27 # THE USE OF DIGITAL IMAGING SYSTEMS FOR DETECTING PLANT CHANGES: THE APOS – AUTOMATED PHENOLOGICAL OBSERVATION SYSTEM

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1. INTRODUCTION

The importance of phenological research for understanding the consequences of global environmental change on vegetation is highlighted in the most recent IPCC reports (2007). Collecting time series of phenological events, at a variety of scales, appears to be of crucial importance to better understand how vegetation systems respond to climatic regimes fluctuations, and, consequently, to develop effective management and adaptation strategies.

Some concerns are related to traditional monitoring of phenology: recording observations dates is labour intensive and costly; quality of data depends heavily upon the observational skills and effort of the observers; data can be affected to a certain degree of subjective inaccuracy; they are typically discontinuous and geographically limited. Moreover, they are typically made on a limited number of individuals, across a limited geographic area or a specific site. Other methods based on satellite remote sensing are used to quantify the seasonal patterns of development and senescence of vegetation (land surface phenology) but they operate at coarse spatial and temporal resolution, and at a regional or larger scale.

To overcome the limitation of field observations by individuals, and to scale between ground-based sampling and regional-scale satellite sampling, different approaches for vegetation monitoring based on "near-surface" remote sensing have been proposed in recent researches. These techniques use radiometric instruments or imaging sensors to quantify, at high temporal resolution, the seasonal changes in the optical properties of the vegetation canopy (Richardson et al. 2009; Sonnentag et al 2012).

In this study, a new system to identify vegetation changes, and in particular the phenological behavior of shrubland species, based on digital image sensors, is presented. The Automated Phenological Observation System (APOS) was developed and tested under the INCREASE EU-funded research infrastructure project (an Integrated Network on Climate Change Research), which is based upon large scale field experiments with non-intrusive manipulations of temperature and precipitation.

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2. MATERIAL AND METHODS

The experimental site is located in North-West Sardinia, Italy, within the Nature Reserve *Porto Conte-Capo Caccia*.

Vegetation of the area mainly consists of Mediterranean shrubland species, both semi-deciduous shrub species, such as *Cistus monspeliensis* L., *Dorycnium pentaphyllum* L., and *Helichrysum italicum* L., and evergreen scattered shrubs (for example *Pistacia lentiscus* L. and *Rosmarinus officinalis* L.). Climate is semi-arid with a remarkable water deficit from May through September and a mean annual rainfall amount of 640 mm.

The APOS system was installed at the experimental site in May 2012 and was operating until November 2013.

For determining the visual coverage (i.e., a specific area that have to be framed) and the related parameters, a specific custom software (VISPO-Visual Positioning) was developed.

From the visual analysis of the high resolution images, dates of the key phenological stages (i.e. leafing and flowering) were identified.

3. RESULTS

The general architecture of APOS (Fig.1) includes several components that perform the following major functions: (1) image acquisition, made using a camera connected to a robot, so as to frame and pan an area in accordance with the visual coverage of the experimental site; (2) image transmission, permitted by a modem-router for broadband access to Internet; (3) image processing (image stitching and elaboration) made by a remote computer.

For the image acquisition, a Canon EOS 7D digital camera with 18-135 mm zoom lens was used. Shutter speed was fixed to daylight as a function of the selected aperture and sensitivity. Manual exposure and "daylight" white balance mode were chosen to obtain an even level for effective post elaboration. ISO sensitivity was set to obtain low noise and low picture grainy (ISO 250). The image recording quality was selected either on RAW and JPEG format.

To keep the system protected from unfavourable environmental conditions, a PVC enclosure with a protecting roof was projected and constructed. To enhance the protection of the system from dust, rain, moisture and salt winds a waterproof covering was specifically designed and created. The camera-robotic mount system together with the protective enclosure was installed on the top of a 3 m trellis.

In the experimental site conditions, the desired panorama covers three experimental plots for climate manipulations including control (no manipulation), warming (overnight cover), and drought (interception of spring/fall precipitation) treatments.

Fig.1 - APOS System installed at the experimental site.

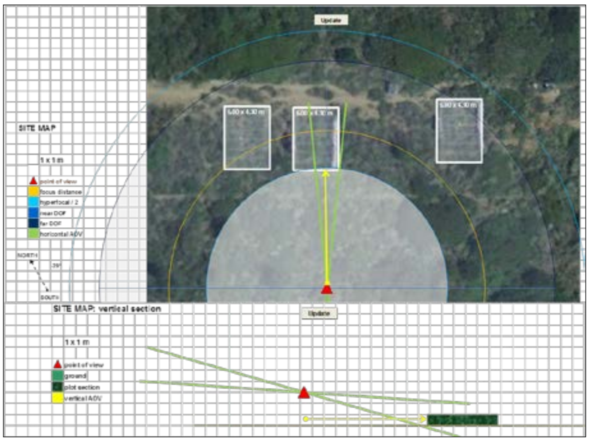

Fig. 2. Graphical representations of VISPO preset horizontal and vertical maps.

To define the rectangular area of the panorama, the upper left photo and lower right photo was set using VISPO. Fig. 2 shows an example of graphical representation on pre-set maps.

The system was set to acquire one panorama per day at noon (36 shots x panorama - 3 rows x 12 columns) with a 30% of image overlapping, and with an horizontal Angle of View (AOV) of 11.6°, and a vertical AOV of 7.7° for a single shot.

Phenology of shrublands was monitored during the period from October 2012 to May 2013. An example of panorama, and two image showing different levels of details, relative to May 6, 2013, is shown in Fig. 3. On each panorama Regions of Interest (ROIs) focusing major species of the shrubland ecosystem were identified. The same ROIs were analysed for all periods and key phenological stages by species were recorded. For example, in Fig. 3 flowering stage of *Cistus monspeliensis* L is clearly visible.

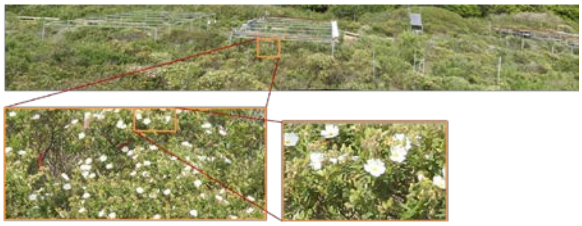

Fig. 3 Panorama and details of vegetation acquired with APOS system at Capo Caccia (IT) experimental site on May 6, 2013. The orange rectangular areas show two different zoom frames of the original panorama.

4. CONCLUSIONS

The comparison between the dates of the phenological stages obtained from the analysis of the ROIs and the dates of the phenological stages recorded in the field from visual direct observations showed that the APOS system is a reliable method to obtain large phenology datasets.

The application of new technologies such as digital imaging systems for detecting vegetation and plant phenology changes appeared to be promising for several reasons: (i) new technologies can make data collection cheaper and easier reducing labor and costs of field observations, (ii) new monitoring tools will exponentially increase rates of data collection, and (iii) long term data collection projects and large, long-term standardized data sets can be easier obtained since data can be systematically recorded and permanently stored.

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