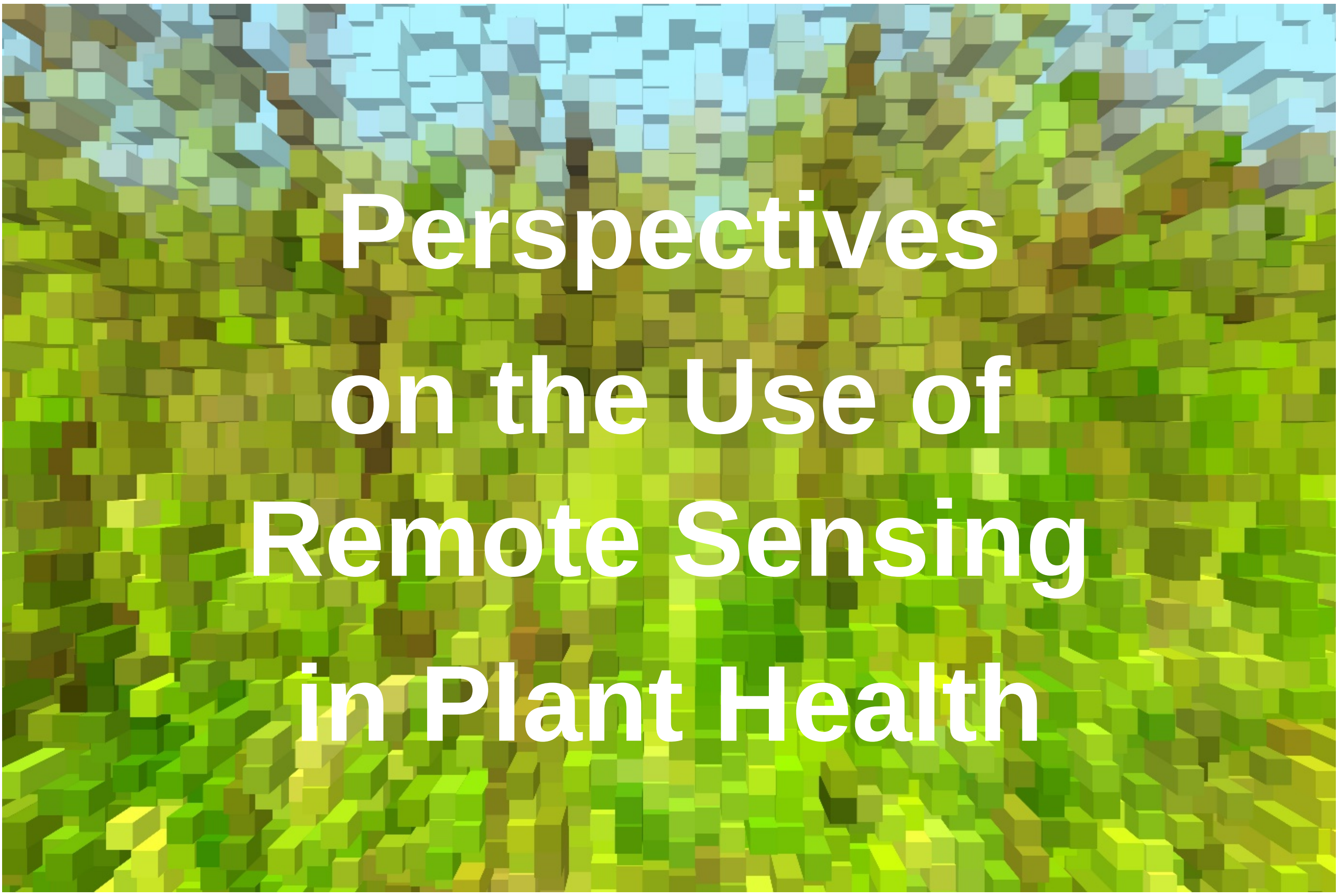

Perspectives on the Use of Remote Sensing in Plant Health

A scientific Colloquium organised by the
European and Mediterranean Plant Protection Organization
and the
Euphresco network for phytosanitary research coordination and funding

UNESCO, Paris, France

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Euphresco

Foreword

Early detection is key to effective intervention in plant health. In order to respond better to outbreaks of new pests, we must either improve contingency planning or surveillance or both. Our contingency plans must deal with outbreaks of the size likely to be detected, and our surveillance must detect outbreaks before they outgrow our contingency plans. Too often pests are already widespread before their presence is detected, our contingency plans cannot cope with the scale of action needed and the newly introduced pest cannot be eradicated or contained.

Even without considering latent infection or cryptic infestation in the early stages of its presence, detection of a pest at a low level is challenging. Finding the first few trees or crops or forest areas with symptoms is, as the old English expression has it, "like looking for a needle in a haystack". But with advances in scanning technology needles in haystacks are no longer as hard to find as they once were. If we continue to explain our problems not only to biologists but also to physicists, engineers and image analysis experts we may find that improving early detection is not only theoretically possible but increasingly affordable.

This colloquium, organised by EPPO and Euphresco and held in the week of the EPPO Council 2018, offers experts from different disciplines and managers of plant health services the opportunity to exchange experience and ideas in this important and rapidly developing area.

Martin Ward

Colloquium agenda

Chair: Toby Clark, Eurisy

09:00-09:10	**Introduction** (Martin Ward, European and Mediterranean Plant Protection Organization)
09:10-09:30	**Remote sensing, an overview** (Paul Brown, FERA Science Ltd., GB)
09:30-10:00	**Understanding forest health by remote sensing** (Angela Lausch, Helmholtz Centre for Environmental Research, DE)
10:00-10:20	**Early detection of diseases in forests and agricultural crops using advanced aircraft-based imaging: principles and case studies** (Pablo Zarco-Tejada, Joint Research Center, IT)
10:20-10:40	**The application of remote sensing for the official monitoring of *Citrus tristeza virus* and *Xylella fastidiosa*** (Anna Maria D'Onghia, CIHEAM of Bari, IT)
10:40-11:10	**Coffee break**
11:10-11:30	**Developments in remote sensing platforms, data and services** (Andy Nelson, University of Twente, NL)
11:30-12:00	**Discussions**
12:00-13:15	**Lunch**
13:15-13:45	**The use of remote sensing: complex regulation and economic feasibility** (François Christiaens, Inra Transfert, FR)
13:45-14:15	**Research needs and opportunities for the use of remote sensing in plant health** (Anna Maria D'Onghia, CIHEAM of Bari, IT and Paul Brown, FERA Science Ltd., GB)
14:15-15:00	**Discussions and conclusions**
15:00	**End of the meeting**

Remote sensing, an overview

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What is remote sensing? The presentation will provide an overview of this area, introducing some of the tools and techniques a remote sensing scientist will utilise daily to interpret and understand land processes. Remote sensing is the science and art of gathering data on an object/area without making physical contact. Aircraft, satellite and drone-based cameras and sensors are used to measure reflected and/or emitted electromagnetic radiation. This information, often captured as images, can then be analysed to extract additional, valuable data. Fera have been using remote sensing for plant health applications for many years, including ground inspection targeting and agricultural crop analysis. Fera are highly experienced in tree species classification and health analysis from remotely sensed data acquired by drones and satellites. The presentation will provide an overview to plant health remote sensing application using example projects, including small area woodland analysis of drone acquired data for inspection targeting and investigating how these small area studies can be scaled up to regional/national areas.

Understanding forest health by remote sensing

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In rapidly changing environments, *in-situ* terrestrial forest ecosystem monitoring approaches have made tremendous progress but they are intensive and often integrate subjective indicators for forest health. Remote sensing (RS) bridges the gaps of these limitations, by monitoring indicators of forest health on different spatio-temporal scales, and in a cost-effective, rapid, repetitive and objective manner. In this presentation, the concept of spectral traits (ST) and spectral trait variations (STV) in the context of forest health monitoring will be introduced and their prospects, limitations and constraints will be discussed. Stress, disturbances and resource limitations can cause changes in forest ecosystem phylogenetic, taxonomic, structural and functional diversity; we provide examples of how the ST/STV approach can be used for monitoring these forest ecosystem characteristics. The presentation will show that RS based assessments of forest health indicators using the ST/STV approach is an affordable and reliable technique suitable for monitoring. Even though the possibilities for observing the phylogenetic and taxonomic diversity of animal species are limited with RS, the taxonomy of forest tree species can be recorded, even though accuracy is subject to certain constraints. RS has proved successful for monitoring the impacts of stress on structural and functional diversity. In particular, it has proven to be very suitable for recording the short-term dynamics of stress on forest health, which cannot be cost-effectively recorded using *in-situ* methods.

Early detection of diseases in forests and agricultural crops using advanced aircraft-based imaging: principles and case studies

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Early detection of crop diseases and monitoring of affected areas are challenging tasks that require large-scale remote sensing technology coupled with advanced data processing methods. In recent years the miniaturization of sensors and vehicles has enabled the acquisition of remote sensing imagery in a cost-effective manner. Plant traits related to photosynthetic functioning and gas exchange retrieved from hyperspectral and thermal imagery have been shown to be feasible for the assessment of vegetation physiological condition. Thermal, narrow-band multispectral and micro-hyperspectral cameras on board manned and unmanned vehicles provide high-resolution remote sensing indicators potentially useful for the early detection of diseases in agriculture. In particular, hyperspectral sensors provide images at optimal high spatial resolution for the selection of pure vegetation pixels, therefore minimizing background and canopy heterogeneity. These images, via segmentation and automatic object-based image analysis, enable early detection of diseases at the tree scale. The work conducted on the assessment of early-disease detection via plant traits will be discussed, comprising radiance- and reflectance-based remote sensing indicators related to physiological condition, such as i) tree crown structure, evaluated by the sensitivity of the near-infrared bands to the foliar scattering of the canopy; ii) epoxidation state of the xanthophyll cycle evaluated by the absorption of three carotenoid pigments that are active in the xanthophyll cycle: violaxanthin (V), antheraxanthin (A), and zeaxanthin (Z); iii) chlorophyll *a*+*b*, evaluated by the absorption of spectral bands in the green, red, and red edge ranges to chlorophyll concentration; iv) blue/green/red ratio indices; v) chlorophyll fluorescence emission by photosystems I (PS-I) and II (PS-II), and vi) thermal-based indicators such as crop water stress index related to stomatal closure and water-stress caused by biotic stress. The use of these plant traits along with machine- and deep-learning algorithms will be discussed in the context of crop diseases, including the applicability of these methods to the new Sentinel-2 satellite data for large-scale assessment of damaged areas.

The application of remote sensing for the official monitoring of *Citrus tristeza virus* and *Xylella fastidiosa*

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Early and rapid detection systems for quarantine pests and diseases are crucial for efficient large-scale surveillance and rapid application of control measures. Research conducted by CIHEAM of Bari showed the application of Remote Sensing (RS) in the official monitoring of 2 quarantine pathogens in Apulia region, Italy: *Citrus tristeza virus* (CTV) and *Xylella fastidiosa* (XF).

An automatic procedure for individual fruit tree identification and data extraction, using GeoEye-1 multispectral image, was developed based on morphological characteristics of tree crowns. A four-step algorithm was implemented to rapidly and accurately capture tree position. This procedure supported RS applications, in a GIS environment, for the identification of trees suspected to be infected with CTV on large scale. Spectral reflectance of CTV-positive plants was higher in visible region and lower in the near infrared region. Specific vegetation indices were selected for the implementation of a CTV detection algorithm for processing WordView-2 satellite image. The correlation with CTV infection ranged from 90% in severely symptomatic trees to 52% in mild chlorotic or apparently asymptomatic trees. The prediction map of a pathogen-free area allowed the identification of a new CTV outbreak, thus revealing the effectiveness of this approach in large scale virus monitoring.

For *Xylella fastidiosa*, photointerpretation of very high-resolution aerial images was successfully applied in the identification of symptomatic trees in buffer/containment zones of the demarcated area. Based on the identification of phototypes, morphologically associated to the Olive Quick Decline (OQD), a total of 637 OQD-like trees out of 17 220 photointerpreted trees (3.7%) were identified. RS was therefore effective in finding new foci of the infection in the containment zone. An innovative and multidisciplinary RS- and IT-based surveillance system was developed and applied in the official monitoring programme to orientate inspections to XF-suspected sites, allowing the immediate modification of the demarcated area.

Developments in remote sensing platforms, data and services

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The quantity of remote sensing data, from space, air and ground-based sensors, continues to increase at a rapid pace. Both the commercial and public sectors are using this data to offer services that range from information streams that still requires remote sensing knowledge for further interpretation and analysis to tailored services that deliver actionable information through an app or support system. This unprecedented amount and diversity of sources is changing the question from “where can I get information” to “how do I choose which information to use”.

The presentation will focus on some recent developments such as:

- The European Union's Earth Observation Programme (Copernicus) which includes the European Space Agency (ESA) constellation of SENTINEL platforms for monitoring the environment with a range of sensor capabilities.
- The Copernicus Data and Information Access Services (DIAS) which aims to deploy operational access platforms to boost user uptake and to stimulate innovation and the creation of new business models based on Earth Observation data and information.

The role of these programmes (and others) will be highlighted in some example applications related to plant health before concluding with some observations on what is needed to make remote sensing a sustainable and reliable source of information for plant health applications.

The use of remote sensing: complex regulation and economic feasibility

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In many countries, a very large number of companies have developed as soon as regulation allowed drone flights. In 2018, the majority of drones acquire images; maps are produced later. Technological advances are enabling drones to fly autonomously (without human control) or to spray products. However currently regulatory authorities do not allow their use.

Raw images of fields acquired by heavy satellites, are becoming freely available. The same applies to computing methods that are required to extract information from images. More and more miniature satellites collect field images daily, closing the gap of the frequent revisit rate. Drones and sensors prices are low and decreasing. Compared to a few years ago, only a few unmanned aerial vehicle (UAV) operators are now in the market. Innovation includes enhanced flight endurance, or swarm flights. The European market for remote sensing for precision agriculture is growing, and it is estimated it will reach 317 M$ in 2020.

Some hurdles still have to be overcome. Data (including archives) from satellites are not easily accessible, and they may lack metadata such as the acquisition date, which is critical to their full exploitation. When plants develop quickly, fields images may be missing: this prevents the predictive models to be run. Despite their reduced costs, miniature satellites still need to prove their reliability. The growth of the drone market will slow down over the next years due to low commodity prices. Drone-service companies still need to embrace cloud computing and storage to be efficient and competitive. The devices used for scientific remote sensing need to be simplified for consumer-grade products. Conversely, basic information extracted from images acquired by off-the-shelf sensors embedded in drones or miniature satellites requires different calibration steps, which require solid agronomic knowledge and skills to be usable by professional end-users. Every crop is different, thus lessons learned from studying high-resolution imagery for one crop are not necessarily transferrable to other crops. Hence the need to disseminate case studies about the benefits of input modulation.

Precision agriculture aims to reduce costs. Farmers' investment in remote sensing technologies is proportional to cost reductions. Other agricultural economic players may be more likely to adopt early remote sensing technologies. For agricultural services, unmanned aerial systems must be viewed as a complement to, rather than a competitor of, satellite and manned aircraft imagery.