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Using ground observations of a digital camera in the VIS-NIR range for quantifying the phenology of Mediterranean woody species

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ABSTRACT

The spectral reflectance of most plant species is quite similar, and thus the feasibility of identifying most plant species based on single date multispectral data is very low. Seasonal phenological patterns of plant species may enable to face the challenge of using remote sensing for mapping plant species at the individual level. We used a consumer-grade digital camera with near infra-red capabilities in order to extract and quantify vegetation phenological information in four East Mediterranean sites. After illumination corrections and other noise reduction steps, the phenological patterns of 1839 individuals representing 12 common species were analyzed, including evergreen trees, winter deciduous trees, semi-deciduous summer shrubs and annual herbaceous patches. Five vegetation indices were used to describe the phenology: relative green and red (green\red chromatic coordinate), excess green (ExG), normalized difference vegetation index (NDVI) and green-red vegetation index (GRVI). We found significant differences between the phenology of the various species, and defined the main phenological groups using agglomerative hierarchical clustering. Differences between species and sites regarding the start of season (SOS), maximum of season (MOS) and end of season (EOS) were displayed in detail, using ExG values, as this index was found to have the lowest percentage of outliers. An additional visible band spectral index (relative red) was found as useful for characterizing seasonal phenology, and had the lowest correlation with the other four vegetation indices, which are more sensitive to greenness. We used a linear mixed model in order to evaluate the influences of various factors on the phenology, and found that unlike the significant effect of species and individuals on SOS, MOS and EOS, the sites' location did not have a direct significant effect on the timing of phenological events. In conclusion, the relative advantage of the proposed methodology is the exploitation of representative temporal information that is collected with accessible and simple devices, for the subsequent determination of optimal temporal acquisition of images by overhead sensors, for vegetation mapping over larger areas.

1. Introduction

1.1. *Using remote and near surface sensing for vegetation phenology observations*

Phenology research of vegetation deals with observing life cycle phases of plants throughout the year (Lieth, 1970). Remote sensing is a well-established tool for vegetation mapping and monitoring (Tucker, 1979; Xie et al., 2008). The unique spectral properties of vital vegetation (Gates et al., 1965; Knipling, 1970) leads to difficulties in species identification by remote sensing observations due to spectral similarity between species; however, multi-temporal imagery can contribute to mapping plant species due to the phenological differences between them (Dudley et al., 2015; Somers and Asner, 2013). Therefore, the timing and number of image acquisitions (temporal resolution) are highly important for accurate identification of species (Hill et al., 2010; Key et al., 2001). Global time series of the Normalized Difference Vegetation Index (NDVI; Tucker, 1979), are available since the early 1980′s (from AVHRR) and at a spatial resolution of 250 m since 2000 (from MODIS), enabling to examine trends and seasonality in vegetation leaf area index and in primary productivity (de Jong et al., 2011; Zhu et al., 2013), as well as to identify the impacts of human

Abbreviations: AHC, agglomerative hierarchical clustering; AOI, area of interest; DL, double logistic function; DP, partial summer deciduous; DS, summer deciduous; DW, winter deciduous; EOS, end of season; EV, evergreen; ExG, excess green; GRVI, green red vegetation index; LAI, leaf area index; LOESS, locally weighted scatterplot smoothing function; MOS, maximum of season; NDVI, normalized difference vegetation index; NIR, near infra-red; PAR, photosynthetically active radiation; SOS, start of season; UAV, unmanned aircraft vehicles

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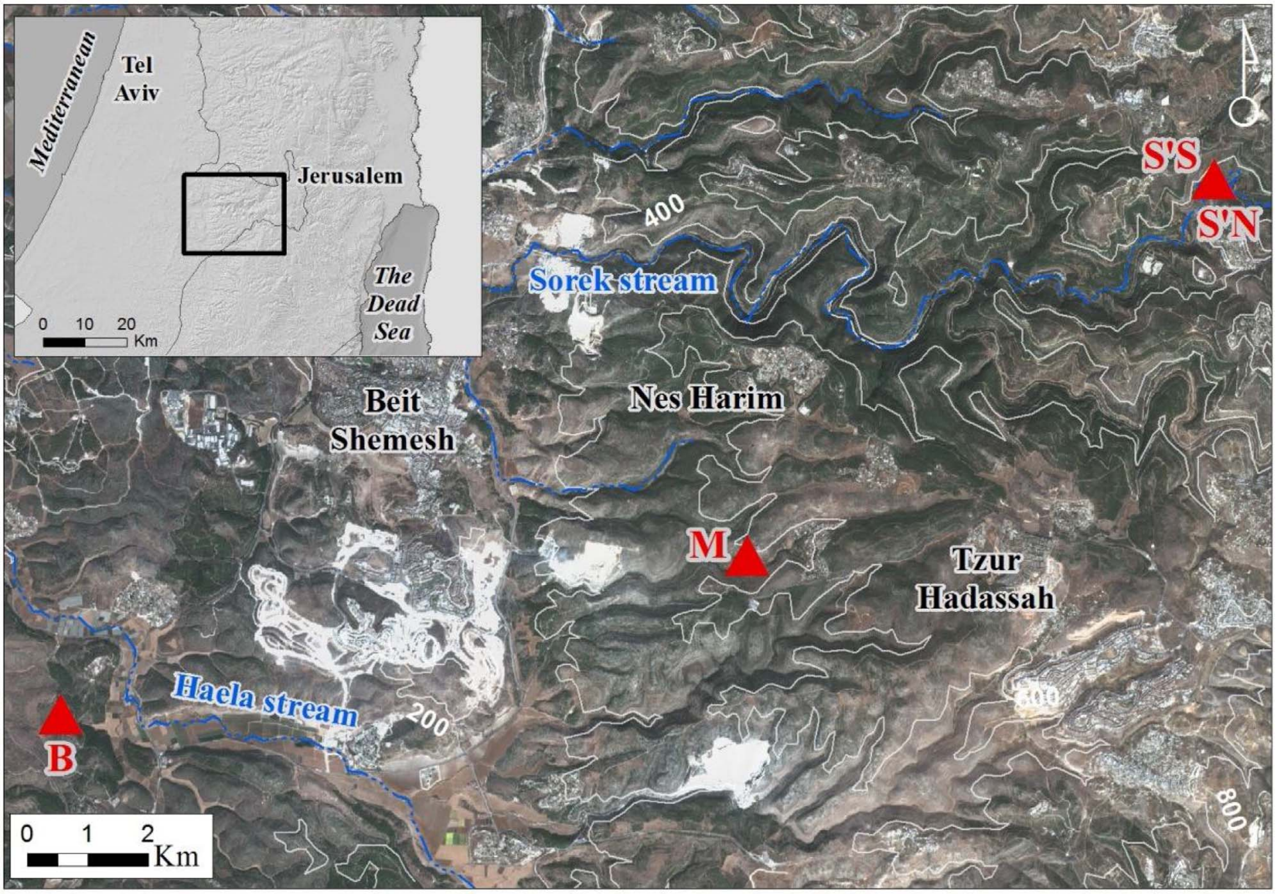

Fig. 1. General map of the research sites. Base map- true color image, obtained from SENTINEL 2 Satellite (European Space Agency). Pixel size- 10 m, acquisition date- 13/10/2016. The white lines represent elevation contours at intervals of 100m. The source of all vector data is the Survey of Israel database. Sites: B- Britanya park; M- Mata; S'S- Sataf, southern facing slope; S'N- Sataf, northern facing slope.

disturbances (Levin, 2016). However, the spatial resolution of globally available time series of NDVI is too coarse to identify phenological patterns at the individual level.

With the increasing accessibility of methods for composing time series from high spatial resolution imagery (primarily unmanned aircraft vehicles- UAV, Anderson and Gaston, 2013), it is necessary to evaluate the tradeoff between maximizing the number of acquisition dates for improving classification accuracy based on phenological differences between target species, and minimizing costs (Lisein et al., 2015; Michez et al., 2016; Schmidt et al., 2014; Schuster et al., 2015). In this context, near-surface data collection by ground based digital cameras is a well-established tool for obtaining phenological observations, which can assist in estimating phenological patterns (Richardson et al., 2007; Wingate et al., 2015). Presently, the majority of camera-based phenological research is not intended for detailed description of multiple species. In fact, most of the relevant studies focus on the correlations between ground and satellite produced vegetation indices (Balzarolo et al., 2016; Hufkens et al., 2012; Nijland et al., 2016); relationships between ground vegetation indices and physical parameters of the vegetation such as leaf area index (LAI) or photosynthetically active radiation (PAR) (Ahrends et al., 2009; Keenan et al., 2014; Sakai et al., 1997); or involve long-term data collection for examining climate change effects (Soudani et al., 2012; Wingate et al., 2015). Studies that examine phenology at the species level usually focus on monoculture canopies (Ide and Oguma, 2010), or refer to a small sample of individuals or species (Almeida et al., 2015; Bater et al., 2011; Beamish et al., 2016; Snyder et al., 2016).

1.2. East mediterranean vegetation

The East Mediterranean region experienced extensive human influences during the last thousands of years − including deforestation, grazing and fires (Naveh, 1982; Perevolotsky and Seligman, 1998), as well as land cover transformations and habitat destruction during the last century (Schaffer and Levin, 2014; Weil and Levin, 2015). As a result, monitoring species richness within local vegetation formations is highly important for conservation (Mandelik et al., 2010; Radford et al., 2011).

In the current research, we focus on East Mediterranean woody species forming typical “Maquis”, “Garrigue” and “Batha” vegetation formations. Maquis is a dense and low forest formation (2–6 m), dominated by multi-stemmed evergreen sclerophyllous trees. Garrigue forms a more open landscape, with evergreen or summer semi-deciduous shrubs as a prominent component (1–2 m). Batha is a steppe-like formation, dominated by dwarf-shrubs and annual herbaceous species (Danin, 1988; Shmida, 1981; Miller, 1983; Ne’eman and Goubitz, 2000). The local evergreen dominant species were found in previous studies to have similar spectral properties (Manevski et al., 2011; Rud et al., 2006). Furthermore, visual identification of the evergreen species is not straightforward due to morphological similarities and small inter-annual differences. Therefore, classification of the woody species of these vegetation formations by remote sensing is a challenging task (Bar Massada et al., 2012; Shoshany, 2000).

1.3. Objectives and hypotheses

The objectives of the present study are to quantify the phenological