Chapter 26

Monitoring of Bark Beetle Forest Damages

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Abstract In this chapter, we present a multi-source remote sensing approach for country-wise monitoring of bark beetle calamity to support government decision making processes. In the first part, we describe the forest health monitoring system, which is based on the analysis of satellite big data—Sentinel-2 observations collected every five days. We propose an automated processing chain for high-quality cloud-free image synthesis for user-defined acquisition periods. Such a processing chain is applied to yield yearly cloud-free images of the entire Czech Republic from 2015 onwards. Based on this data, we assess forest health trends using Sentinel-2 derived vegetation indices and in situ data of forest status. Finally, we demonstrate the benefits of multi-source remote sensing for timely and objective mapping of bark beetle spread by combining several data sources, including planet high-resolution satellite data, Sentinel-2 forest health maps and other maps of forest conditions. Detected bark beetle sanitary logging and dead standing wood polygons are used by the Ministry of Agriculture of Czech Republic in their decision processes regarding the management of affected forest areas.

26.1 Introduction, Motivation and Goals

In recent years, there is significant forest health decrease in the Czech Republic (Fig. 26.1), with similar trends of rapid increase in forest harvested area observed also for other European countries [1]. Forest loss and forest health decay can be attributed to various factors, both biotic and abiotic. These are independent of the forest owner and his/her management practices, resulting in loss of forest value compared to the unaffected forests (Fig. 26.2). One of the serious obstacles for finding a solution to the situation is the lack of timely and objective information about the forest conditions, especially for forest plots of small sizes. Under the ongoing bark beetle calamity, such information should be ideally updated multiple times a year,

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Fig. 26.1 Percentage share of salvage logging (dashed line—secondary y-axis on right) to total logging (green line—primary y-axis on left) and salvage logging (red line—primary y-axis on left)

Fig. 26.2 Decrease of timber price in Czech Republic between 2011 and 2020 (green—high quality wood, blue—low quality wood) as a result of oversupply of raw wood due to the bark beetle calamity

ideally as a convenient Web service for a broad range of users and the government decision making. As an example, the government in Czech Republic compensates the forest damage and potential loss to forest owners by the means of direct subsidies and indirect tax reliefs. In order to correctly identify the affected forest owners and their eligibility for subsidies/tax relief, the Ministry of Agriculture of Czech Republic

must precisely spatially locate the affected areas. For this purpose, the field surveys were traditionally used. These are, however, local, costly, and subjective.

The main goal of this pilot is the development of Web-based mapping services for government decision making in the field of forestry which would help in the ongoing unprecedented outbreak of bark beetles. The services should objectively describe the current health status of the forests and allow for timely pro-active management in the forests with regards to the allocation of both the harvesting resources and finances into the most affected regions.

26.2 Pilot Set-Up

We developed a processing chain for satellite data interpretation for forest health assessment and started its routine deployment at FMI's infrastructure. Country-wise forest health trends are obtained in two relatively independent steps:

Step 1—Sentinel-2 satellite data preprocessing and cloud-free mask synthesis.

Step 2—Retrieval of absolute values of forest leaf area index (LAI) and its trends.

The key to assessing the health status of forests from remote sensing data is the availability of a high quality (i.e., cloud-free) image mosaic that is generated from all-available Sentinel-2 satellite observations. This is a basic prerequisite for any remote sensing data interpretation. The methodology for forest health assessment proposed here presents a novel processing chain for automated cloud-free image synthesis based on the analysis of all available Sentinel-2 satellite data for a selected sensing period (e.g., the vegetation season from June to August) via three successive processes:

- (1) batch downloading of all-available Sentinel-2 observations,
- (2) atmospheric corrections of raw images (so-called L2 process), and
- (3) automated synthetic mosaic generation (so-called L3 process, or space-temporal image synthesis (see Fig. 26.3)).

Due to its high computational and data storage requirements, the processing chain is implemented on IT4Innovations supercomputer facility (© 2018 VŠB-TU Ostrava), which enables for distributed computing on many computational nodes. In the first step, Sentinel-2 scenes are automatically downloaded from Copernicus Open Access Hub (global Copernicus data access point) and CESNET (collaborative ground segment of Copernicus implemented in Czech Republic). Next, the atmospheric and topographic corrections are performed for each Sentinel-2 image using sen2cor tool (ESA). Then, each pixel in image mosaic is evaluated independently in the time series of images. Selection of the highest quality pixel, having lowest cloud cover and being in vegetation growing season, is based on a decision tree using the values of vegetation index sensitive to biomass (e.g., the normalized difference vegetation index, or NDVI). In addition to highest NDVI value, several other rules are applied in the form of a decision tree: these include cloud masking

Fig. 26.3 Flowchart of the processing chain from automated production of cloud-free satellite images from source Sentinel-2 observations

and a priori assumptions on reflectance range in visible and near-infrared regions. An example of the synthetic cloud-free mosaic and the individual dates is shown in Fig. 26.4.

In the presented methodology, health status is not assessed as absolute amount of leaf biomass (having LAI as proxy for leaf biomass), but as its change over time. The basic premise is that the health status can be objectively determined only by observing the relative change in LAI over time. In the first step, we calculate selected vegetation indexes (e.g., normalized difference vegetation index—NDVI, red edge inflection point—REIP, and normalized difference infrared index—NDII), and image transformations (e.g., components of tasseled cap transformation) and compare their sensitivity against in situ data from sampled plots (e.g., LAI and ICP Forests plots). For each dataset, linear regression models between in situ data and Sentinel-2 indices were calculated and evaluated. For indices yielding best linear fit, the neural network was trained and applied per pixel to retrieve prediction LAI maps.

In summary, we propose a forest health classification system, which will evaluate forest health on pixel level as a change in LAI values over time and classify each pixel in the following five categories:

- I. Significant increase: increase in LAI by 1.5 and higher,
- II. Moderate increase: increase in LAI from 0.5 to 1.5,
- III. Stable conditions: change of LAI between -0.5 and 0.5 ,
- IV. Moderate decrease: decrease in LAI from -1.5 to -0.5 ,

Fig. 26.4 Automated per-pixel selection of best quality observation from the time series of Sentinel-2 observations

V. Significant decrease: decrease in LAI higher than -1.5 .

The countrywide assessment of forest health is carried out on cadastral level, where the area of forest stands of classes IV and V are evaluated for the total forest area of cadastre for stands of age between 0 and 80 years. This condition is put due to the fact that it is not possible to distinguish between sanitary logging and planned logging for old-grown forests—both will be reflected by a sharp decrease in LAI values. Each cadastre is assigned to one of the following categories:

- I. Category 1: 0–5% of class IV and V forests—healthy stands,
- II. Category 2: 5–10% of class IV and V forests—predominantly healthy stands,
- III. Category 3: 10–15% of class IV and V forests—moderate conditions of stands,
- IV. Category 4: More than 15% of class IV, and
- V. forests—damaged stands.

Maps of retrieved LAI from 2015 to 2018 and the between year changes are being routinely published on FMI's mapserver (<https://geoportal.uhul.cz/mapy/MapyDpz.html>). This allows easy access of the maps for end users—stakeholders in the forestry sector in Czech Republic (Ministry of Agriculture, Forests of the Czech Republic, Military forests, etc.). This Web-based mapping solution is capable of combining different map sources for background map layer (topographic maps, orthophotographs, base maps, cadastral maps) on both desktop and mobile Web

browsers (user geolocation is available for mobile platforms). Example of a country-wide LAI map for 2018 is shown in Fig. 26.5, LAI change between 2018 and 2017 in Fig. 26.6.

The forest health maps were also published as Web-mapping service (WMS) on FMI's mapserver (WMS URL: https://geoportal.uhul.cz/wms_dpz/service.svc/get). This allowed dissemination of the results to the broad forestry community (Fig. 26.7). The following map layers were made available:

- Leaf area index maps of 2015, 2016, 2017, 2018, 2019, and 2020.

Fig. 26.5 Example of FMI's mapserver with forest health map of 2018

Fig. 26.6 Example of FMI's mapserver with forest health map trends between 2017 and 2018 (change in leaf area index)

Fig. 26.7 Web-mapping service of forest health maps (Leaf area index map of 2018) running in QGIS 3.6.0 environment

- Leaf area index change maps of 2016–2017, 2016–2018, and 2017–2018.

In addition to routine publication of LAI maps and its trends on a Web-based portal, the data has been used by the Ministry of Agriculture for allocation of available harvesting resources to fight the unprecedented bark beetle outbreak that forests in Czech Republic are currently undergoing. Here, the Sentinel-2 based LAI maps were combined with the timely clear cut and standing dead wood detection from planet commercial satellite data of high spatial (<5 m) and temporal (daily), canopy height model of stereo-orthoimagery, and tree species map to identify the most affected cadastrals, where the sanitary logging occurs. Combination of these unique data sources allowed us to detect the recent salvage logging and dead wood in mature spruce forests—areas affected by the unprecedented bark beetle calamity in Czech Republic (see Fig. 26.8 for more details).

The resulting analyses—polygon layers of timely detection of salvage logging and dead wood—are published on (1) FMI's mapserver, (2) WMS service of the mapserver, and (3) specialized Web-based portal “Kurovcovamapa.cz” (see Fig. 26.9).

26.3 Business Value and Impact

The Web-mapping service for government decision making will in the future be extended to allow publication of the results to the broad forestry community of

Fig. 26.8 Workflow of multi- source remote sensing approach for bark beetle monitoring (www.kurovcovamapa.cz)

Fig. 26.9 Web-based portal “Kurovcovamapa.cz” for the broad public allowing easy access to timely information in the bark beetle calamity in Czech Republic

the Czech Republic as dedicated WMS services and specialized map portals (e.g., “Kurovcovamapa.cz”). According to those maps, the Ministry of Agriculture of Czech Republic issued a “Public decree”—a legislation instrument to help forest owners by reducing the regulation of their obligations under the Czech forest law, so that they can manage the bark beetle calamity in the most affected regions (Fig. 26.10). The decree is regularly updated several times per year to reflect the

Fig. 26.10 Legislative instrument (the public decree) with an annex that defines the list of cadastral units selected according to the analyses presented in this chapter

actual situation of the forests (Fig. 26.11). All these measures will help reduce the overall loss for forest owners due to climate change and the ongoing bark beetle calamity in the Czech Republic.

Fig. 26.11 Cadasters of bark beetle calamity identified using multi-source remote sensing approach, green—cadasters unaffected by bark beetle calamity, red—calamity zones of bark beetles. Cadasters are updated typically three times per year in the vegetation season

26.4 Conclusions

The exploitation of described DataBio pilot results was successfully achieved via:

- Map portal of the Forest Management Institute (<https://geoportal.uhul.cz/mapy/MapyDpz.html>)
- Web-mapping service for online publication of forest health layers in GIS and Web environment (https://geoportal.uhul.cz/wms_dpz/service.svc/get)
- Specialized Web portal “Kurovcovamapa.cz” (<https://www.kurovcovamapa.cz/>)

Moreover, based on the timely detection of recent salvage logging and dead wood, the Ministry of Agriculture of the Czech Republic issued a public decree to apply different forest management regimes in the areas with ongoing beetle calamity. The areas are updated regularly and are based on the outcomes of the DataBio pilot. Presented work thus demonstrates the potential of the integration of multi-source remote sensing (e.g., the multispectral Sentinel-2 data, high spatial and temporal resolution planet data, and the ancillary forestry data) for the decision making in the forestry sector.

Reference

1. Ceccherini, G., Duveiller, G., Grassi, G. et al. (2020). Abrupt increase in harvested forest area over Europe after 2015. *Nature* 583, 72–77. <https://doi.org/10.1038/s41586-020-2438-y>.

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