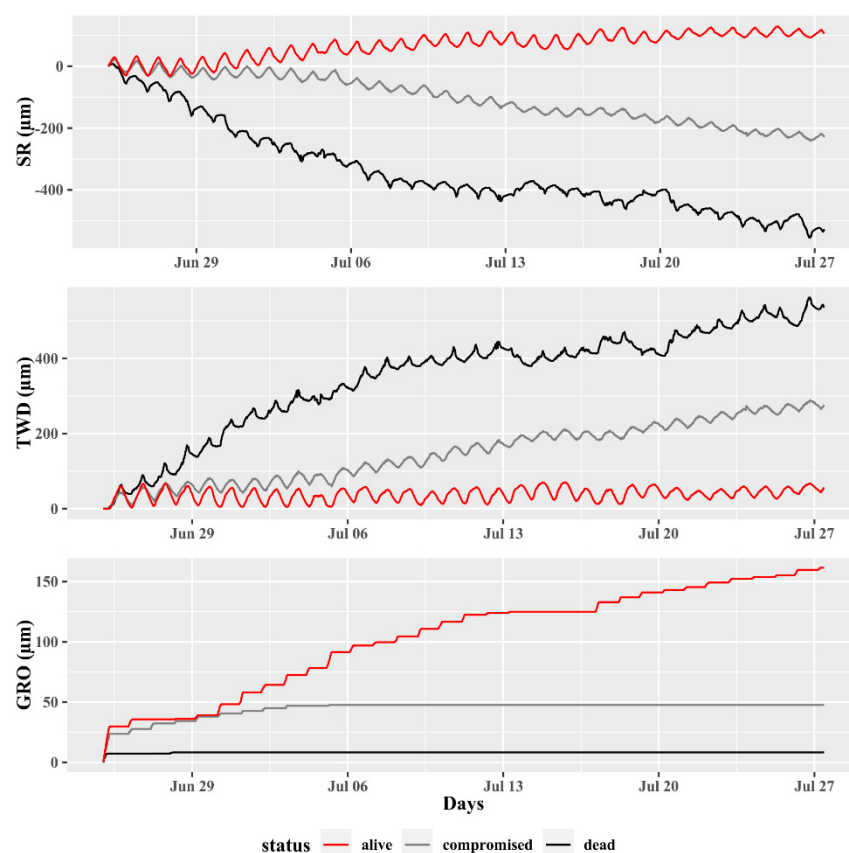


Figure 2. Time course of the stem radius variation (SR, μm), tree water deficit (TWD, μm), and stem growth (GRO, μm). Dendrometer data were recorded from 25 June to 27 July 2020. The solid lines represent the mean of five trees for alive (red), compromised (grey), and dead tree (black), respectively.

Photosynthesis is the main source of carbon for plants and chlorophyll fluorescence and the content of antioxidant levels in leaves has been often associated with the photosystem efficiencies and crown vitality [2]. As the photosynthates produced within the source (needles) are translocated towards the C-sinks such as cambium or stored as starch within the phloem and ray parenchyma, the carbohydrates content within the bark was considered a suitable predictor of tree vitality [20,21]. Therefore, the strength of the carbon source and the C-pools stored within the bark were able to support the growth in alive trees avoiding soluble carbon depletion and starvation during summer.

The amplitude and duration of stem shrinkage and swelling were similar among the vitality classes (data not shown). These results showed that the amplitude and duration of dendro phases were not able to identify the contrasting class vitality in our trees. However, alive and compromised trees could be easily separated from dead ones when the time lag between the occurrence of the minimum daily temperature and the onset of stem shrinkage was considered (Figure 3). In alive and compromised trees, the onset of the stem shrinkage was always delayed with respect to the occurrence of the daily minimum air temperature (on average 117 min). On the contrary, the time lag recorded in dead trees was short (on average 5 min), and in many cases, it coincided or anticipated the occurrence of the minimum temperature.

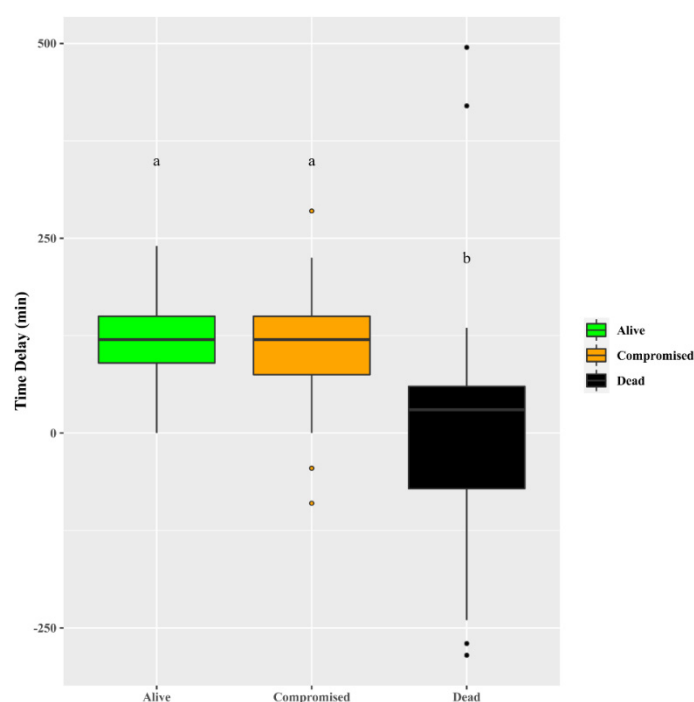


Figure 3. Box plots represent the range of the time delay (minutes) between the occurrence of daily minimum temperature and the onset of stem shrinkage in alive (green), compromised (orange), and dead (black) trees of *Pinus radiata*. Each box shows the distribution of 25th–75th quartiles, the horizontal line within the box represents the mean. Vertical bars and circles indicate the minimum and maximum values and outlier data. Different letters indicate significant differences ($P < 0.05$).

The strong dependence of the stem shrinkage to the air temperature in dead trees could be mostly driven by the thermal coefficient of cell wall components rather than to water fluxes induced to the air evaporative demand. Our results are in agreement with previous findings showing a high synchronization between the air temperature and stem radial variation in logs of chestnut, beech, and scotch pine subjected to thermal gradient cycles in a controlled environment [22]. The long-time delay between the occurrence of the onset of stem shrinkage and daily minimum temperature observed in alive and compromised trees can be explained considering the main role of crown transpiration demand in driving water fluxes within the stem. The onset of the stem shrinkage was correlated with the increasing of sap flow and crown transpiration in the early morning in poplar and olive [23,24]. After dawn, the increasing photosynthetic photon flux density induces the stomata opening and water is retrieved from the storage compartments (i.e., bark, phloem, ray parenchyma, and stem elastic tissues) to support the crown transpiration. The water withdraw causes the emptying of these tissues determining stem shrinkage.

4. Conclusions

We demonstrated that point dendrometers and the stem cycle analysis approach could be usefully integrated in the monitoring of tree vitality in urban areas. Although our “case study” was only focused on *Pinus radiata* trees, we showed that GRO was a promising parameter to separate alive from compromised and dead trees. On the other hand, the time lag between the occurrence of minimum daily temperature and the onset of stem shrinkage was able to separate alive and compromised from dead trees. Further trails will be assessed to elucidate the possible use of dendro phases on the tree vitality assessment in different species and urban areas with the aim of developing integrated systems able to send “early alerts” and improve the decision-making management in urban forestry.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

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Conflicts of Interest: The authors declare no conflict of interest.

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