ESTIMATION OF BIOPHYSICAL PARAMETERS IN MEDITERRANEAN CONIFER FOREST UNDER DECLINE CONDITION BY USING AHS AIRBORNE DATA

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ABSTRACT:

The retrieval of physiological indicators from remote sensing data is an important issue for the assessment of forest decline. In this study, a diurnal airborne campaign was conducted over a pine forest with the Airborne Hyper spectral Scanner (AHS) to evaluate the response of different physiological indicators of forest decline. Field data were collected during summer of 2008: visual degree of defoliation, needle pigments concentration, needle water content, stomata conductance, stem water potential, and crown temperature. AHS sensor data were acquired at two times (8 GMT and 12 GMT), collecting 2 m spatial resolution imagery in 80 spectral bands in the 0.43-12.5 µm spectral range. NDVI was calculated from the reflectance bands, and the thermal bands were assessed for the retrieval of land surface temperature. The results obtained highlight the potential of thermal remote sensing data for forest decline detection. Tc-Ta data were successfully related to forest decline showing differentiated values between the mean crown temperature of non-affected trees (303.97±0.69 and 303.31±1.45K), moderately affected trees (307.60±1.51 and 307.83±1.63) and severely affected trees (308.63±1.18 and 308.15±0.97). The water potential (WP) and the stomata conductance (GI) measurements were related to Tc-Ta yielding a R^2 of 0.35 (WP) and 0.76 (GI), for *P. sylvestris* and 0.50 (WP) and 0.79 (GI) for *P. nigra*. Other variables such as LAI or leaf water content did not show any potential discrimination between different levels of damage. The results demonstrate the potential application of high-spatial thermal data to evaluate water stress. The detection of this process by the AHS sensor is a highly significant advantage with regard to early stress detection in a declining Mediterranean pine forest.

1. INTRODUCTION

The term forest decline has been widely used to describe the degradation status of forest ecosystems. In the last decades of the 20th century, different syndromes of forest decline in Mediterranean conifers have been described associated with photogenic infections and the climate change or the interaction of both factors. In Spain, several forest decline processes have been recorded in *Pinus* species, and, in particular, in *Pinus sylvestris* L. During the decline process,

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different types of transformations occur in the structure, morphology and physiology of the plant including: alterations in photosynthetic activity, pigment content, alterations in the internal structure of leaves and changes in water content at a cell level. The spectral signature of the plant cover is sensitive to these alterations. The analysis of these variables from remote sensing imagery has important potential implications for forest management and forest stress detection. Chlorophyll concentration and other biochemical constituents have been modeled for coniferous forest canopies (Zarco-Tejada et al., 2004; Moorthy 2008, Zhang et al., 2008). Water stress restricts transpiration, inducing closure of stomata and less water evaporation, resulting in an increase in leaf temperature (Jackson, 1986), which has been successfully assessed based on water potential and stomata conductance measurements and related to vegetation indices such PRI (Suarez et al., 2009). Other studies have suggested the use of canopy temperature as a water stress indicator, using the relationship between temperature and specific physiological parameters such as stomata conductance and water potential (Sepulcre-Canto 2006).

However, very limited references have shown feasible remote sensing methods for successfully linking thermal response of vegetation cover and water stress in Mediterranean forest canopies. The aim of this study is to present progress made on the application of hyper spectral high-spatial resolution data (AHS sensor) and thermal imagery to obtain spatial and temporal variability in canopy temperature for two types of Mediterranean conifers under different decline levels.

2. MATERIAL AND METHODS

2.1 Field data collection

The study area is located in Sierra de Filabres, Almeria (Southern Spain) (37° 13' 27" N, 2° 32' 54" W). Field data collection was conducted in the last week of July 2008, within the same week of the image acquisition. Two sets of measurements were collected at 8:00 and 10:00 (GMT). The trees monitored were 36 *Pinus nigra* and 36 *Pinus sylvestris*, 12 trees per damage level. The degree of damage was visually estimated according to crown defoliation (Ferretti, 1994), and aggregated at three different levels: no damage (0-30%), moderate damage (30-60%), severe damage (60-100%). Physiological parameters measured on the total trees were: chlorophyll concentration (a and b), needle water content, stomata conductance (CIRAS-1, PP Systems, Hitchin Herts, Great Britain) and crown temperature (Infrared thermometer, Optris LS), measured at the same time of the flight 8:00 and 10:00 (GMT) and stem water potential measured at 4:00 GMT (pre-dawn) and 12:00 GMT (mid day) (Scholander pressure bomb, SKYE SKPM 1400). Field LAI was obtained with hemispherical photography (Nikon Coolpix 950).

2.2. Airborne campaign and AHS reflectance and land surface retrieval.

The airborne campaign was conducted by the Spanish Aerospace Institute (INTA) with the Airborne Hyper spectral Scanner (Sensytech Inc., currently Argon St. Inc., USA). The AHS sensor data acquisition was conducted at 8 GMT and 12 GMT, collecting 2 m spatial resolution imagery in 38 bands in the 0.43-12.5 µm spectral range, with 90º FOV and 2.5 mrad. At-sensor radiance processing and atmospheric correction were performed by the INTA. The atmospheric correction was conducted with the ATCOR4 based on the radiative transfer model MODTRAN using the aerosol optical depth at 550 nm collected with a Micro-Tops II sun photometer (Solar Light, Philadelphia, PA, USA)

Land surface temperature retrieval from thermal remote sensing data was obtained with the two-channel algorithm proposed by Sobrino *et al*., (2002) taking into account the emissivity and water vapor effects. The emissivity value applied for vegetation was 0.98. Water column absorbed was calculated with the PcModwin radiative transfer model and water vapor column collected with a Micro-Tops II sun photometer. A full description of land surface temperature retrieval from thermal imagery from AHS can be found in Sepulcré-Cantó et al. (2006). The mean air temperature during the flight was 20.89(±0.046) at 8 GMT and 24.51(±0.11) at 12 GMT. The data was collected by the Astronomy Observatory of Calar Alto, located within the study area.

2.3. Analysis of forest decline through thermal remote sensing data.

The first step of the study consisted of the selection of physiological variables related to forest decline processes. The three damage levels identified in the study area were associated with physiological parameters (chlorophyll concentration, water potential, stomata conductance, leaf area index and percentage of defoliation). The measurement of the physiological parameters permitted the identification of the variables most related to forest decline.

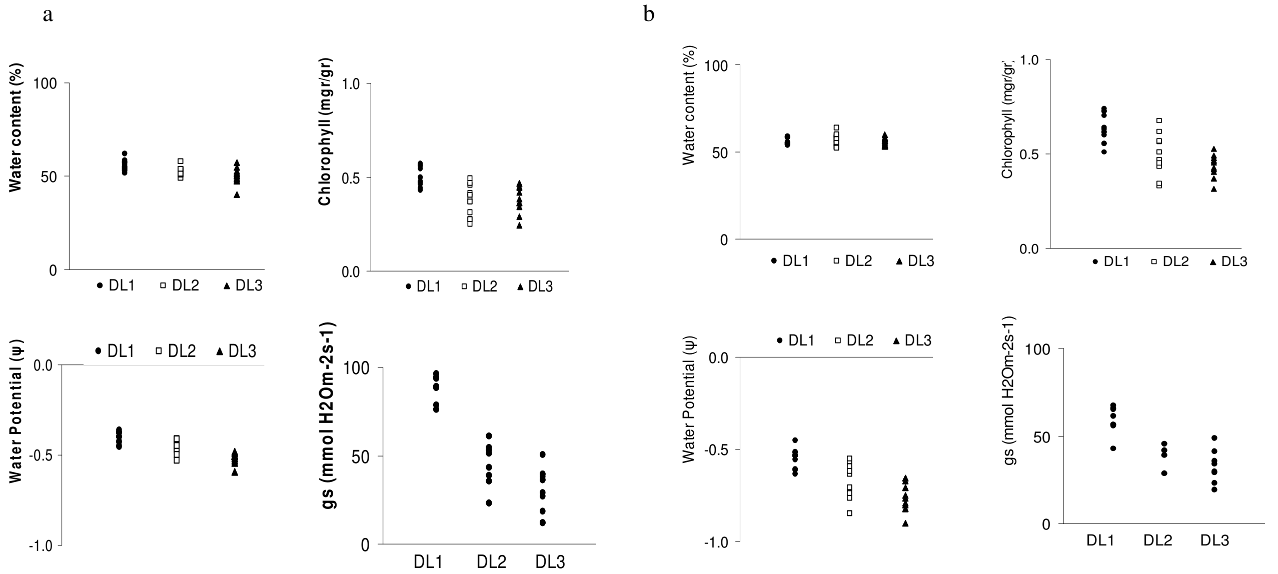
The second step consisted of the discrimination of forest decline through thermal imagery data. Thermal differences between crown temperature retrieved from the AHS sensor and the air temperature were related through regression analysis to water potential, stomata conductance, water content and chlorophyll concentration for *Pinus sylvestris* and *Pinus nigra*. With 2 m spatial resolution, crown temperature was discriminated from soil and shadow pixels. However, the assumption of non-spectral mixing could not be confirmed, mainly for trees with high defoliation values. In order to analyze the effect of soil spectral mixing, the thermal data were related to structural data (LAI, percentage of defoliation and basal area) and the NDVI.

3. RESULTS AND DISCUSSION

3.1. Physiological variables related to forest decline processes in *Pinus sylvestris* and *Pinus nigra*.

Comparing both species, *P. sylvestris* showed a greater physiological and structural dysfunction related to forest decline than *P. nigra* (Fig. 1). For both species, water potential (WP), stomata conductance (SC) and chlorophyll concentration (C a+b) were seen to be affected by forest decline. Mid-day water potential was slightly higher for *Pinus sylvestris* than for *Pinus nigra*. The ranges of water potential measurements agree with the water potential observed in summer for *P. sylvestris* in Spain (Peguero-Pina et al., 2007). Stomata conductance measurements depicted significant differences between stressed and non-stressed trees and non-significant differences between species. Results agree with the measurements obtained on *Pinus sylvestris* by Piguero-Pina (2007). Chlorophyll content Ca+b was higher in *Pinus sylvestris* than in *Pinus nigra*. For both species, higher values in chlorophyll content were collected on non-stressed trees than on stressed trees.

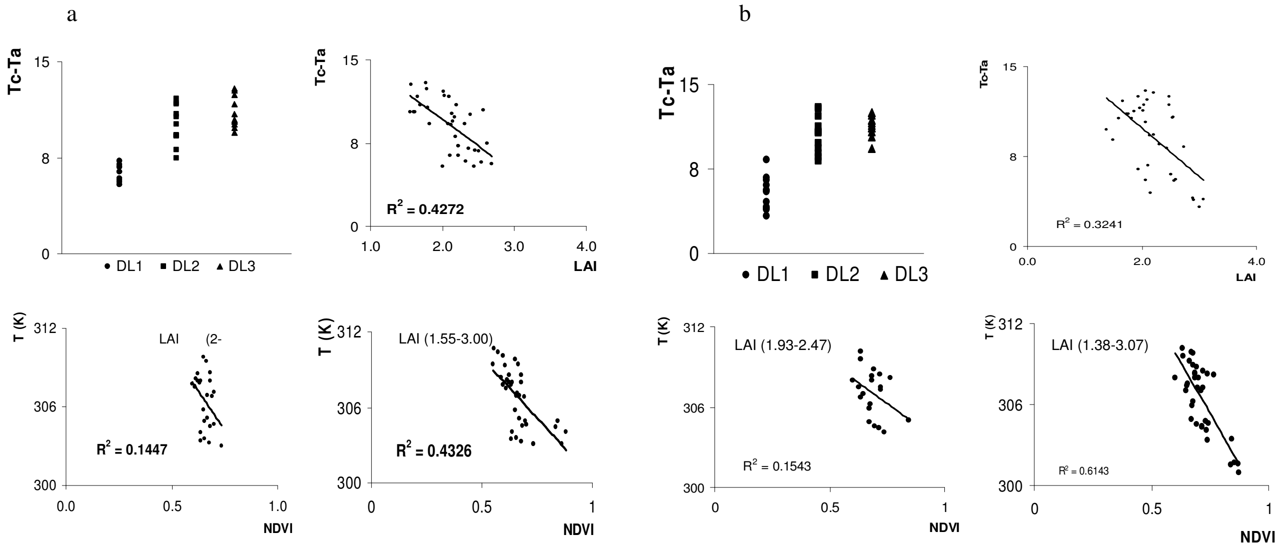
In contrast, leaf water content (LWC) and the leaf area index (LAI) did not show a good discrimination capacity between different levels of damage (Fig. 1). Leaf water content measurements could have been influenced by the exceptional rain conditions a week before field work (data not included). However, water vegetation stress is not suitable for the assessment of leaf water content as many species may show signs of evapotranspiration reduction without experiencing a reduction in leaf water content (Ceccato et al., 2001). It has been typically assumed that chlorophyll concentration and the degree of leaf mortality were proportional to moisture content (Illera et al, 1996). However, this assumption may be correct for some species but it cannot be generalized to all ecosystems (Ceccato et al., 2001). The same occurs with the LAI, typically generalized as a good indicator of forest decline in the remote sensing community (Treitz and Howarth, 1999).



1. Relationships between biophysical variables and level of damage on *Pinus sylvestris* (a) and *Pinus nigra* (b). DL1: damage level 1, DL2: damage level 2, DL3, damage level 3.

3. 2. Thermal imagery data and decline processes in *Pinus sylvestris* and *Pinus nigra* forests.

High-spatial thermal remote sensing data derived from the AHS sensor showed clear thresholds of crown temperature retrieved from trees with different degrees of affectation. For both species, Tc-Ta (Temperature of the tree crowns – Temperature of the air) values were higher in affected trees than in non-affected trees (Fig. 2a and 2b). The mean temperature difference between damage levels and non-damage levels was of 4.654ºK for *P. sylvestris* and 6.57ºK for *P. nigra*. Following the same order, the mean crown temperature for undamaged trees was 303.97ºK (±0.69) and 303.31ºK (±1.45), for moderate damage level 307.60ºK (±1.51) and 307.83ºK (±1.63) and for severe damage level 308.63ºK (±1.18) and 308.15ºK (±0.97). Those temperature results showed non significant differences per levels between species. Due to the large differences between soil and crown temperature, measurements were related to structural variables (LAI, basal area and NDVI). Results showed a significant relationship between Tc-Ta and the basal area, the leaf area index, and the NDVI. Thus, in order to demonstrate that high-spatial thermal remote sensing imaging can be related to water stress as a resulting in stomata closure, crown trees with different levels of affectation and LAI differences of under 1 unit were analyzed (Fig. 2a and 2b). The relationships between NDVI and Tc-Ta yielded a low coefficient of determination (r^2=0.19 and r^2=0.19) for *P sylvestris* and *P. nigra,* respectively. Those results demonstrate that the structure was not the driver between Tc-Ta and stomata conductance when sample training LAI differences are lower than 1 unit. Focusing on those training areas, results showed a significant relationship between Tc-Ta and stomata conductance and water potential, variables related to water stress (Fig. 3a and 3b). The leaf water potential (WP) and stomata conductance (GI) measurements were related to Tc-Ta, yielding a r^2 of 0.35 (WP) and 0.70 (GI), for *P. sylvestris* and 0.484 (WP) and 0.71 (GI) for *P. nigra*. Those results indicate the suitability of using AHS thermal data for forest decline identification related to water stress and based on the crown temperature of trees with a similar LAI. Water stress results in stomata closure and reduced transpiration rates, due to a decrease in leaf water potential and a decrease in photosynthetic activity. The reduction in transpiration affects the temperature balance (Tc-Ta) recorded by the sensor. The detection of this process by the AHS sensor is a relevant result in early stress detection of Mediterranean pine forest affected by decline processes.



2. Relationships between thermal image at tree scale and structural parameters measured on *Pinus sylvestris* (a) and *Pinus nigra* (b). DL1: damage level 1, DL2: damage level 2, DL3, damage level 3.

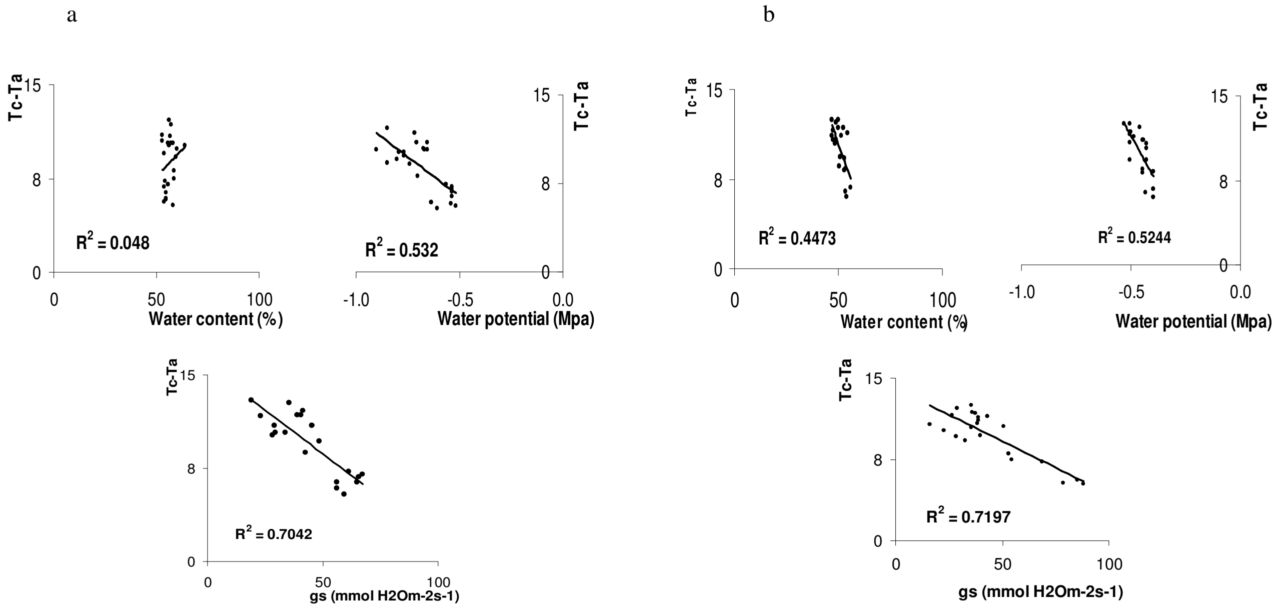


Fig.3. Relationships between thermal image and physiological parameters measured on trees with LAI (1.6 to 2.7) *Pinus sylvestris* (a) and *Pinus nigra* (b). DL1: damage level 1, DL2: damage level 2, DL3, damage level 3.

4. Conclusions

This study makes a new contribution to the application of thermal remote sensing data to the detection of forest decline processes. The use of AHS data presented here enables the development of crown mapping based on Tc-Ta at 2.5 m spatial resolution related to forest decline showing its discrimination capacity between defoliation levels. Thermal data derived from the AHS sensor were affected by soil mixture when comparing crowns with differences in LAI values of over 1 unit. However, the Tc-Ta retrieved from trees keeping this range and showing the three levels of affectation exhibited non-significant relationships with vegetation fractional cover and with stomata conductance and water potential. Other variables such as LAI or leaf water content did not show any potential discrimination between different levels of damage.

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