17th International Conference on Environmental Science and Technology

Athens, Greece, 1 to 4 September 2021

Determining the phenological stages of Nestos-Delta (*Alnus glutinosa*) riparian forest (Natura 2000 site) by using radiation transmittance data

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Abstract Trees' phenology is a key factor for most forests' physiological processes. The precise definition of the start-end dates and the duration of each phenological stage is critical. In the present study, radiation data were used from pyranometers installed at the *Alnus glutinosa* riparian forest of Nestos-Delta (Natura 2000 site), within the implementation of LIFE-PRIMED project. The pyranometers were placed inside the stand (below the trees' canopy) and also in a forest opening. The radiation transmittance coefficient τ (unitless) was estimated on a daily basis for the period October 2019 to December 2020. τ can be used for the forest's phenological stages determination. Four stages were identified. The first concerns the development of leaves and starts at mid April until mid June, as τ decreases with a rate of about 0.0071 d^{-1}. At the second stage (mid June to mid September) the canopy is fully developed and effective and τ presents almost stable low values (0.13). During the third stage (mid September to late December) senescence and gradual rejection of leaves occurs as τ increases with a rate of 0.0062 d^{-1}. During the last stage of the leafless canopy (late December to mid April), τ becomes maximum (0.6) and stable.

Keywords: Forest micrometeorology, LIFE-PRIMED, solar radiation, light transmittance, deciduous forest

1. Introduction

The study of the optical properties and especially reflectivity (abledo) of a natural surface either by using ground measurements or remote sensing techniques (satellite data) can give important information for the plants physiological processes for many crops or natural forests (Burba and Verma 2001; Baldocchi et al. 2004). Radiation data can be also used for the precise determination of plant phenological stages (Burba and Verma 2001; Proutsos et al. 2004). For example Proutsos et al. (2004) studied the changes in absorbance, reflectance and transmittance of global solar radiation in a forest canopy and defined precise dates for the start, the duration and the end of the leaf development and senescence in an oak (*Quercus frainetto*) deciduous forest in Greece. Such knowledge is of high importance in ecological and environmental studies, mainly due to the effect of the optical characteristics (reflectance, absorbance and transmittance) on the distribution of solar radiation inside and above plant canopies, controling the energy partitioning inside the ecosystem and the energy exchange between the ecosystems and the environment (Vermaas 1998; Song 1999; Liakatas et al. 2002). Additional, the available radiant energy that reaches the forest floor can have a significant impact on the forest's biodiversity.

In the present work, we used the radiometers (pyranometers) for determining the phenological stages of the priority habitat 91E0* (Natura 2000) riparian forest of Nestos-Delta in northern Greece, with dominant species the *Alnus glutinosa*, by analyzing the changes of the radiation transmittance coefficient (τ).

2. Study site, Materials and Methods

The fan-shaped Nestos Delta (long. 24.76º, lat. 40.92º) extends to an area of about 23,000 ha and was created by alluvial deposits of Nestos river. It is considered one of the most important wetlands of Greece and Europe, mainly due to its size and the variety of habitats inside the protected area. A high number of 28 different habitat types, compared to the 88 habitat types of European importance hosted in Greece (Greece State of the Environment Report/Summary, 2018) are present in the protected Natura 2000 site (GR1150010: Delta Nestou kai Limnothalasses Keramotis – Evryteri perioxhi kai paraktia zoni) and three of them are priority ones: coastal lagoons (1150*), Mediterranean temporary ponds (3170*) and Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (91E0*) (https://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=GR1150010).

The priority habitat 91E0* (alluvial forest) is present to both sides of the Delta and covers a total area of about 514ha. The dominant tree species include *Alnus glutinosa* and *Fraxinus exelsior* in addition to *Fraxinus. angustifolia*, *Salix alba*, *Juglans. regia*, *Cornus sanguirena*, *Quercus robur* ssp. *pedunculiflora* and *Ulmus minor* ssp. *canescens*.

There is also a variety of plant species at the forest floor including the climbers *Periploca graeca* and *Hedera helix* and herbaceous species such as *Aegopodium podagraria, Mentha aquatica, Lysimachia punctata, Petasites hybridus, Silene baccifera, Circaea lutetiana, Arum maculatum* etc, indicating the high species richness of the forest floor.

The climate of the region is humid according to the UNEP (1992) Climate Zone Classification System which is based on Thronthwaite's (1948) water budget, with Aridity Index (AI) values varying from 0.69 for the climatic period 1930-1960 to 0.70 for the period 1960-1997, as estimated by the historic data of the nearest meteorological station of Kavala (Tsiros et al. 2020). However, precipitation changes in the broader area indicate a translocation of rainfall, occurred during the last 50 years in Nestos Delta with significant precipitation decreases in the coastal area (where the alluvial forest extends) and increases at the mountainous area (Proutsos et al. 2019), suggesting that the natural vegetation at the coastal zone could be more vulnerable to climate change.

At the riparian forest, in order to determine the radiation distribution in the canopy, two meteorological stations were installed. The first was operating below the trees canopy inside the forest, while the second in a nearby forest opening (Figure 1). Both stations were installed at the eastern bank of the river where the priority habitat 91E0* with dominant trees of *Alnus glutinosa* expands and were equipped with global solar radiation sensors (Apogee SP110, USA).

The measurements derived from the radiometers were taken every 10 sec and averaged every 15 minutes. The daily averages of the global solar radiation flux densities were extracted by averaging the 96 daily values. From the daily fluxes, the transmission coefficient (τ) was determined as the ratio of the global solar radiation measured from the station below the canopy to the respective radiation flux density measured by the station installed at the forest opening. The measurement units of the radiation flux densities is in W m^{-2}, whereas τ is dimensionless.

Figure 1. Meteorological stations installed in Nestos Delta riparian forest below the trees canopy (a) and at a nearby forest opening (b).

3. Results and Concluding Remarks

The daily values of the radiation transmittance coefficient (τ) derived from incoming shortwave radiation flux densities above and below the forest canopy is presented in Figure 2. Its annual distribution present clear and changes of τ at specific dates and can be used to precisely define the phenological stages of the forest.

Coefficient τ in Figure 2 present stable and high values in the winter period from 17 December to 13 April reaching a value of 0.582 with low standard deviation (0.047). This is the period that the deciduous trees are leafless and solar radiation can penetrate easily the forest canopy and reach the floor with flux densities of about 58.2% of the above measured relative flux. This period of 119 days, could allow the development of vegetation on the forest floor,

which, however, is rather prevented due to the weak radiation fluxes (above canopy 122.5 W m^{-2}, below canopy 71.3 W m^{-2}), the small daylength and the low air temperature.

In the next time period (63 spring days), which starts in 14 April, τ presents a rapid decrease with an average rate of 0.0071 d^{-1}, reaching a minimum in 15 June. During this stage, new leaves start to grow on the tree branches and reach their maximum leaf area when τ becomes minimum. The average radiation fluxes at this stage are 263.0 and 84.3 W m^{-2}, above and below canopy respectively and the average τ is 0.34 highly varying from day to day (sd=0.137).

At the next stage, the trees have a fully developed canopy with mature green leaves. During this stage, which starts in 16 June and ends in 15 September, τ has stable minimum values (average 0.128 with sd=0.016), since the solar rays cannot transmit through the dense leaf-mass. The above canopy radiation is high, with an average value of 280.3 W m^{-2} for the total 99 day-period, however only a percentage of 13% (35.3 W m^{-2}) reaches the forest floor. It should be noted that the sunlight that reaches the floor is "filtered" by the canopy and is relative poor at Photosynthetically Active Radiation (PAR) wavelengths (400-700 nm) that can support the photosynthetic process of the plants (Liakatas et al. 2002; Proutsos 2011).

As leaves grow old, the absorbed radiation decreases and higher quantities of light can transmit through the canopy. At this stage, which starts in 19 September and ends in 16 December (99 days), leaves start to senescence and fall from the trees, or remain on the tree branches as dead-dry leaves. Coefficient τ at this stage increases with a rate of 0.0062 d^{-1}, which is lower compared to the stage of leaf development. The above and below canopy radiation flux densities are 124.3 and 39.5 W m^{-2}, respectively.

The above pattern indicates that the transmittance coefficient τ can be an useful tool for monitoring and accurately defining the phenological stages of the *Alnus glutinosa* riparian forest in Northern Greece. In a previous work by Proutsos et al. (2004) for a deciduous oak forest (*Quercus frainetto* Ten.) in Greece (Peloponnese), the authors came to the same conclusion. However, the different species and regions (different latitude, elevation and aspect) can highly affect the forests' phenology, with significant impact on the forest biodiversity, since the annual growth of the plant species growing below the trees' canopy is associated with the phenological stages of the dominant trees and is synchronized in order to grow in specific periods with respect to solar radiation availability.

Acknowledgments: This work was financially supported by the project LIFE PRIMED "Restoration, Management and Valorization of PRIorityhabitats of MEDiterranean coastal areas" (LIFE17 NAT/GR/000511) which is co-financed by the European Commission's LIFE NATURE Program.

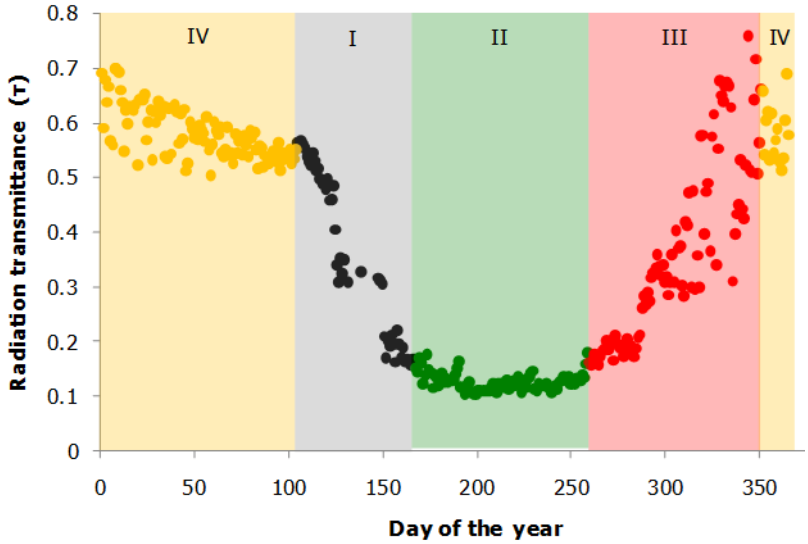

Figure 2. Daily changes of the solar radiation transmittance ratio (τ) in Nestos Delta riparian forest.

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