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Remote Sensing in support of Plant Health Measures - Findings from the Canopy Health Monitoring (CanHeMon) project

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Contents

Abstract

The Canopy Health Monitoring (CanHeMon) project ran at the Joint Research Centre of the European Commission from mid-2015 to mid-2018 and was funded by DG SANTE. Its aim was to develop and implement remote-sensing based monitoring of a section of the Pine Wood Nematode buffer zone to support the measures against this quarantine plant pest there, and particularly the detection of pine trees in poor health . This report describes the main findings from the project, which achieved the detection of ca. 19 000 individual declining coniferous trees through remote sensing, and an outlook on the potential future use of remote sensing in support of plant health measures.

Foreword

The Canopy Health Monitoring (CanHeMon) project ran at the Joint Research Centre of the European Commission from mid-2015 to mid-2018 and funded by DG SANTE. This report provides the key findings of the project and a broader outlook on the use of remote sensing to support plant health policy in the EU.

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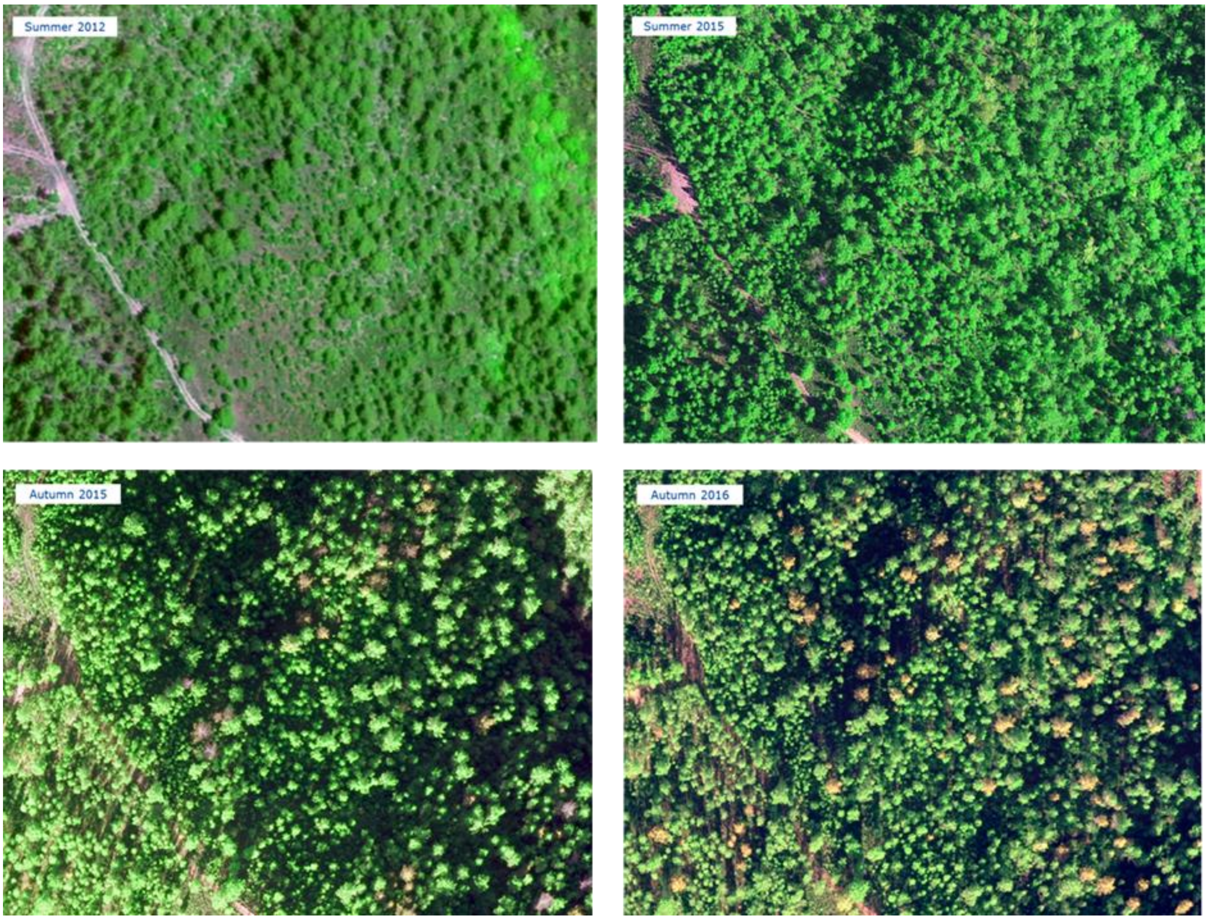
Executive summary

Policy context

DG SANTE is responsible, among other things, for the European Union's Plant Health legislation, which aims to put in place effective measures to protect the Union's territory and its plants, as well as ensuring trade is safe and the impacts of climate change on the health of EU crops and forests are mitigated. For specific harmful organisms that threaten its crops and forests, the EU takes emergency control measures. These organisms include the Pine wood nematode (*Bursaphelenchus xylophilus*), a quarantine pest that can kill European coniferous tree species and is spreading through Portugal since the end of the 1990s. As part of the emergency measures against the Pine wood nematode (Decision 2012/535/EU), Portugal should perform, outside and during the flight season of the vector, surveys of the coniferous trees located in the 20 km buffer zone established along the Spanish border with the aim to detect trees which are dead, in poor health or affected by fire or storm. According to the Decision, these trees shall be felled and removed each winter lest they attract the longhorn beetle (*Monochamus* species) that is responsible for spreading the nematode. Monitoring such a large area (> 20 000 km^2) for individual trees in declining health is a daunting task, particularly as large stretches of the area are hard to reach with vehicles or on foot. The aim of the CanHeMon project was to demonstrate how remote sensing could support this monitoring task, by collecting and analysing remote sensing data of the area to pinpoint individual coniferous trees in declining health.

Figure 1. The figures show the same forested area, imaged by 50 cm orthophotos acquired in 2012 by the Portuguese authorities and by subsequent, higher-resolution, images acquired by the CanHeMon project. In this rendering, healthy pine trees are bright green, unhealthy ones yellow, and dead ones pale purple. The area measures ca. 350 m across and is part of the 400 km^2 area monitored during the project.



The work needed to adhere to a tight time schedule as trees might not decline and attract long horn beetles until late summer or early autumn, meaning remote sensing data should depict the state of the trees in the autumn. Then, the images had to be processed and analysed within weeks in order for the results to be useful for implementing the emergency measures. These measures namely stipulate that all declining trees must be removed by the end of April.

Main findings

Through dedicated airborne campaigns, CanHeMon acquired, in late November 2015 and November 2016, remotely sensed images of a 400 km^2 area in Portugal near Castelo Branco. This area is at particular risk of Pine wood nematode infection, and could be a gateway for the pest spreading to Spain [1]. Through automated image analysis, aided by visual checks of the images, CanHeMon detected and pinpointed more than 19 000 pine trees that had declined in health in this area over the course of 2016, which was a particularly dry year in the region. The analyses, completed in January of 2017, provided the exact coordinates of all trees individually, so they could be checked by people on the ground.

Further tests showed that, with dedicated computing hardware [2] and knowhow it is possible to apply this image analysis technique over larger areas, even the entire Pine wood nematode buffer zone, provided remote sensing data are purpose-collected.

To facilitate the use of remote sensing derived results in the field, the project developed a mobile application. The application also allows users to provide field observations to the remote sensing laboratories so they can be used to improve image analyses. To permit the use of the application in remote terrain, it also works when the user is off-line.

Key conclusions on opportunities and challenges in using remote sensing to support plant health measures

— Implementing plant health measures can be labour intensive, and there are **many opportunities for remote sensing technologies to contribute** to their efficacy. CanHeMon used remote sensing to detect individual coniferous trees that needed to be removed because they could contribute to the spread of a quarantine pests, a task that is difficult to complete from the ground only. In addition, remote sensing can help to increase preparedness for outbreaks (e.g. mapping the distribution of host plants), or in early detection of potentially infected plants [3]).

— As epidemiological characteristics vary widely between pest outbreaks, **remote sensing campaigns need to be optimized on a case-by-case basis** [4]. Such optimization needs to balance multiple criteria, which include:

- The optimal **timing** and frequency for observations. Often, the timing of image acquisition needs to be chosen to coincide with precise phases in disease or stress symptom development, as well as opportunities for intervention. To support the measures against the Pine wood nematode, it was critical that images be collected at the end of autumn, while standard aerial surveys for land cover mapping are usually carried out in summer when more light is available.
- The **spatial detail** required (individual trees vs. entire landscapes). Eradication of a plant pest generally requires that individual infectious plants can be detected. However, freely available satellite images are not of sufficient spatial resolution to distinguish individual trees. Nonetheless, with their wide-area coverage satellite images are often well-suited to map the damage caused by an endemic plant pests over large areas [5, 6]. Instead, when particular orchards need to be inspected frequently, acquiring images from a drone, might be the most cost-efficient.

- The **characteristics** of the plants to be detected. Detecting early symptoms of a disease sets very different requirements on **camera specifications**, compared to detecting more advanced symptoms that affect an entire crown or canopy.
- The **acceptable margin and type of errors**. In CanHeMon, errors in remote sensing analyses were of two kinds; healthy trees might be mislabelled as unhealthy during image analyses, or existing unhealthy trees could be missed by the image analysis. Both errors have different implications: the first type might increase the likelihood of Pine wood nematode spreading undetected, while the second one might lead to unnecessary field inspections of trees. The design of remote sensing campaigns, and analyses, should be adapted to the balance risk managers wish to strike between these two risks. For the project, we built a dedicated web-interface to visually inspect the declining trees in the remotely sensed images, allowing accurate assessment of the margin and types of error in the detection, in order to decide if the image analysis algorithm needed further refinement.

Outlook

— Remote sensing data are becoming more readily available; the EU's Copernicus programme is now generating 12 TB of images per day. At the same time, the INSPIRE directive enables the sharing of aerial photographs between public sector organisations, and images are being taken from a growing range of platforms which includes, not only satellites and manned aircraft but also drones, low-cost small satellites, and in the future, high-altitude pseudo satellites. Furthermore, technological innovation is bringing down the size and cost of sensors, further advancing quantitative remote sensing [7]. Meanwhile, images collected by citizens on the ground are now more easily acquired too for mass analysis (e.g. [8]).

— Modern computing infrastructure is increasing the speed at which large volumes of image data can be processed. CanHeMon demonstrated that 30 cm aerial photographs of the entire Pine Wood Nematode buffer zone can be analysed for clearly declining trees in a matter of hours on the JRC's dedicated computing cluster, a task which could take more than a year on a standard desktop PC. Infrastructure to collect orthophotos over large areas is available throughout Europe, but as these images do not offer much spectral detail, they generally do not allow detecting phenomena that are not obvious to the naked eye. Meanwhile, work lead by the JRC in parallel to CanHeMon showed that, over smaller areas, early and even non-yet-visible symptoms of *Xylella fastidiosa* infection in olive trees, are detectable using very high resolution images from hyperspectral and thermal cameras on aircraft [3].

— New developments in machine learning algorithms can greatly expand the use of image analysis in plant health management, not only detecting plants in decline, but also in attempts to attribute decline symptoms to a particular disease [9] and detecting insect pests themselves in images. Since the completion of the CanHeMon project, the JRC has tested the use of Neural Networks based on instance segmentation to detect and outline large declining trees in the images acquired over Portugal. Preliminary results show great promise of this method to make the image analysis both faster and more generalizable and transferrable.

— Often, machine learning algorithms rely heavily on training data, illustrating the importance of easily exchanging field observations, laboratory measurements, and results of remote sensing analysis. As remote sensing technology further develops, its benefits to plant health management will depend in part on the ease with which its results can be used in the field and laboratory and, vice versa, how easily lab and field measurements can be integrated in remote sensing analyses.

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