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Potential and limitations of using digital repeat photography to track structural and physiological phenology in Mediterranean tree-grass ecosystems

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Tree-Grass ecosystems are global widely distributed (16-35% of the land surface). However, its phenology (especially in water-limited areas) has not yet been well characterized and modeled. By using commercial digital cameras, continuous and relatively vast phenology data becomes available, which provides a good opportunity to monitor and develop a robust method used to extract the important phenological events (phenophases). Here we aimed to assess the usability of digital repeat photography for three Tree-Grass Mediterranean ecosystems over two different growing seasons (Majadas del Tietar, Spain) to extract critical phenophases for grass and evergreen broadleaved trees (autumn regreening of grass- Start of growing season; resprouting of tree leaves; senescence of grass – End of growing season), assess their uncertainty, and to correlate them with physiological phenology (i.e. phenology of ecosystem scale fluxes such as Gross Primary Productivity, GPP). We extracted green chromatic coordinates (GCC) and camera based normalized difference vegetation index (Camera-NDVI) from an infrared enabled digital camera using the “Phenopix” R package. Then we developed a novel method to retrieve important phenophases from GCC and Camera-NDVI from various region of interests (ROIs) of the imagery (tree areas, grass, and both - ecosystem) as well as from GPP, which was derived from Eddy Covariance tower in the same experimental site.

The results show that, at ecosystem level, phenophases derived from GCC and Camera-NDVI are strongly correlated (R^2 = 0.979). Remarkably, we observed that at the end of growing season phenophases derived from GCC were systematically advanced (ca. 8 days) than phenophase from Camera-NDVI. By using the radiative transfer model Soil Canopy Observation Photochemistry and Energy (SCOPE) we demonstrated that this delay is related to the different sensitivity of GCC and NDVI to the fraction of green/dry grass in the canopy, resulting in a systematic higher NDVI during the dry-down of the canopy.

Phenophases derived from GCC and Camera-NDVI are correlated with phenophase extracted from GPP across sites and years (R^2 =0.966 and 0.976 respectively). For the start of growing season the determination coefficient was higher (R^2 =0.89 and 0.98 for GCC vs GPP and Camera-NDVI vs GPP, respectively) than for the end of growing season (R^2 =0.75 and 0.70, for GCC and Camera-NDVI, respectively). The statistics obtained using phenophases derived from grass or ecosystem ROI are similar.

In contrast, GCC and Camera-NDVI derived from trees ROI are relatively constant and not related to the seasonality of GPP. However, the GCC of tree shows a characteristic peak that is synchronous to leaf flushing in spring assessed using regular Chlorophyll content measurements and automatic dendrometers.

Concluding, we first developed a method to derive phenological events of Tree-Grass ecosystems using digital repeat photography, second we demonstrated that the phenology of GPP is strongly dominated by the phenology of grassland layer, third we discussed the uncertainty related to the use of GCC and Camera-NDVI in senescence, and finally we demonstrate the capability of GCC to track in evergreen broadleaved forest crucial phenological events. Our findings confirm digital repeat photography is a vital data source for characterizing phenology in Mediterranean Tree-Grass Ecosystem.