Remote sensing for high-throughput phenotyping of forest genetic trials using UAVs

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The analysis of genetic differentiation in key functional traits of forest species is a fundamental step to understand the adaptive structure of populations and their potential to react to environmental changes. While traditional phenotyping techniques are costly and time-consuming to implement in forest trees, and especially so in the case of adult individuals, remote sensing data derived from cameras mounted on UAVs (unmanned aerial vehicles) provide potentially valid high-throughput information for assessing morphophysiological differences among individuals. In this work we characterise, for the first time, the extent of intra-specific genetic variation in key functional traits for a widespread conifer through UAV data. Three flights (July-2016, November-2016 and May-2017) were performed in a genetic trial located in Spain which consisted of 56 populations of the circum-Mediterranean conifer *Pinus halepensis* Mill. Ortho-mosaics of RGB (red, green, blue), multispectral (visible and near infrared wavelengths) and thermal images of the trial were obtained with centimetric spatial resolution. The images were analysed to retrieve values of canopy temperature, vegetation cover and several vegetation indices at the plot level (i.e., composed by trees belonging to the same population). Differences among populations emerged consistently across flights for vegetation cover and vegetation indices related to green biomass, indicating genetic divergence in crown architecture and density. On the other hand, differences in needle pigments were found only in May-17 and were probably related to contrasting phenology of needle emergence and development among populations. This finding, coupled with the absence of genetic divergence in photosynthetic efficiency-related indices across flights, points to a negligible genetic differentiation in the photosynthetic machinery of *P. halepensis*. Differences in canopy temperature were significant in July-16 (peak summer), being indicative of variation in stomatal conductance among populations under drought stress. Volume over bark, taken as an estimation of above-ground growth, was positively correlated with green biomass and negatively correlated with canopy temperature at the population level, indicating a significant influence of canopy properties and stomatal conductance on growth in *P. halepensis*. This work is the first attempt to apply high-throughput phenotyping techniques in forest genetics based on aerial images. Our results suggest that remote sensing data derived from UAV is a promising tool to assess genetic differentiation in phenotypic traits, potentially improving our ability to bridge genomics and phenomics in forest tree species.

Keywords: Remot sensing, Unmanned aerial vehicles, Genetic trial, Forest species, High-throughput phenotyping , Pinus halepensis