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Chapter 24
Forest Variable Estimation and Change Monitoring Solutions Based on Remote Sensing Big Data

Jukka Miettinen, Stéphanie Bonnet, Allan A. Nielsen, Seppo Huurinainen, and Renne Tergujeff

Abstract In this pilot, we demonstrate the usability of online platforms to provide forest inventory systems for exploiting the benefits of big data. The pilot highlights the technical transferability of online platform based forest inventory services. All of the services tested in the piloting sites were technically implemented successfully. However, in new geographical areas, strong user involvement in service definition and field data provision will be needed to provide reliable and meaningful results for the users. Overall, the pilot demonstrated well the benefits of technology use in forest monitoring through a range of forest inventory applications utilizing online big data processing approaches and inter-platform connections.

24.1 Introduction, Motivation, and Goals

Remote sensing data from traditional aerial platforms, unmanned aerial vehicles (UAV), and satellite sensors presents an optimal way to timely collect information on forest cover and characteristics over large and small interest areas. The amount of available remote sensing data has greatly escalated during the past decade. This escalation is caused by a growing number of sensors, more frequent observations, and an increasing spatial and spectral resolution of the sensors. The remote sensing data boom enables implementation of more frequent and detailed remote sensing-based forest monitoring approaches than previously possible.

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At the same time, new big data processing approaches need to be developed to fully exploit the potential provided by the increasing data volumes. Particularly, the availability of the Copernicus Sentinel-2 multispectral optical data and its applicable free data policy present a great opportunity for developing low-cost commercial applications for environmental monitoring. Online platforms, such as the Forestry Thematic Exploitation Platform (Forestry TEP; https://f-tep.com/) and the EO Regions! (https://www.eoregions.com/), enable creation of services for efficient processing of satellite data to value-added information.

The goal of this pilot was to develop a forest inventory system on the Wuudis Service (https://www.wuudis.com/) based on remote sensing data and field surveys. Selected DataBio project partners integrated their existing market-ready or almost market-ready technologies into the Wuudis Service, and the resulting solutions were piloted with the Wuudis users, forestry sector partners, associated partners, and other stakeholders.

24.2 Pilot Set-Up

The consortium for this pilot consisted of: (1) Wuudis Solutions, Finland, (2) VTT Technical Research Centre of Finland (VTT), (3) Spacebel, Belgium, and (4) Technical University of Denmark (DTU). In addition, Forest Management Institute (FMI) from the Czech Republic coordinated their own pilot activities with this pilot. All activities were linked to the Wuudis platform, and inter-platform connections were developed between Wuudis and two other platforms coordinated by consortium members: Forestry TEP coordinated by VTT and EO Regions! coordinated by Spacebel.

Three different test sites were used in the pilot: (1) the Hippala forest estate in Southern Finland, (2) Walloon Region, Southern Belgium, and (3) the forest property 'Barbanza, Enxa, Xian, Dordo, Costa de Abaixo e O Sobrado', located at the municipality of Porto do Son, A Coruña province in Galicia, in Northwestern Spain. The Galician site is owned by the rural community 'Comunidade de Montes Veciñais en Man Común (CMVMC) de Baroña' and managed by the Asociación Sectorial Forestal Galega (ASEFOGA), a forest owners' association based in Santiago de Compostela.

In the pilot sites, VTT, Spacebel, and DTU conducted demonstrations and further development of their forest monitoring applications and services. In parallel, FMI was developing a new methodology for forest health assessment, which allows assessment of forest health in the entire area of Czech Republic. The results of the FMI work (described in detail in 'Chapter 26 Forest damage monitoring for the bark beetle') can be linked to the online platforms used in the pilot through the Open Geospatial Consortium (OGC), Web Map Service (WMS), and Web Map Tile Service (WMTS) interfaces.

24.3 Technology Used

24.3.1 Technology Pipeline

In this pilot, technology pipelines were established to facilitate smooth utilization of remote sensing data for forest inventory purposes in an online environment. The pipelines combined data sources, processing software components, and inter-platform communication into continuous processing chains that enable fast data processing and smooth delivery of the results. Figure 24.1 presents an example of the forest inventory pipeline that was created to allow efficient forest structural variable estimation with VTT proprietary software utilizing the *Probability* [1] method and to connect this process with the Wuudis platform. The pipeline utilizes the Forestry TEP platform for data sourcing and processing, feeding information to the Wuudis platform. The VTT software Envimon and Probability are used in data analytics. The four main components of the DataBio generic pipeline (i.e., data acquisition, data preparation, data analytics, and data visualization and user interaction) are marked in red text in Fig. 24.1.

The pipeline presented in Fig. 24.1 generates layers of forest structural variable estimates, by combining information derived from the 10 m resolution Sentinel-2 data with field sample plots. Sample plot data collected by the Finnish Forest Center (FFC) is used as a reference in the estimation model training.

For easy integration of satellite maps and the analyzed (highlighted) theme maps, standard OGC WMS or WMTS interfaces were used as a starting point. The Wuudis
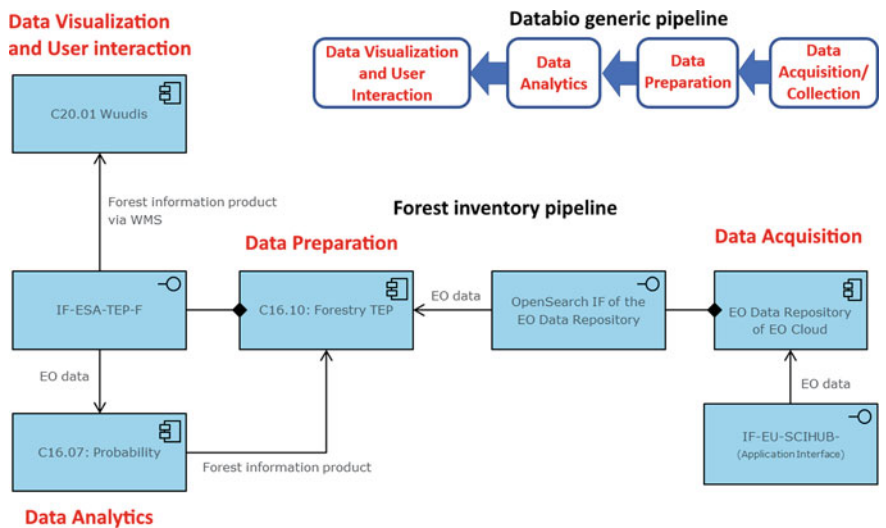
Fig. 24.1 Example of the forest inventory pipeline established in the pilot, with reference to the generic DataBio pipeline concept

Service is using OpenLayers as the mapping client library. In the first stage of the project, the forest variable estimates produced by VTT were presented as image raster data (GeoTIFF format) with 10 m pixel resolution, with one image band per variable and each pixel containing the estimated variable value. The output was made available for integration in the Wuudis end user system via WMS interface from the Forestry TEP.

In the second stage of the pilot, the system was further developed to enhance the connection between Forestry TEP and the Wuudis platform. Delivery of the VTT forest variable estimates produced with the *Probability* [1] method was enabled in the Extensible Markup Language (XML)-based Finnish Forest Information Standard [2] format. This approach allows to use forest management plan geometries as a baseline; remote sensing based, pixel-format information is expanded to these geometries and stored back in an updated forest management plan. In this enhanced system, the data is provided from the Forestry TEP in a ready-to-use format (for the end users), which could be used in Wuudis or any other online platform with no further calculations needed. The Forestry TEP service also allows retrieving the forest variable estimates in a standard Geographic JavaScript Object Notation (GeoJSON) format.

In the Hippala pilot area, Finland, the estimated forest variables include: stem number; stem volumes for pine, spruce, broadleaved, and total; diameter; basal area; and height. Figure 24.2 illustrates the species-wise volumes estimated for the Hippala forest estate.

The technology pipeline presented above relates to a larger context of connection and optimal utilization of various types of online platforms. Figure 24.3 presents Forestry TEP as an online platform that enables efficient exploitation of the Copernicus Sentinel satellite data in forest monitoring and analysis. The satellite data is sourced from the European Space Agency (ESA) and made available on platform,

Fig. 24.2 Visualization of species-wise volumes generated using the Forestry TEP platform at Hippala. Shown is the estimated stem volume of the dominating tree species in each 10 m by 10 m area (red = broadleaved, blue = pine, green = spruce). The darker the color, the higher the volume (range around 0–300 m^3/ha). Forest stands are outlined by red lines
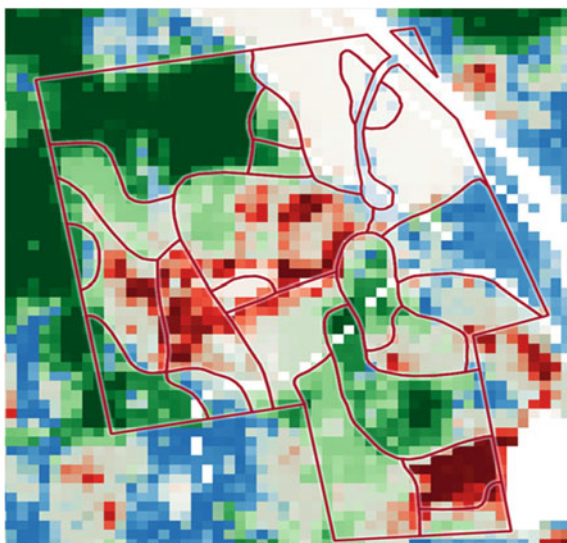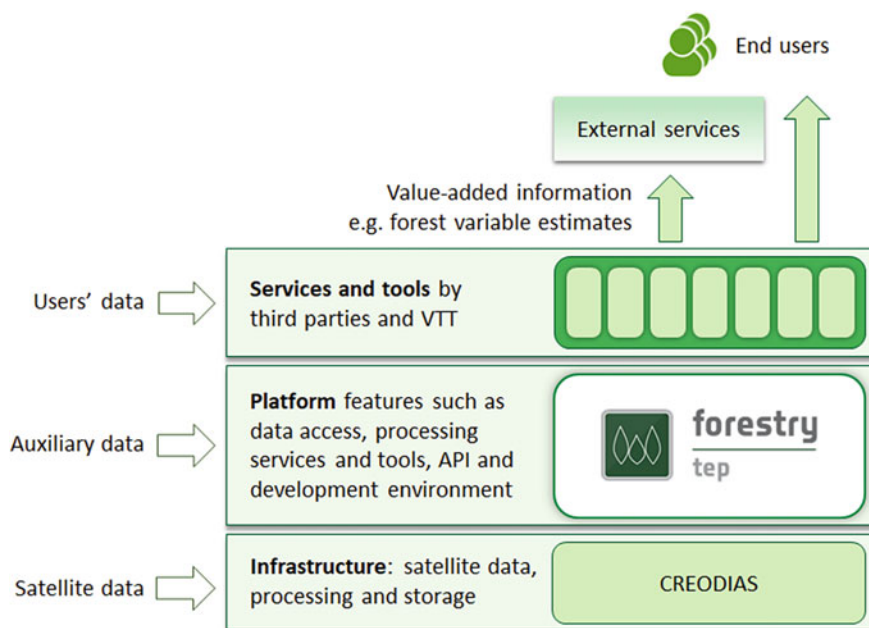
Fig. 24.3 Forestry TEP is an online platform for efficient exploitation of Copernicus Sentinel and other satellite data in forest monitoring and analysis. Along with the data, the platform offers processing services and tools and allows to develop and share new services

via the underlying infrastructure and data services of CREODIAS, one of the five Copernicus Data and Information Access Services (DIAS) platforms. Forestry TEP provides processing services and tools and serves also as a platform for new services, such as the Envimon and Probability tools of VTT that were used in this pilot. Subsequently, the results produced in Forestry TEP can serve as input for various external service platforms (like Wuudis or EO Regions!). In the expanding landscape of different types of platforms with increasing data volumes, efficient inter-platform pipelines are essential in enabling exploitation of the full potential of EO big data for forest inventory purposes.

In the DataBio project, inter-platform connections between EO Regions! and Wuudis were also developed, enabling numerous possibilities to feed the Wuudis Service in geographical and dendrometric content. EO Regions! is a commercial showcase of a satellite image processing system (e.g., Sentinel-2) allowing automated processing. The products can be downloaded by the customer (after online ordering) or directly connected to another platform dedicated to a specific theme (e.g., forest management). The connections between EO Regions! and Wuudis (Fig. 24.4) allow several scenarios for combined use of the two platforms. Users can, e.g., (1) work independently on either platform to import their data, or (2) use mobile applications to encode dendrometric data, or (3) order forestry services from either platform. In all
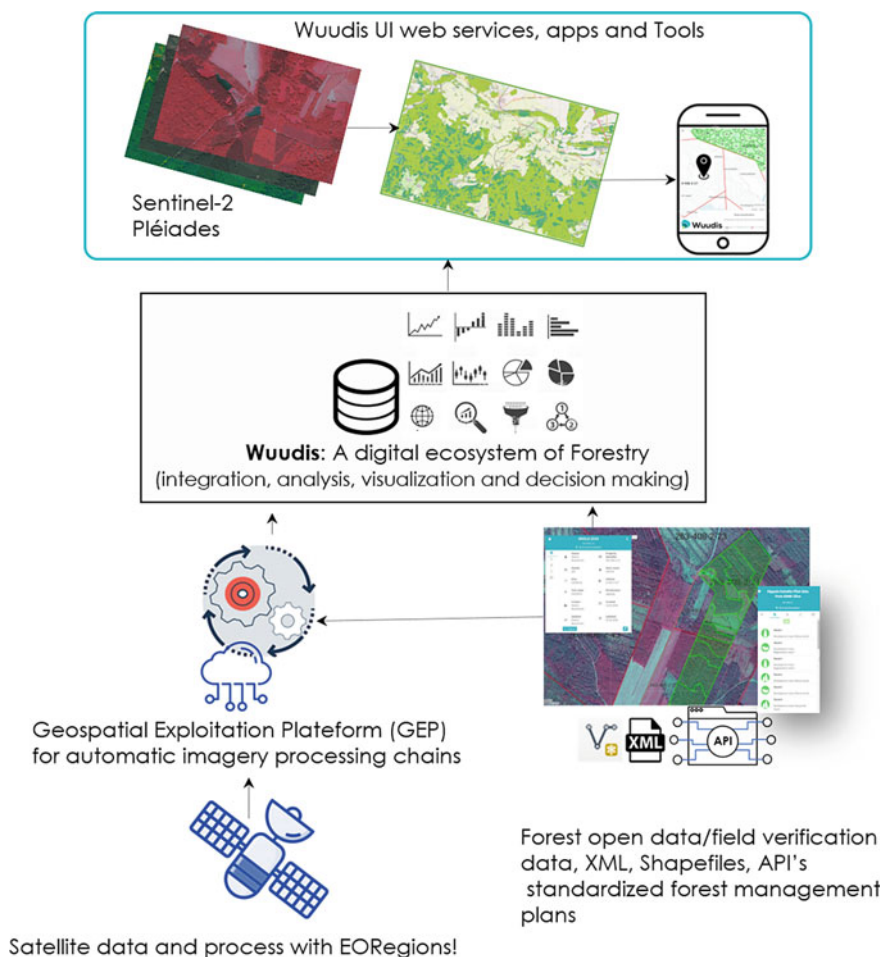
Fig. 24.4 EO Regions! platform provides access to various remote sensing services based on earth observation data, in particular the Copernicus data, allowing automated processing and connection with other platforms

of these cases, the users will benefit from the increased offering and functionalities provided by the connection between EO Regions! and Wuudis.

In addition, a study on the usability of Senop hyperspectral camera for boron deficiency mapping was performed at a test site in Finland. Finally, several demonstrations of the transferability of the technical capabilities were performed in a test site in Galicia, Spain, where teams from DTU, FMI, and VTT applied their methods in coordination with Wuudis platform. Figure 24.5 shows the Spanish study site stand boundaries in the Wuudis platform. The user interface of Wuudis platform provides stand-wise information that can be used for forest management planning and monitoring decision making. In addition to basic information (like property codes, area,
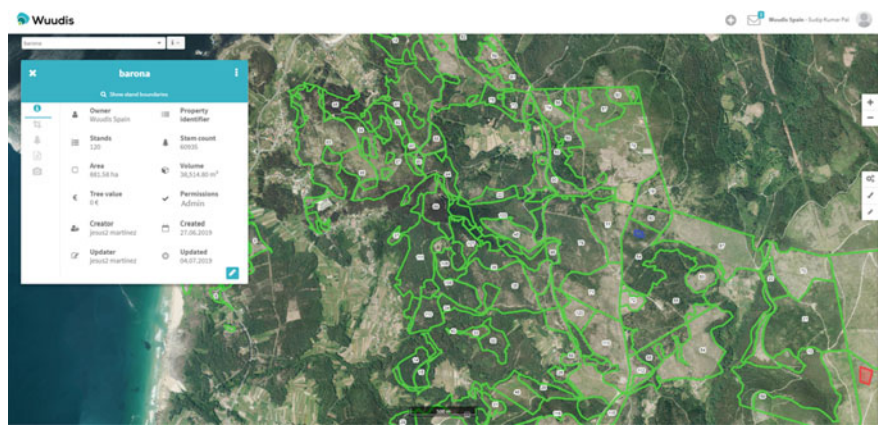
Fig. 24.5 Pilot site in Galicia populated with forest estate data in Wuudis Service. The user can browse through information such as ID, area, stem count, volume, and tree value for each forest stand, and visualize supporting material such as field photos

etc.), forest variable information such as development level, stem count, and volume can be provided, as well as derived information including, e.g., the value of trees. In addition, the system allows inclusion of remote sensing imagery and photos, as well as other supporting material such as field measurement results.

Figure 24.6 illustrates a demonstration of tree height estimation in the Galician pilot area by the *Probability* [1] method, visualized on the Forestry TEP platform. The estimation was conducted using Mar 29, 2019, Sentinel-2 satellite imagery and field measurements by Wuudis Solutions staff. There are some higher than expected values for open areas and shrublands, since these areas were not represented in the limited field reference data, but overall the forest areas clearly stand out with a range of tree height values around 8–18 m.
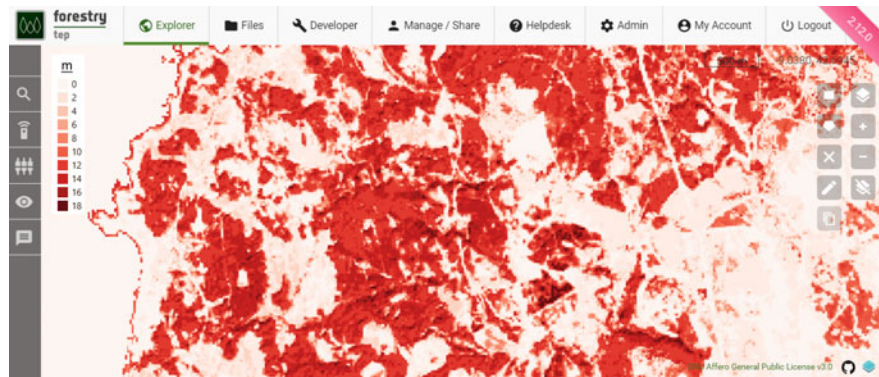
Fig. 24.6 Tree height (in meters) estimation in the Galician conditions, visualized in the Forestry TEP platform (legend pasted on the image)

24.3.2 Data Used in the Pilot

The pilot utilized several different types of remotely sensed datasets as well as field data (Table 24.1). Remotely sensed datasets included Sentinel-1 and Sentinel-2 satellite data and airborne hyperspectral remote sensing data. In the Finnish test site, sample plot data by the Finnish Forest Center was used as reference in the estimation model training. In the Galicia test site, Wuudis Solutions staff conducted field work, collecting forest variable information from ten forest stands. The measured information included six different forest structure variables: (1) species, (2) age, (3) basal area, (4) stem count, (5) mean diameter, and (6) mean height. The field data was recorded in the Wuudis platform, together with photographs. In addition, all available information from the forest estate stands were recorded into the Wuudis system.

The Sentinel satellite data was found to be very useful for operational forest monitoring applications in online platforms. The systematic acquisition scheme and high temporal frequency (i.e., short revisit time) provide large amounts of data suitable for high temporal resolution service provision. The high number of spectral bands (10) usable for forest monitoring purposes in the Sentinel-2 satellites, combined with the

Table 24.1 Data assets utilized in the pilot. GB stands for gigabyte, TB for terabyte, and PB for petabyte

Data type	Dataset	Dataset original source	Dataset location	Volume (GB)	Velocity (GB/year)
Satellite data	Sentinel-1	Copernicus program	Online repositories such as DIAS or the Copernicus Open Access Hub	1–8 GB per scene	~1.5 PB
Satellite data	Sentinel-2	Copernicus program	Online repositories such as DIAS or the Copernicus Open Access Hub	~1 GB per scene	~800 TB
Airborne data	Hyperspectral remote sensing data	Senop hyperspectral camera	Wuudis platform	*n.a	n.a
Field data	Forest plot data for Finland	Finnish Forest Center	Metsään.fi [3]	n.a	n.a
Field data	Forest plot data for Galicia	Wuudis staff	Wuudis platform	n.a	n.a

*n.a. not available

10–20 m spatial resolution, enables development of high-quality forest monitoring applications. Furthermore, Sentinel-1 and Sentinel-2 data is stored in centralized platforms, such as the Copernicus Data and Information Access Service (DIAS) platforms or the Copernicus Open Access Hub, and can be accessed directly with processing platforms like Forestry TEP.

In the pilot, two different types of field datasets were used. The national coverage sample plot data by the Finnish Forest Center that was used as reference in Finland was confirmed to be very suitable for the online applications demonstrated in this pilot. However, such field datasets are not available in all countries. The amount, quality, and timeliness of field data often play a crucial role in EO big data-based forest inventory applications, and therefore, operational collection of such data is very important, for example, the pilot in Galicia, Spain, depended on collection of on-site field data for the testing and demonstration of the products and services. However, due to limited resources, only a small amount of data could be collected, which considerably limited the scope of demonstration that could be conducted.

24.3.3 Reflection on Technology Use

Overall, the pilot demonstrated well the benefits of technology use in forest monitoring through a range of forest inventory applications utilizing EO big data and online big data processing approaches. These applications and services were further developed to improve user experience. One of the key development aspects in the pilot was the inter-platform operability. The services were integrated with the Wuudis platform, demonstrating the possibilities and benefits of inter-platform interactions. The resulting solutions were piloted with Wuudis users, forestry sector partners, associated partners, and other stakeholders.

The experiences from the pilot confirm the value of big data in forest monitoring and encourage further development of big data approaches for forest monitoring purposes. The massive increase in remote sensing data volumes over the past decade has enabled remote sensing-based forest monitoring in unprecedented levels of frequency and detail. Big variety of data sources is available, each with their own characteristics in, e.g., spatial resolution, update frequency, level of detail and accuracy for the thematic task at hand, and cost. This allows picking the most suitable data for the need or to combine various approaches for the best overall effect. The freely available satellite data from the Copernicus Sentinel program is a key opportunity for many tasks, especially when aiming to cover large areas. Standardized processing pipelines in the online environment, such as the ones developed in this pilot, are crucial in taking full advantage of the high volumes of data in an operational and effective manner.

24.4 Business Value and Impact

The entire pilot focused on development and integration of marketable forest inventory services into the Wuudis platform and other related platforms. Overall, the pilot results were successful in demonstrating the usability of a range of forest inventory applications on the platform. The pilot demonstrated the functionality of inter-platform connections and service provision, which enables wider exploitation of the services developed in and outside of this pilot. The services are applied on the respective platforms and exploitation of the services is growing.

Table 24.2 presents the key performance indicators (KPIs) measured during the pilot. The Wuudis tree-wise monitoring MVP (minimum viable product) service was launched in June 2018 and sold to leading forest management associations (forest management associations of Pohjois-Karjala, Savotta, and Päijänne) and forest industries in Finland. Over 5000 ha were monitored by the Wuudis network of service providers.

In addition to the measurable KPIs, the pilot aimed at testing and demonstrating new services for forest damage monitoring. Several services were successfully tested and demonstrated in Belgium, Finland, and Spain, utilizing several online platforms and inter-platform connections. This will increase the service offering in all the involved platforms (Wuudis, Forestry TEP, and EO Regions!) and enable higher revenue in the future.

The pilot is a good example on how research results are used in business development. The pilot brought together new commercial partners for added-value services on top of Wuudis platform. Business agreement between Wuudis Solutions and Spacebel regarding the distribution of the Wuudis Services to the forest users of the EO Regions! platform and the commercialization of Spacebel's earth observation forest products in the Wuudis platform were set up during the project. Negotiations on operational-level inter-platform connections between Wuudis and Forestry TEP

Table 24.2 Pilot KPIs

KPI description	Goal description	Base value	Target value	Measured value	Unit of value
Usability of tree-wise monitoring service MVP	Goal is to sell the tree-wise monitoring service MVP to forest management associations in Finland	0	No target value	3	Number of customers
Surface processed with MVP	The goal is to increase the area processed using the MVP service	0	4000	5000+	ha

as well as with the Finnish state forest enterprise Metsähallitus are also ongoing at the time of writing.

Because of the pilot, Wuudis Solutions is now able to better understand the needs of the Spanish market. Wuudis Service was tested in a real business environment, and the results were encouraging. Wuudis Solutions is expanding its customer base in Spain through establishment of a subsidiary, Wuudis Solutions S.L. in November 2019 and partnering with local airborne data service providers like Agresta. Wuudis Solutions has already secured new implementations and R&D projects in Spain/Galicia (e.g., TEMPO, ICEX, Galician Wood Cluster).

24.5 How-to-Guideline for Practice When and How to Use the Technology

For forest monitoring stakeholders, be they private forest owners, forestry companies, or public entities, the best avenue for big data utilization for forest monitoring purposes is through online platforms. As described in Sect. 24.3 above, there are several levels of online platforms enabling utilization of EO data for forest monitoring purposes. These include, for example, the DIAS platforms providing data access to forestry-related Big Data and several platforms providing forestry-related applications and services. These platforms include, for example, the Forestry TEP, EO Regions!, and Wuudis platforms used in this pilot.

The application platforms provide direct access to satellite data and auxiliary datasets, and ready-made applications for the utilization of the data for forest monitoring purposes. In addition, e.g., Forestry TEP offers an application development interface, where users can develop their own applications utilizing the Big Data available on the platform. Inter-platform connections bring further benefit to the users through wider service offering.

On a general level, more effort is needed to increase the interest toward platform services in the forestry community and to ensure smooth user experience. In many parts of Europe, the forestry sector has a long history with strong traditions in forest management practices. It may take some time to change the perspective of the forestry stakeholders to fully approve big data-based approaches. In order to increase the interest from the user side, the service providers now need to (1) further develop methods to fully exploit EO big data for forest monitoring, (2) convince the forestry stakeholders about the concrete benefits of online services in efficient utilization of big data, and (3) further improve cooperation between service providers to ensure smooth and effortless user experience and increased interest.

The importance of local promotional activities and locally tuned services cannot be overemphasized. This can be achieved through strong involvement of local level actors (such as regional forest administrations or local forest associations), which enables direct connection to local datasets and stakeholders. This, in turn, allows fine-tuning of the provided services according to local practices and requirements.

24.6 Summary and Conclusion

Overall, the pilot demonstrated well the benefits of technology use in forest monitoring through a range of forest inventory applications utilizing big data and online big data processing approaches. In addition, the pilot highlighted (1) the technical transferability of online platform-based forest inventory services and (2) importance of local involvement in fine-tuning services to meet local needs. All of the services tested in the pilot areas were technically implemented successfully. However, stronger user involvement in service definition and field data provision would be needed to provide more reliable and meaningful results for the users.

The pilot was very successful in further developing capabilities to perform comprehensive and near real-time quantitative assessment of forest cover over the project pilot areas. This type of near real-time forest monitoring allows monitoring of forest damages, deforestation, and forest degradation.

The pilot was also generally successful in creating the inter-platform connections. However, the challenges of integration of services between platforms and service providers became clear during the pilot. Best practices for inter-platform cooperation between service providers (both technical and financial) need to be further developed to enable smooth and effortless user experience, to gain the maximum benefit from the range of service providers working together.

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