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REDDCopernicus

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Compendium of Research and Development Needs for Implementation of European Sustainable Forest Management Copernicus Capacity; Version 2

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Summary

This deliverable identifies and prioritizes the major research gaps in the context of European Sustainable Forest Management (SFM). The thematic areas covered are based on the project proposal, Stakeholder requirement analysis and pan-European criteria for Sustainable Forest Management. The first version of the deliverable provided a literature review of the current status of research on satellite based Sustainable Forest Management monitoring. In this second version of the document, the main focus is on European Stakeholder requirements and ongoing European forest monitoring activities (particularly the National Forest Inventories). Stakeholder requirements are collected through surveys and a virtual workshop. In the final version of the document, the research gaps between the Stakeholder requirements and existing offer will be identified and prioritized, to support future development of Copernicus products improving the capabilities for Sustainable Forest Management monitoring.

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Executive Summary

Introduction

The 'Research priorities for European sustainable forest management' work package (WP 11) of the REDDCopernicus project is part of Task 4: 'Research and infrastructure gaps'. The main aim of WP 11 (Research priorities for European sustainable forest management) is to identify and then prioritise the main research topics for EO of Sustainable Forest Management in Europe. This work was started in 2019 by a literature review of the current research activities on EO based monitoring of Sustainable Forest Management. In 2020, the main focus was on Stakeholder involvement. A virtual workshop for European Sustainable Forest Management Stakeholders was organized and a Stakeholder survey supported by interviews was undertaken to gather information on requirements related to Sustainable Forest Management.

Results of WP 11 are reported in the 'Compendium of Research and Development Needs for Implementation of European Sustainable Forest Management Copernicus Capacity' deliverable, which is developed into its final form in three versions. In this second version of the deliverable (D11.2), the main focus is on European Stakeholder requirements and ongoing European forest monitoring activities (particularly the National Forest Inventories).

Approach of the Analysis

The analysis of the European Stakeholder requirements related to Sustainable Forest Management monitoring had two main parts: 1) 'Earth Observation for European Sustainable Forest Management'-workshop and 2) Stakeholder survey. Together these two parts allowed collection of comprehensive information on Stakeholders' requirements, current practices and future perspectives related to Sustainable Forest Management monitoring.

The 'Earth Observation for European Sustainable Forest Management'-workshop was originally planned to be organized as a physical meeting. However, due to the COVID-19 pandemic and the restrictions related to it, the event was converted into a virtual workshop. The Stakeholder workshop was successfully conducted with 60 participants representing EU and national government institutes, private sector, non-governmental organizations and associations as well as the research community. It allowed interaction between Stakeholder groups that often do not meet in similar events, providing a lot of valuable information. A short synthesis of the virtual workshop and all slide shows presented during the day, were posted on the REDDCopernicus website (https://www.reddcopernicus.info/post/report-from-our-webinar-earth-observation-for-european-sustainable-forest-management-24-sep-2020).

The other main component of the Stakeholder requirements analysis was the survey conducted to gather information on the Stakeholder's Sustainable Forest Management monitoring needs and objectives, as well as the use of Copernicus and other Earth Observation (EO) data. The survey consisted of 13 questions, covering two main sections: 1) General views on Sustainable Forest Management monitoring and 2) Utilization of remote sensing approaches in Sustainable Forest Management monitoring. The Ministerial Conference on the Protection of Forests in Europe (MCPFE, i.e. Forest Europe) sustainability criteria were used as the framework in the survey. Altogether 122 organizations were contacted, covering a wide range of Stakeholders throughout Europe. Overall, 47 responses were received, including 20 responses from organizations responsible for European National Forest Inventories.

European Stakeholder Requirements

The Stakeholder survey and the virtual workshop provided a wealth of information ranging from broad perspectives on the use of remote sensing for forest monitoring to details on required information and remote sensing products. Here we summarize the key points of Stakeholder requirements related to Sustainable Forest Management in Europe:

1. *Need for EO based Sustainable Forest Management approaches:* Sustainable Forest Management is a complex issue with multiple aspects and often contradictory effects on sustainable development goals on forestry. Nevertheless, it is clear that Sustainable Forest

Management monitoring is increasingly required in all stakeholder groups, and there is a strong need for new monitoring approaches to meet the increasing requirements. 85% of the respondents to the Stakeholder survey had reporting or monitoring requirements or other interest related to Sustainable Forest Management and 76% of the respondents were already using remote sensing to support their activities. Remote sensing provides tools for transparent and comparable monitoring approaches, but EO approaches will not provide solutions for all requirements.

2. *Thematic requirements*: Stakeholders ranked the 'Forest Resources and their Contribution to Global Carbon Cycles', the 'Forest Ecosystem Health and Vitality' and the 'Biological Diversity in Forest Ecosystems' as the three most significant aspects of sustainability for the coming years, and the aspects where new monitoring approaches were most needed. The usability of EO data for 'Forest Resources and their Contribution to Global Carbon Cycles' and 'Forest Ecosystem Health and Vitality' monitoring was seen promising, but the usability of EO approaches for monitoring the 'Biological Diversity in Forest Ecosystems' was doubted. Forest biodiversity, biomass/carbon and disturbance monitoring were seen as the most important topics.

3. *Spatial resolution requirements*: The most used remote sensing data types for Sustainable Forest Management monitoring were airborne LiDAR, aerial imagery and 10-30 m spatial resolution optical imagery. There were requests for regularly updated European wide airborne LiDAR and less than 1 m spatial resolution aerial imagery coverage. These types of datasets were seen particularly necessary for monitoring various biodiversity indicators (e.g. species and diameter distribution, forest structure). However, 10-30 m optical satellite imagery was also found useful for Sustainable Forest Management monitoring purposes e.g. for biomass/carbon as well as forest disturbance and health monitoring.

4. *Temporal resolution requirements:* Although there were several aspects of forest sustainability where annual monitoring was considered to be sufficient (e.g. long term trends in productivity), temporal resolution was currently seen as one of the main limitations in existing Copernicus core products, in the context of Sustainable Forest Management monitoring. For many purposes, the Stakeholders needed monthly or higher temporal resolution. This applied particularly to the change monitoring products that were high in demand among Stakeholders. The new Copernicus EO data (e.g. Sentinel-2 and 1) would allow creation of high temporal resolution core products.

Other issues raised: In addition to the requirements listed above, several related issues were raised. These included e.g. 1) funding and compensation mechanism for forest ecosystem services, 2) the importance of the socio-economic Sustainable Forest Management indicators, highlighting that a combination of data sources will always be needed to monitor Sustainable Forest Management and 3) the importance of National Forest Inventory field data, and other field datasets. Related to the last point, avenues to fully utilize these data for European and National level EO based Sustainable Forest Management monitoring should be found, without compromising the sensitivity of the datasets.

Copernicus and National Forest Inventories in Europe

Special analysis of the Stakeholder perspectives and survey answers concentrating on organizations responsible for National Forest Inventories reveal a few aspects and key points where synergy between Copernicus Services and National Forest Inventories could be further enhanced in Europe. The findings are also valuable in defining optimal designs for global Copernicus components.

National Forest Inventory arrangements: Europe has a long history of forest inventories and most countries have well established National Forest Inventories. Different countries have different institutional and technical arrangements for conducting the inventories. Technical approaches vary between countries due to varying forest conditions, but are typically highly developed and optimized, providing high quality and results answering the needs of national users. On one hand, the variability of European approaches complicates the harmonization (and thereby comparability) of the inventories in different countries, but on the other hand, it provides a wide spectum of established examples of National Forest Inventory arrangements that can be used as examples for countries outside Europe.

Field data collection: All European National Forest Inventories are primarily based on field measurements. This results in an immense, continuously updating, database of field measurements covering nearly all European countries. This source of field measurements should be fully utilized to maximize the synergy with Copernicus EO data. There are two major avenues to utilize this synergy to increase the use of Copernicus data: 1) Through approaches (e.g. platforms and tools) that allow creation of National (or any other interest area) products using a combination of field datasets and Copernicus EO data. The (often confidential) field data could be uploaded by the user or be available in the system. Many countries utilize already such approaches in their own systems, but others do not have the resources or knowhow to set up such systems. And 2) for European level Copernicus core products, the National Forest Inventory field measurements would form an invaluable training and reference dataset. It would benefit all parties through improved accuracy of the products in the varying forest conditions around Europe. Technical solutions should be sought that would allow utilization of national field measurement datasets for training and accuracy assessment of European wide products, while preserving the confidential aspects of the data. Again, online platforms, or interaction with different platforms (e.g. database/analysis and processing platforms), could provide solutions for creation of such systems.

Utilization of EO imagery: The Copernicus Sentinel satellites (most particularly Sentinel 2 and 1) provide large amounts of suitable data for National Forest Inventory purposes, and are already used in several European countries. Creation of the types of services discussed in the previous chapter, allowing users to produce their own products designed for national level forest monitoring, would further increase the use of Copernicus EO data for national level monitoring. Apart from the 10-30 m spatial resolution data, the National Forest Inventories utilize increasing amount of airborne LiDAR data and Very High Resolution (VHR) satellite imagery. In long term, continued improvement of the spatial resolution of Copernicus EO data will enable increased usability of EO datasets e.g. for biodiversity and forest health related monitoring tasks. Many of the EO based approaches developed in Europe can also be applied globally, with algorithms tuned to national conditions around the world.

Utilization of EO based products: To increase the use of Copernicus products in National Forest Inventories in Europe and beyond, the key point is to provide products that meet the needs of the users. There are many ways to meet the needs of the users. From products design point of view, products with continuous variables (like e.g. biomass per hectare, or tree cover %), are generally more adaptable and allow further development better than products with categorical variables (like land cover classes). It is also important to involve Stakeholders and future users strongly in the design of any future products. Due to the improving online data processing capabilities, future EO core products can also include increasing amount of flexibility/adaptability, with provision of platforms and tools that can be used to tune the products for national circumstances. In these respects, appropriate capacity building may be required to ensure that users have the knowledge required to maximize the usability of the products for their national conditions, whether it be in Europe or anywhere else in the world.

Way Forward

The Stakeholder requirements and views reported and discussed in this document outline the framework for the analysis of research gaps in European Sustainable Forest Management monitoring. During 2021, the Stakeholder requirements and views will be compared with the status of research and existing Copernicus products. The literature review was first reported in D11.1 (Compendium of R & D Needs for Implementation of European Sustainable Forest Management Copernicus Capacity; v.1), and will be updated during 2021 for the final analysis.

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List of Abbreviations

AGB	Above Ground Biomass
ALOS	Advanced Land Observing Satellite
CALM	Criteria for consistently Assessing Levels of Maturity
C3S	Copernicus Climate Change Services
CEPF	Confederation of European Forest Owners
CHIME	Copernicus Hyperspectral Imaging Mission for the Environment
CLC	Corine Land Cover
CLMS	Copernicus Land Monitoring Service
COVID-19	Coronavirus Disease 2019
DG DEFIS	Directorate General, Defence Industry and Space
DG ENV	Directorate General, Environment
DIABOLO	EU Horizon 2020 project: Distributed, Integrated and Harmonised Forest Information for Bioeconomy Outlooks
DIAS	Data and Information Access System
EARSC	European Association of Remote Sensing Companies
EC	European Commission
EEA	European Environment Agency
EFFIS	European Forest Fire Information System
ENFIN	European National Forest Inventory Network
EO	Earth Observation
ESA	European Space Agency
EU	European Union
FISE	Forest Information System for Europe
FM	Forest Monitoring
FSC	Forest Stewardship Council
GFOI	Global Forest Observations Initiative
GOFC GOLD	Global Observations of Forest Cover and Land Use Dynamics
ICT	Information and Communication Technology
LiDAR	Light Detection And Ranging
LMS	Land Monitoring Services
LULC	Land Use Land Cover
MCPFE	Ministerial Conference on the Protection of Forests in Europe
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NGO	Non-Governmental Organization
NIR	Near Infrared
NFI	National Forest Inventory
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PEFC	Programme for the Endorsement of Forest Certification
R&D	Research and Development
REDD+	Reducing Emissions from Deforestation and Degradation "plus" conservation, the sustainable management of forests and enhancement of forest carbon stocks
RMSE	Root Mean Square Error
ROSE-L	L-Band Synthetic Aperture Radar Imaging Mission

SAR	Synthetic Aperture Radar
SFM	Sustainable Forest Management
TCD	Tree Cover Density
TEP	Thematic Exploitation Platform
UN	United Nations
VHR	Very High Resolution
VIIRS	Visible Infrared Imaging Radiometer Suite
WP	Work Package

1 Introduction

1.1 'Research Priorities for European Sustainable Forest Management' Work Package (WP 11)

The 'Research priorities for European sustainable forest management' work package (WP 11) of the REDDCopernicus project was part of Task 4: 'Research and infrastructure gaps', which built on top of Task 1: 'Assessment of requirements and capacities'. In Task 1, existing capacities in Earth Observation (EO) for Forest Monitoring (FM) in Europe were reviewed and requirements in international and European policy segments, Stakeholders and Users were identified. Subsequently, Task 4 aimed to identify research gaps for EO FM in tropical dry and humid forests (WP 10), as well as for Sustainable Forest Management (SFM) monitoring in Europe (WP 11). Gaps in the Copernicus space component and in the Information and Communication Technology (ICT) infrastructure for the provision of operational Forest Monitoring Services were also investigated in Task 4 (WP 12).

The main aim of WP 11 (Research priorities for European sustainable forest management) was to use Task 1 results, recent research outputs and other relevant information to identify and then prioritise the main research topics for EO of Sustainable Forest Management in Europe. This work was started in 2019 by a literature review of the current research activities on EO based monitoring of Sustainable Forest Management. In 2020, the main focus was on Stakeholder involvement. A virtual workshop for European Sustainable Forest Management Stakeholders was organized and a Stakeholder survey supported by interviews was undertaken to gather information on requirements related to Sustainable Forest Management.

Results of WP 11 were reported in the 'Compendium of Research and Development Needs for Implementation of European Sustainable Forest Management Copernicus Capacity' deliverable, which was developed into its final form in three versions. The first version (D11.1) outlined the major research areas applicable to the project based on the project proposal and the results of Task 1 and presented the results of an extensive literature review on the status of research in satellite based Sustainable Forest Management monitoring. The literature review included outputs of key international networks like GFOI and GOFC-GOLD, specific thematic meetings like ForestSat as well as peer reviewed research publications.

In the second version of the deliverable (D11.2), the main focus was on European Stakeholder requirements and ongoing European forest monitoring activities (particularly the National Forest Inventories). Stakeholder requirements were collected through surveys and a virtual workshop. A representative set of Stakeholders were invited to a workshop that was organized as an online gathering (due to the COVID-19 pandemic) on the 24th September 2020. Participants included representatives from 1) international forest companies, 2) organisations connected with European forest and environmental policies and strategies, 3) forest owners associations, 4) forest certification organisations, 4) environmental NGOs as well as 5) university and research groups active in forestry EO.

The third and final version of the document (D11.3) will synthesize all findings from WP11 and present the final refined compendium of research priorities for implementation of European Sustainable Forest Management Copernicus capacity. The research gaps between the Stakeholder requirements and existing offer will be identified and prioritized, to support future development of Copernicus products improving the capabilities for Sustainable Forest Management monitoring. In addition, the final version will include discussion of new research needs potentially emerging in the near future.

1.2 European Sustainable Forest Management Requirements and Stakeholders

In the European Union, the Member States formulate forest policies within a clearly defined framework of established ownership rights and with a long history of national laws and regulations based on long term planning. The European Union has a long history of EU measures supporting forest-related

activities. The current European Forest Strategy from 2013 (EU 2013, EU 2018) recognizes a need for a policy framework to coordinate forest-related policies that pertain to the complete forest related sector of the society. The guiding principles of the 2013 strategy include Sustainable Forest Management, multifunctional role of forests, resource efficiency and global forest responsibility. The Sustainable Forest Management considerations include the need to maintain and enhance forest cover, and to collect harmonized Europe-wide information on the multifunctional role of forests and forest resources. Development of modules on forest and natural disturbances such as fires and pests, on forests and the bio-economy, forests and climate change, and forest ecosystem services to contribute to EU's forest accounting is also seen important in the Sustainable Forest Management context. As countries are including Sustainable Forest Management criteria into their forest policies, the reporting requirements of actors operating in forests, as well as the monitoring requirements of regulatory agencies are rapidly increasing and becoming more complex. Surveillance and reporting of new indicators requires novel forest monitoring EO products.

The role of Sustainable Forest Monitoring is expected to further strengthen in the upcoming post-2020 EU Forest Strategy, to be launched in 2021. The European Parliament resolution of 8 October 2020 on the European Forest Strategy (https://www.europarl.europa.eu/doceo/document/TA-9-2020-0257_EN.html) highlights the "*crucial role played by the post-2020 EU Forest Strategy and the European Green Deal in meeting the goals of the Paris Agreement and the UN 2030 Agenda for Sustainable Development"*. They note that the post-2020 EU Forest Strategy should be aligned with the European Green Deal and the EU Biodiversity Strategy and that Sustainable Forest Management should make forests more adaptable to changing climate conditions and promote their environmental, but also societal and economic sustainability. They further highlight the Ministerial Conference on the Protection of Forests in Europe (MCPFE, i.e. Forest Europe) process in defining internationally agreed Sustainable Forest Management definitions that have been incorporated into national legislation and into the voluntary systems, such as forest certification systems, that are in place in the Member States.

The MCPFE, (i.e. Forest Europe) is a pan-European voluntary high-level political process for dialogue and cooperation on forest policies in Europe, which develops common strategies for its 47 signatories on how to protect and sustainably manage their forests. The MCPFE has agreed on the criteria and indicators for Sustainable Forest Management (MCPFE 2015) that includes six major thematic areas of sustainability in the context of forest management: 1) Forest resources and their contribution to carbon cycles, 2) Forest ecosystem health, 3) Productive functions of forest (wood and non-wood), 4) Biodiversity, 5) Protective functions of forests, 6) Socio-economic functions and conditions. The set of indicators are to be updated in the next 8th Ministerial Conference on the Protection of Forests in Europe, to be held in Bratislava, Slovakia, on the 14 - 15 April 2021. These criteria will provide the framework for analysis of the research priorities in WP 11.

Certification is another major issue affecting the requirements of sustainability monitoring, particularly in the case of private companies and the forest product market. Forest certification is a mechanism for tracing and labelling timber, wood and pulp products and non-wood forest products, where the quality of forest management is evaluated using a set of standards. Forest certification typically covers origin of forest products, logging practices, social and economic well-being of workers and local communities as well as transparency and inclusiveness in decision making. Consumers, businesses and policy makers are more and more interested in verifying the sustainability of the forest products they use, increasing the value of certification for forestry companies.

The two largest forest certification programs are the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). Both of these are globally recognized and both of them set international frameworks and criteria for developing national and subnational certification standards. National level standards include a set of detailed criteria and indicators that certified forest operators need to monitor and report on. In general, the certification criteria agree well with the ones outlined by the MCPFE (see above). However, the national criteria, and corresponding indicators (*e.g.* harvest levels, protection corridors, leave trees and regeneration status), may require provision of very specific and detailed information. The possibilities to provide these pieces of information by the means of EO data is one of the major aspects to be analysed in WP 11.

An extensive Stakeholder analysis was conducted in WP1 and results were provided in deliverable D1.1 'Stakeholder and Requirements Assessment Report'. The deliverable D1.1 put its main emphasis on tropical countries and the REDD+ process. Six main groups of Stakeholders, relevant for the entire REDDCopernicus project, were identified: 1) European Commission, 2) Financiers, donors and international development agencies, 3) REDD+ country users, 4) Research and scientific community, 5) International initiatives and NGO's and 6) Private sector organizations. Apart from groups 2 and 3, the same groups of Stakeholders applied in the European Sustainable Forest Management context. In addition, national government agencies in European countries were considered key Stakeholders in Sustainable Forest Management monitoring. As described above, the number of regulations has been rapidly growing due to the expanding list of criteria and indicators defined in forest policies across Europe. Government agencies play a major role monitoring the abidance of these regulations and thereby the success of the forest policies. EO based forest monitoring products may become indispensable means for implementing these monitoring requirements in an effective and affordable way.

Another major player in the European context is the service sector providing EO and related services for actors in the forestry and forest products field. This service sector in Europe is dominated by the private sector. The European Association of Remote Sensing Companies (EARSC) promotes the use of EO technology and especially the companies in Europe which offer EO-related products and services. According to EARSC, there were nearly 600 EO service sector companies in Europe with nearly 1.4 billion € revenue and nearly 10 000 people employed already in 2019[1]. Environmental monitoring (including forestry) is one of the major focus areas of the European private EO sector.

Likewise, the private Users of EO data, products and services are a very complex and expanding group. On the core, there are all companies directly involved in forestry activities. For these companies, up-to-date accurate information on forests is a key requirement of effective operations. Furthermore, they need to monitor and report their activities to fulfil EU and national level frameworks and policies. Similarly, the entire pulp and paper industry, as well as mechanical forest industry (*i.e.* sawmill, plywood, chipboard *etc.*) is heavily dependent on information on the availability, type, quality and distribution of raw materials. They often also own forest land and conduct their own wood procurement operations. Furthermore, they are increasingly certified by international forest certifiers, requiring regular monitoring and reporting of their activities. EO can support all of these activities.

More and more companies not directly involved in forest management activities are also either required or voluntarily interested in EO based forest monitoring activities. For example, due to increasing legislation, certification and consumer pressure, many companies sourcing their raw materials from forested landscapes choose to use EO based products and services for monitoring and reporting their raw material sourcing. These companies may include *e.g.* food manufacturers, energy companies and sellers of wood based products (*e.g.* furniture). This tendency is expected to continue in the future as environmental issues in general are becoming more and more integrated part of business practices.

1.3 Copernicus Evolution

The Copernicus programme (EU 2014) aims to monitor the Earth, its environment and ecosystems in order to ensure its citizens are prepared and protected for crises, security risks and natural or man-made disasters. It provides data and information at the disposal of citizens, public authorities and policy makers, scientists, entrepreneurs and businesses on a full, free and open basis. Copernicus is a User driven programme providing services that are based on User requirements. Currently it provides a wide range of services under six themes, including Copernicus Land Monitoring Services (CLMS) with products suitable for forest management monitoring.

[1] EARSC Industry Facts and Figures, https://earsc.org/industry-facts-figures/, accessed 14 Jan 2021

The Copernicus services aim to provide highly operational services integrated into one system from sensing to interpreted information delivery. Although continuity of these services is the overarching priority, the Copernicus services are not static, but evolve with emerging and well identified User requirements and EU policies. The evolution of the Copernicus space component is interlinked with the development of services and is based on an analysis of options to meet evolving User needs.

Currently, the core of the Copernicus space component is the Sentinel constellation, a family of six satellite missions developed specifically for the Copernicus programme (presented in REDDCopernicus deliverable D2.2 'Review Assessment for Forest Monitoring Capacity'). Among these satellites, particularly the 10-20 m resolution datasets from the Sentinel 1 (radar) and 2 (optical) satellite missions enable creation of potentially highly usable products for Sustainable Forest Management. One of the main aspects of WP11 is to find out the current status of research and potential R&D needs to fully utilize the potential of the existing Copernicus space component to meet the evolving needs of European Stakeholders in the context of Sustainable Forest Management. This will support optimal evolution of Copernicus services to meet the evolving Stakeholder requirements related to European Sustainable Forest Management.

Another aspect of WP11 related to the evolution of the Copernicus programme is to evaluate the Stakeholder needs for Sustainable Forest Management in the light of the completeness of Copernicus satellite data offer. Review of current research together with User requirements will reveal potentially missing aspects of Copernicus space component. This information will directly feed to WP12, which concentrates on the needs of Copernicus infrastructure evolution. Current plans for the space component evolution include *e.g.* L-Band Synthetic Aperture Radar Imaging Mission (ROSE-L) and Hyperspectral Imaging Mission (CHIME). The usability and importance of these (and other) types of data to meet the Stakeholder requirements will be analysed during the research review.

1.4 Objectives

In the first version of the 'Compendium of Research and Development Needs for Implementation of European Sustainable Forest Management Copernicus Capacity' deliverable (D11.1), the major research areas applicable to REDDCopernicus project in the context of European Sustainable Forest Management were outlined and the state of research in these areas was analysed through extensive literature review.

The main objective of this second version of the deliverable (D11.2) was to compile European Stakeholder requirements related to Sustainable Forest Management monitoring and European forest monitoring activities taking place on national level (particularly the National Forest Inventories). This information, together with the review of research activities reported in D11.1, will enable subsequent identification and prioritization of research topics in support of Sustainable Forest Management.

In addition to the introduction, this document has three main sections: 1) European Stakeholder requirements related to Sustainable Forest Management monitoring, 2) Copernicus and National Forest Inventories in Europe and 3) Preliminary findings on Sustainable Forest Management monitoring research priorities.

The 'European Stakeholder requirements related to Sustainable Forest Management monitoring'-section reports the organization of and findings from the Stakeholder survey and virtual workshop. The 'Copernicus and National Forest Inventories in Europe'-section gives an overview of the practices established across Europe and potential synergies with Copernicus. National Forest Inventories are well developed in Europe and provide multitude of information on national level. The potential utilization of this information to support Sustainable Forest Management monitoring is analysed. Further, the practises developed in Europe may provide valuable input for forest monitoring in other parts of the world as well. The analyses thereby feeds information to other work packages as well.

The 'Preliminary findings on research priorities'-section reports the first indications of the research gap analysis by combining the main findings of the research literature review reported in D11.1 and the European Stakeholder requirements and National Forest Inventory practices reported in this document (D11.2). Detailed analysis of the research priorities will be conducted during the last year of the project

utilizing all the information collected over the course of the project and reported in the final version of the deliverable (D11.3).

2 European Stakeholder Requirements Related to Sustainable Forest Management Monitoring

2.1 Approach of the Analysis

The analysis of the European Stakeholder requirements related to Sustainable Forest Management monitoring had two main parts: 1) 'Earth Observation for European Sustainable Forest Management'-workshop and 2) Stakeholder survey. Together these two parts allowed collection of comprehensive information on Stakeholders' requirements, current practices and future perspectives related to Sustainable Forest Management monitoring. The findings of this analysis were reflected with the current status of research (reported in D11.1) to prioritize research needs for European Sustainable Forest Management monitoring. The 'Earth Observation for European Sustainable Forest Management'-workshop was originally planned to be organized as a physical meeting. However, due to the COVID-19 pandemic and the restrictions related to it, the event was converted into a virtual workshop. The practical arrangements, structure and main findings of the virtual workshop are provided in Section 2.2. The Stakeholder survey was conducted through a set of 13 questions sent directly to selected Stakeholders using one-on-one email correspondence. The survey was also made available on the project website, with invitation of all interested stakeholders to participate in the survey. The survey practicalities and results are reported in Section 2.3.

2.2 'Earth Observation for European Sustainable Forest Management'-Workshop

2.2.1 Aims of the Workshop

The overall aim of the workshop was to bring together Stakeholders of Sustainable Forest Management to discuss the requirements, current activities, and potential of EO based Sustainable Forest Management monitoring in Europe. The virtual workshop offered the participants with an opportunity to share their views of Sustainable Forest Management monitoring and learn about the latest developments in the topic.

Specific aims for the workshop were to:

- Provide an overview of the Sustainable Forest Management definitions and requirements on European level.
- Gather information on Stakeholder requirements and activities of government level actors, private sector and non-governmental organizations.
- Analyse the current level of usage of EO for Sustainable Forest Management monitoring among stakeholder groups.
- Discuss the preliminary findings on research needs collected by the REDDCopernicus consortium.
- Present recent research developments in the field of EO based Sustainable Forest Management monitoring.

2.2.2 Practical Arrangements

The 'Earth Observation for European Sustainable Forest Management'-workshop was organized by the VTT Technical Research Centre of Finland. As mentioned above, the event was originally planned to be organized as a physical workshop. The preparation for the September 2020 workshop was started

with the selection and contacting potential speakers in April. By the end of May 2020, the agenda was ready and invitations were about to be sent. However, in June it was decided that organization of a physical workshop in September cannot go ahead due to the COVID-19 pandemic. Thus, it was decided that a virtual workshop was to be arranged as an online event on the 24th September 2020.

This decision sparked a new round of preparations. The agenda was modified to better suit a full day virtual workshop, all presenters were re-contacted and investigations on potential online platforms were started. The first online workshop announcement and participant invitations were sent out early July. It was also decided at this point that the virtual workshop will be held using MS Teams platform.

Although a physical workshop would have been preferred, the benefit of a virtual workshop was that it allowed a larger participation and thereby a wider base of feedback from the Stakeholders. Yet, the goal was not to have much more than 60 people in the workshop, in order to ensure technical smoothness of the event. In addition to the 18 external speakers already confirmed, 75 European Sustainable Forest Management Stakeholders were invited to participate in the virtual workshop. Apart from one last minute presenter cancellation, the preparations went well until the end. The virtual workshop was attended by 60 participants, representing EU and national government institutes, private sector, non-governmental organizations and associations as well as the research community. The final announcement (including the final agenda) is attached to this deliverable as Annex 1. The list of participants has been compiled (60 names), but it is not included here in order to avoid disclosure of personal data.

2.2.3 Workshop Sessions and Discussion

The virtual workshop was divided into four sessions including 1) Introduction to Sustainable Forest Management in Europe, 2) Government level activities, 3) Private sector approaches for Sustainable Forest Management monitoring, and 4) Research activities on Sustainable Forest Management monitoring. Each of the sessions consisted of presentations from key stakeholders and leading experts in the field and allowed discussion on the current issues on Sustainable Forest Management monitoring.

The Introduction session started with presentation of the REDDCopenicus project in general, and the European Sustainable Forest Management aspect in the project in particular. This was followed by an analysis of the UN Sustainable Development Goals from the perspective of forestry and the introduction of the Ministerial Conference on the Protection of Forests in Europe (MCPFE, i.e. Forest Europe) sustainability criteria. The session included also presentation of the main results of an earlier EU/H2020 DIABOLO project, which concentrated on field data harmonization across Europe. The session ended in presentation of preliminary results of the REDDCopernicus survey on Sustainable Forest Management monitoring in Europe, which was designed to gather information on requirements and current practices in Sustainable Forest Management monitoring among European forestry Stakeholders.

The discussion was mainly related to the type of outputs expected from the REDDCopernicus project, and how potential future products differ from existing products (e.g. the Maryland University tree cover change monitoring). Apart from technical differences (e.g. higher spatial resolution), it was highlighted by Michel Massart (EC DG-DEFIS) that one of the objectives is also to develop European competences, European autonomy and independent source of information for the European Union. Overall, the session provided a good introduction of the terms, underlying objectives and current views of Stakeholders on Sustainable Forest Management monitoring issues in Europe.

The Government session included presentations from both European level organizations providing datasets and platforms in support of Sustainable Forest Management monitoring as well as national institutes responsible for forest monitoring activities. A large variety of European level datasets and supporting analysis infrastructure for forest monitoring activities were highlighted in two presentations covering the Copernicus Land Monitoring Service (CLMS) component and the newly launched Forest Information System for Europe (FISE). In addition, the crucial importance of National Forest Inventories providing information for national and international reporting was emphasized. In many countries, remote sensing based approaches are already used by agencies responsible for fulfilling legislative monitoring and reporting requirements.

The discussion was focused on the ways remote sensing are used in national level monitoring. The increasing use of airborne LiDAR in Northern Europe was pointed out, but it was also highlighted that data availability does not allow European wide approaches based on airborne LiDAR data. In-house and commissioned development of national wide monitoring approaches was the most common way of using Sentinel 1 and 2 data. The main reason for this was that even though the data was considered to be highly suitable for many Sustainable Forest Management monitoring needs, the required high temporal monitoring frequency (< 1 month) was not supported by most Copernicus products (like the Copernicus high-resolution forest layers).

The Private sector session provided perspectives and requirements from the Confederation of European Forest Owners (CEPF) and three forestry companies. It was revealed that the perspectives on and opportunities of Sustainable Forest Management vary widely within Europe with different strengths, weaknesses, threats and opportunities in the Boreal, Temperate and Mediterranean forests. This affects also the types of information required for Sustainable Forest Management monitoring purposes in the near future in different parts of Europe. Private companies operating in Europe have increasing number of requirements related to Sustainable Forest Management monitoring. Particularly carbon (climate) and biodiversity aspects of Sustainable Forest Management are gaining importance and requiring ever more efforts from forestry companies to fulfil reporting related to legislation, certification and consumer interaction. The Forestry TEP, an online processing environment for EO based forest monitoring was also presented, as an example of novel opportunities to implement Sustainable Forest Management systems effectively online.

In addition to the economic aspects and compensation possibilities (for forest ecosystem services) of Sustainable Forest Management, the discussion dealt with potential use of remote sensing approaches to support private sector needs. Remote sensing is already used to help fulfil many Sustainable Forest Management monitoring requirements, but often with airborne data. Space-borne EO data was, however, considered potentially usable in providing transparent and comparable large area monitoring data, illustrating aspects of Sustainable Forest Management to non-experts and building trust on responsible wood use.

In the Research session, prominent experts on biodiversity, biomass, burnt area and forest disturbance monitoring presented the latest research developments. Clear potential for EO based Sustainable Forest Management monitoring was identified e.g. for biotic and abiotic forest damage monitoring. At the same time, it was acknowledged that current EO data and methods may not be able to resolve e.g. many biodiversity related monitoring needs.

The questions were mainly related to the researchers' perspectives on the further development possibilities of the presented approaches. Spatial resolution of 10-20 m was foreseen feasible for many European wide applications (e.g. biotic damage and burnt area mapping), with the existing satellite fleet. Challenges were seen in the technical processing of the data due to immense data volumes. Regarding biomass mapping, great leaps of accuracy may not be possible with the existing satellites. However, new L-band and space-borne LiDAR missions are expected to enable improvement in forest biomass mapping accuracy. There was also lively discussion on the reliability and credibility of European wide maps for national level analyses. Discrepancies between European wide products based on the University of Maryland tree cover change and national statistics in the Northern Europe, particularly after 2015, were discussed, but no clear reason for the large discrepancy could be identified.

2.2.4 Workshop Feedback and Main Findings

Overall, the virtual workshop was considered a success by both organizers and participants. Technically, the workshop proceeded smoothly, without any major difficulties. Additionally, the participants thanked the organizers particularly for the wide range of different topics included in the presentations, with a variety rarely seen in similar events. This allowed interaction between Stakeholder groups that often do not meet in similar events. The dominance of Northern Europe among the presenters was noted as an issue in the workshop. Due to this reason, additional steps were taken in the Stakeholder survey to ensure as wide response from Central and Southern European Stakeholders as possible, by contacting all European National Forest Inventory contact points (see Sections 2.3).

Overall, the virtual workshop highlighted the multiple aspects of sustainability, and the sometimes contradictory effects of sustainable development goals to the forestry sector. This complexity complicates monitoring of sustainability of the forestry sector, but on the other hand, it highlights particularly the need for transparent and comparable monitoring methods, which EO approaches can provide. Also, the importance of the existence and usability of European wide criteria and indicators for Sustainable Forest Management deserves to be emphasized. They provide a European wide framework to which countries and certification agencies can base their own sustainability criteria and indicators. It is important that there are no major inconsistencies between different sustainability criteria in different countries.

More effective combined use of National Forest Inventory ground measurements and EO data is another European wide possibility that should be seized more effectively. Increasingly abundant and high quality EO data from the Sentinel Programme and other satellites enables up-to-date monitoring of forest resources in Europe. At the same time, European countries have the most advanced field measurement based National Forest Inventories accumulating invaluable ground datasets. Too often, these two pathways do not meet each other. Use of EO data in National Forest Inventories, and wise versa, use of National Forest Inventory ground measurements to support development of EO based products is an area where tighter cooperation and more effective utilization of resources should be sought. The FISE platform is a good example of developments that may facilitate easier data exchange and utilization of National Forest Inventory and other *in situ* data in the future. Direct inter-platform connections to EO data processing platforms (like the DIASes or Forestry TEP) would enable effective utilization of the ground and other reference datasets in EO based monitoring.

It became obvious during the workshop that there is a strong demand for Sustainable Forest Management monitoring in both government and private sectors. However, Sustainable Forest Management is a complex and multi-threaded issue, tightly connected to bio-economy, and the national economies overall. Significant issues related to the funding and compensation mechanisms as well as securing future value chain for forest based products need to be solved. Remote sensing approaches have the potential to help in this. Biodiversity, forest disturbance and carbon balance monitoring were seen as the most important aspects of Sustainable Forest Management monitoring in the near future. EO approaches may not be able to respond to all biodiversity monitoring requirements, but they can be used for many aspects of biodiversity monitoring (e.g. fragmentation).

Forest disturbance, on the other hand, can be effectively monitored with EO data. Currently, the greatest difficulty is to assign the detected changes into various change agents (e.g. logging, biotic damage, fire, wind). However, researchers in the workshop were confident that identification abilities of the change agents will improve in the near future with the help of increased temporal resolution and auxiliary information (e.g. wind and fire data). Biomass and carbon monitoring with radar based approaches is very much waiting for new L-band and space-borne LiDAR satellites. In the meanwhile, empirical modelling approaches based mainly on optical data and extensive field reference data have been used for national and smaller area analyses, highlighting the potential of EO based approaches even in the biomass and carbon domain.

Another major aspect discussed in the workshop was the temporal resolution of EO products. The stakeholders would in many cases need e.g. monthly (or higher) temporal resolution monitoring results. Currently, most Copernicus products (like the high-resolution forest layers or Corine land cover map) do not support this type of high temporal monitoring. Instead, the various online processing platforms, like the Data and Information Access Systems (DIAS) and the Thematic Exploitation Platforms (TEP), like the Forestry TEP presented in the workshop, offer an optimal environment to utilise Copernicus satellite data and products in combination with users's own data for operational monitoring systems requiring high temporal frequency.

Together with the Stakeholder survey, the general findings of the virtual workshop will form key part of the analysis of research priorities in the domain of Sustainable Forest Management monitoring in Europe. A short synthesis of the virtual workshop and all slide shows presented during the day, were posted on the REDDCopernicus website (https://www.reddcopernicus.info/post/report-from-our-webinar-earth-observation-for-european-sustainable-forest-management-24-sep-2020).

2.3 Stakeholder Survey/ Interviews

2.3.1 Survey Background and Practicalities

The overall aim of the Stakeholder survey was to gather information on the Stakeholder's Sustainable Forest Management monitoring needs and objectives, as well as the use of Copernicus and other Earth Observation (EO) data. The survey consisted of 13 questions, covering two main sections: 1) General views on Sustainable Forest Management monitoring and 2) Utilization of remote sensing approaches in Sustainable Forest Management monitoring. The survey was designed to be easy and fast to fill (not taking more than 20 min), in order to increase the number of responses.

The Ministerial Conference on the Protection of Forests in Europe (MCPFE) sustainability criteria were used as the framework in the survey. The criteria and their indicators (Table 1) were provided in the survey form (Annex 3) for easy reference of the Stakeholders not previously familiar with the criteria. Criterion 6 (Socio-Economic) was not included in the survey due to the fact that it was not considered applicable to EO. More information on the criteria can be found at the MCPFE website (https://foresteurope.org/ministerial-conferencies/).

Table 1: Ministerial Conference on the Protection of Forests in Europe (MCPFE) sustainability criteria and indicators used in the Stakeholder survey

Criteria	Indicator
1. Maintenance and Appropriate Enhancement of **Forest Resources and their Contribution to Global Carbon Cycles**	1.1 Forest area
	1.2 Growing stock
	1.3 Age structure and/or diameter distribution
	1.4 Forest carbon
2. Maintenance of **Forest Ecosystem Health and Vitality**	2.1 Deposition and concentration of air pollutants
	2.2 Soil condition
	2.3 Defoliation
	2.4 Forest damage
	2.5 Forest land degradation (trends)
3. Maintenance and Encouragement of **Productive Functions of Forests** (Wood and Non-Wood)	3.1 Increment and fellings
	3.2 Roundwood
	3.3 Non-wood goods
	3.4 Services (value of marketed services)
4. Maintenance, Conservation and Appropriate Enhancement of **Biological Diversity** in Forest Ecosystems	4.1 Diversity of tree species
	4.2 Regeneration
	4.3 Naturalness
	4.4 Introduced tree species
	4.5 Deadwood
	4.6 Genetic resources
	4.7 Forest fragmentation
	4.8 Threatened forest species
	4.9 Protected forests (area of)
	4.10 Common forest bird species
5. Maintenance and Appropriate Enhancement of **Protective Functions** in Forest Management (notably soil and water)	5.1 Protective forests (area of) – soil, water and other ecosystem functions - infrastructure and managed natural resources

The Stakeholder survey was sent directly to selected Stakeholders using one-on-one email correspondence. This approach was chosen to maximize response proportion. In addition, a blog post advertising the survey was posted on the REDDCopernicus website, with a link to the survey form (https://www.reddcopernicus.info/post/join-our-european-sfm-stakeholder-survey). The Stakeholders contacted directly for the survey included organizations from five different Stakeholder groups:

1. EU or other intergovernmental organization/agency
2. National governmental organization/agency
3. Non-governmental organization/association
4. Private commercial company
5. Research institute/University/Academia

Altogether 122 organizations within the above-listed groups were contacted, covering a wide range of Stakeholders throughout Europe. Two reminders were sent to people who had not responded. A special group overarching the above-listed Stakeholder groups was formed to cover organizations that conduct National Forest Inventories in European countries. Altogether 28 National Forest Inventory contact points (derived from European National Forest Inventory Network, ENFIN, http://www.enfin.info/) were contacted to gather information on the views and current practices of National Forest Inventories in Europe, regarding issues on Sustainable Forest Management. Overall, 47 responses were received, including 20 responses from organizations responsible for European National Forest Inventories. Special characteristics of the replies received from the National Forest Inventory organizations will be discussed in section '3.2 Perspectives from the National Forest Inventory organizations' survey answers'.

Table 2: Numbers of responses received to the Stakeholder survey from different types of organizations

Type of Organization	**Number of replies**
EU or other intergovernmental organization/agency	4
National governmental organization/agency	13
Non-governmental organization/association	9
Private commercial company	7
Research institute/University/Academia	13
Other (State owned commercial company)	1
Total	**47**

The survey had three different types of questions: 1) Yes or No, 2) Selection of options that apply in the respondent's case and 3) Ranking of given alternatives in the order of importance. For the first two types of questions, the interpretation of results was straightforward. For the third type, points were given to different alternatives based on the ranking given by the respondents, so that the first ranked option was given the full points. For example, if there were five items to rank, the top ranked option was given five points, with decreasing points to the other options, so that the lowest ranked option got one point.

2.3.2 Survey Results

The results of the Stakeholder survey highlight several interesting aspects on the requirements, views and current practices related to Sustainable Forest Management monitoring in Europe. Firstly, 85% of the respondents said they had some sort of reporting or monitoring requirements or other interest related to Sustainable Forest Management monitoring. This highlights the relevance of sustainability in forest management nowadays, and thereby the importance of the development of EO approaches to support Sustainable Forest Management monitoring. As far as the sustainability criteria are concerned (Figure 1), national criteria are the most used reference systems among stakeholders, followed by the MCPFE and certification agency criteria. Under the "Other" criteria people listed e.g. project or donor defined criteria, EU Nature Directives and the State of Europe's Forest Reporting.

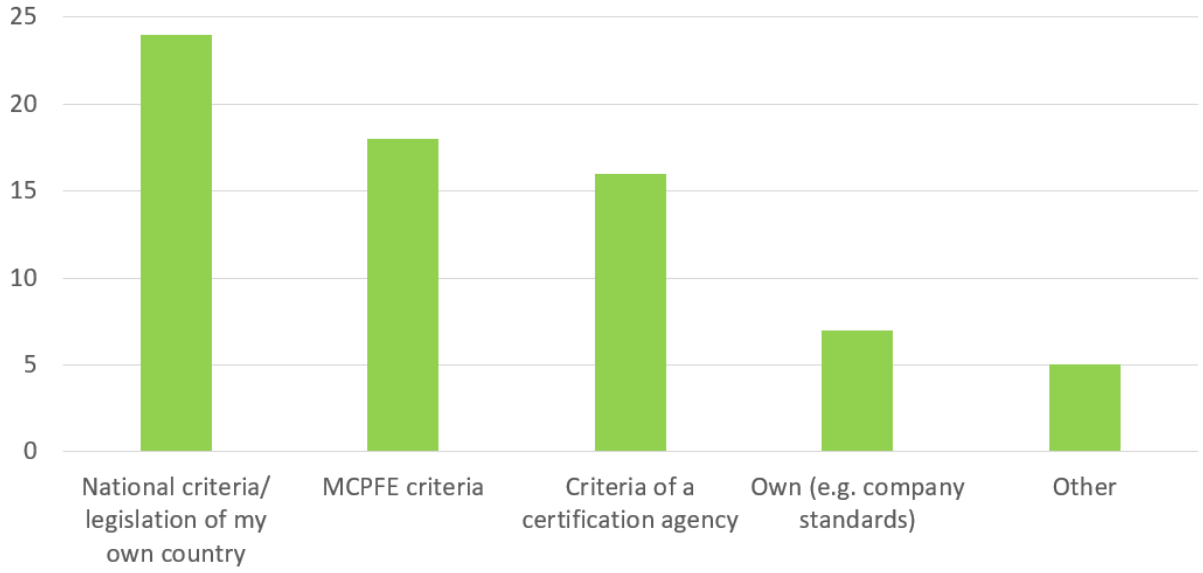

Figure 1: Stakeholder survey: Which sustainability criteria do you follow in your work?

The wide use of national criteria emphasizes the importance of national forest legislations in the EU member states, in defining the requirements of Sustainable Forest Monitoring, and thereby the flexibility and adaptability needed from any potential European wide products to serve the purpose for Stakeholders. However, it must be noted that the MCPFE criteria specifically aims to create a common framework for the national criteria, reducing their differences and thereby improving usability of European wide products. The certification agency criteria, on the other hand, are particularly important for private companies. But they are also used as common reference by various associations and non-governmental organizations.

When asked about the significance of different aspects of sustainability in the near future (Figure 2) the respondents ranked the 'Forest Resources and their Contribution to Global Carbon Cycles', the 'Forest Ecosystem Health and Vitality' and the 'Biological Diversity in Forest Ecosystems' as the top three topics. These three were closely followed by the 'Productive Functions of Forests', while the 'Protective Functions in Forest Management' ranked clearly lowest in importance. The results are perhaps not surprising, considering the pressing issues of climate change and biodiversity, as well as the recent increase of biotic and abiotic damages in European forests. The same three aspects (practically carbon, health and biodiversity) were even more clearly dominating when the stakeholders were asked about the need for new monitoring approaches (Figure 3).

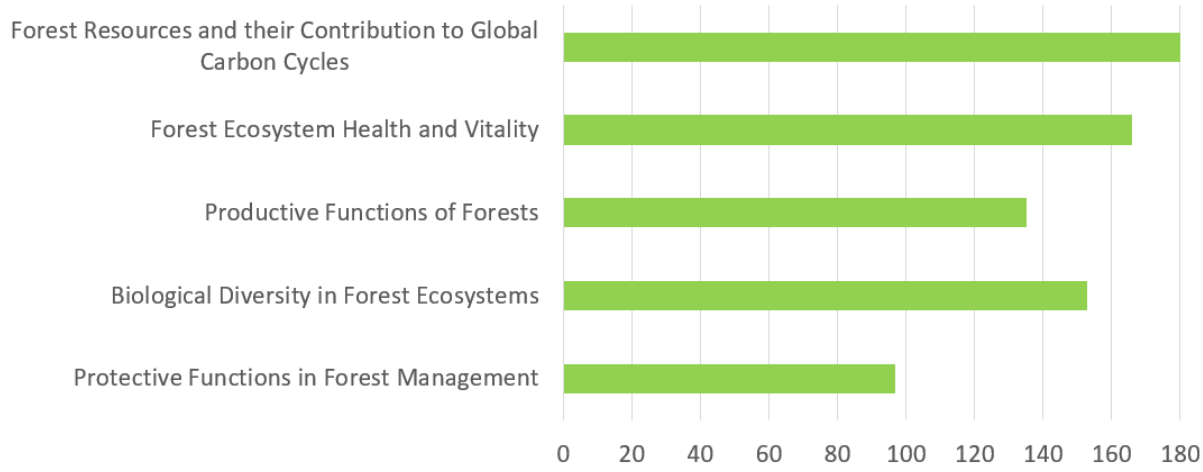

Figure 2: Stakeholder survey: Rank the following aspects of sustainability based on your view of potential future (3-10 years period) reporting and monitoring needs?

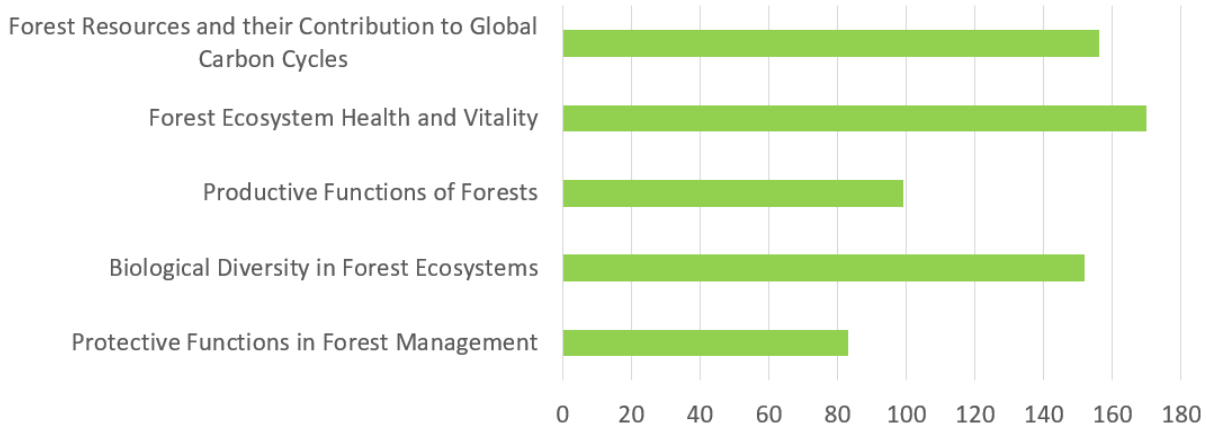

Figure 3: Stakeholder survey: In your opinion, which of the following aspects of sustainability would most urgently need some new (potentially EO based) approaches for reporting and monitoring?

While the above questions referred to the general aspects of Sustainable Forest Management monitoring, the rest of the survey concentrated specifically on the use of remote sensing in Sustainable Forest Management monitoring. Overall, 76% of the respondents said they are using some sort of remote sensing to support their activities related to Sustainable Forest Management monitoring. Overall, rather a wide range of different types of remote sensing data have been used for Sustainable Forest Management monitoring (Figure 4), but the three most used are clearly airborne LiDAR, aerial imagery and 10-30 m spatial resolution optical imagery. These three are first followed by thematic products. Among the 'Other' datasets, respondents mentioned e.g. coarse resolution data (like MERIS, MODIS, VIIRS, Sentinel-3), Google Earth imagery and orthophoto maps. Due to the requirements of high spatial resolution on monitoring many sustainability related issues (like tree species variety, buffer zones, remnant trees), it is perhaps not surprising that airborne datasets have been widely used for the purpose. But it is important that also 10-30 m optical satellite imagery has been found useful for Sustainable Forest Management monitoring purposes by many respondents. This encourages development of satellite based products enabling European wide monitoring.

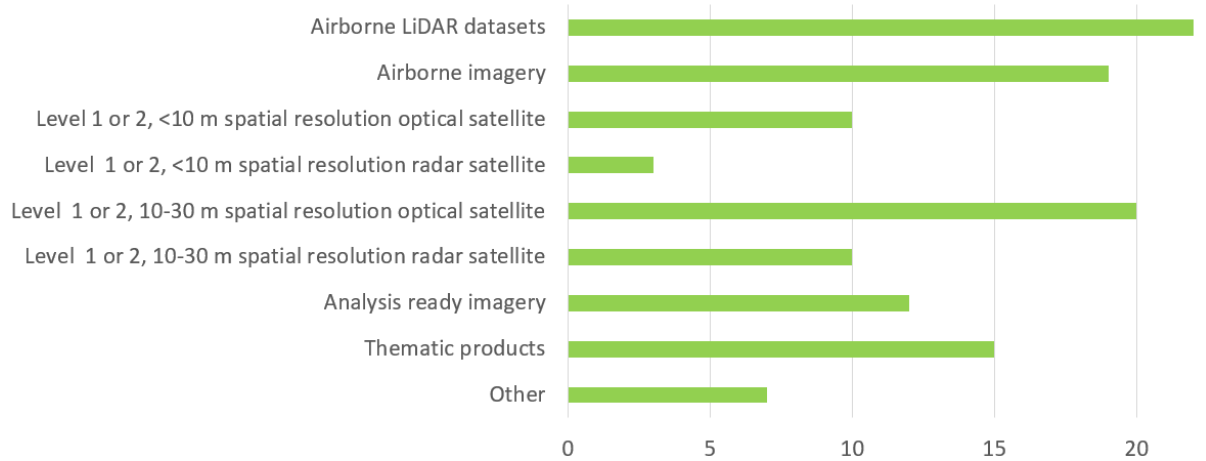

Figure 4: Stakeholder survey: Which type of remote sensing data or products do you currently use?

Among the existing Copernicus products (Figure 5), two have been clearly the most popular for Sustainable Forest Management monitoring purposes: 1) Corine Land Cover (CLC) map and 2) Sentinel-2 global mosaic. The Corine Land Cover map, with its general and national versions had been used for Sustainable Forest Management monitoring by altogether 22 of the respondents (i.e. nearly half), while the Sentinel-2 mosaic had been used by 11 respondents. In addition to these, e.g. EFFIS fire

products were found useful. Among the "Other Copernicus products and services", people listed e.g. Sentinel-2 imagery, ESA Globbiomass and Copernicus Climate Change Services C3S. The popularity of the Corine Land Cover product highlights the potential use base that EO based products have, if they meet the requirements of the Stakeholders. A key reason for the success of the Corine Land Cover may be the fact that it is produced by countries themselves and many countries have also national versions of the product, particularly designed to suit the conditions of the country. This kind of adaptability to national (or any particular interest area) conditions is a key criteria for the success of EO based products.

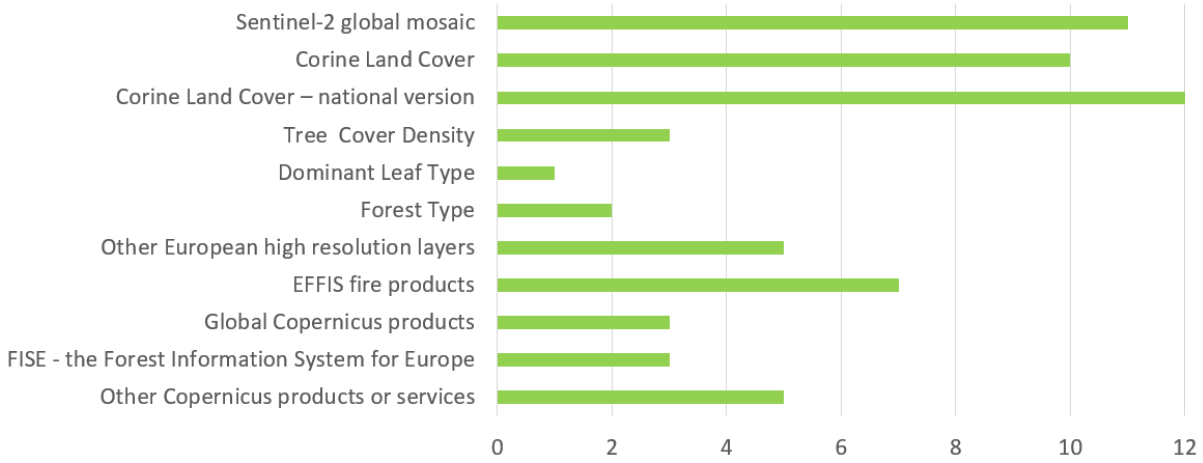

Figure 5: Stakeholder survey: Have you used some of the following Copernicus products or services to support your Sustainable Forest Management reporting, monitoring or research needs?

The reasons why respondents had not used existing Copernicus products (Figure 6) were mainly related to inadequate characteristics of the products for Sustainable Forest Monitoring purposes. It was particularly highlighted that the spatial and temporal resolutions of the products are not high enough for Sustainable Forest Management monitoring purposes. Also, the thematic classes used may not match the requirements of the users. It was commented that the products should have at least annual (or even twice a year) temporal coverage and higher (1-3 m) spatial resolution. It was also emphasized that the European wide products do not provide the required detail and accuracy for specific conditions of different parts of Europe. In addition, some respondents highlighted the fact that their organization does not have the equipment, knowledge, and experience required to utilize EO products. They were hoping for support from European institutes and faculties to be able to use the Copernicus products more productively.

Figure 6: Stakeholder survey: If you have not used the Copernicus products, what are the main reasons for this?

It is also obvious, that the Stakeholders strongly doubt the usability of current EO data and products for monitoring the 'Biological Diversity in Forest Ecosystems' and the 'Protective Functions in Forest Management' (Figure 7). Majority of the respondents were in the opinion that current EO data and products can best support monitoring of the 'Forest Resources and their Contribution to Global Carbon Cycles', the 'Forest Ecosystem Health and Vitality' and the 'Productive Functions of Forests' criteria. Although it is true that several aspects of biological diversity may be difficult to monitor with existing EO datasets, ways to utilize EO data for this purpose as well should be sought, particularly due to its rising importance for European forestry Stakeholders.

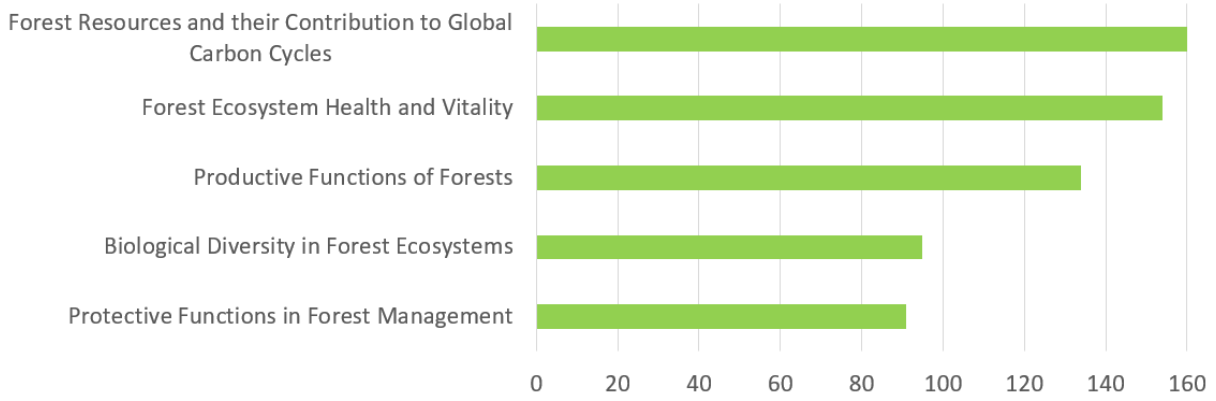

Figure 7: Stakeholder survey: Rank the following aspects of sustainability according to your view on how well current EO data and products can support monitoring and reporting requirements of the criteria.

When asked about the usability of potential future EO products (Figure 8), the votes were scattered widely throughout all the provided ideas. This highlights the large variety of Stakeholder needs related to Sustainable Forest Management in Europe. No single product idea was considered clearly more desired than the others were. If some tendency want to be seen in the results, one could say that change detection products (outlined as annual 10-20 m resolution products in the survey) felt most attractive to the users. All of the five suggested change products were ranked above the rest of the products. The two most desired products were biotic and abiotic damage maps in 10-20 m spatial resolution. This also matches well with the Stakeholders' views on the need for new approaches for forest health and vitality monitoring.

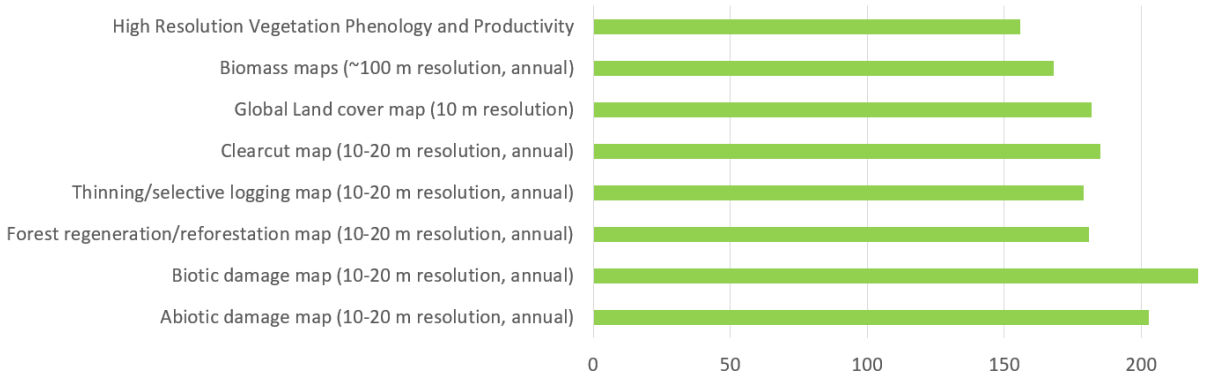

Figure 8: Stakeholder survey: Rank the following ideas of potential future product types based on usability for your Sustainable Forest Management reporting, monitoring or research needs.

Finally, the respondents were given the opportunity to freely express their ideas on what kind of EO data or products would be most needed to support Sustainable Forest Management monitoring in Europe. Many replies further emphasized the importance of the types of products suggested in the earlier questions, related to monitoring changes caused by biotic, abiotic and human intervention. People also raised current issues like the increasing bark beetle attacks, storms and flooding which need to be monitored, and emphasized the role of pro-active health and vitality monitoring. Methods for more accurate and comprehensive monitoring of the diversity of tree species, deadwood, threatened forest species and old-growth forests were considered important. In addition, specific requests were made e.g. for annual land use land cover (LULC) change maps, freely available very high resolution (VHR) imagery, open and free LiDAR data for the whole EU (repeated every 3-5 years) as well as change alerts that could be further investigated on the ground.

In a broader picture, the respondents raised important issues on the ways EO is used to support Sustainable Forest Management and wider forest policies. The importance of the socio-economic indicators was highlighted. They are an integral part of the Sustainable Forest Management. Thus, EO alone will never suffice for Sustainable Forest Management monitoring, but a combination of data sources is needed. It was also mentioned that: *"EO has both the potential to be used for operational monitoring and as well for independent surveillance and verification of SFM (national and/ or supranational level). Both approaches need attention and to be developed further."*

One respondent summarized well the concerns that were reflected by many respondents in their comments: *"As already commented above, the new high-resolution remote sensing technologies in Earth observations are very much needed and will to great extent facilitate forest inventory and forest management planning. At the same time, access to information on national forest resources is a sensitive issue and requires a parallel political solution. At the moment, we observe that some international institutions are trying to establish forest data systems based on satellite Earth observation systems to replace forest data that can be provided by the governments (e.g. FISE). This is very sensitive politically and requires a prior solution by the governments. Another issue is that the modern technology cannot and should not replace policy makers in deciding about according to what sustainability criteria the monitoring, assessment and reporting will be done in the future. Therefore, an optimal solution is that the European countries, European Commission, assisted by international specialized agencies continue working on the refinement of criteria and indicators for SFM under the MCPFE (i.e. Forest Europe) process. Only criteria and indicators worked out in such a transparent and inclusive way and politically accepted can serve as an appropriate basis for international forest monitoring based on the modern Earth observation technologies."*

DG ENV highlighted in a discussion that a general problem is that European wide data for Sustainable Forest Management is lagging behind, which means that no up-to date information is available for decision making and monitoring. The national data has limitations in many countries. Therefore, European wide up-to-date datasets would be highly needed. Furthermore, currently many European wide analyses are based on datasets and approaches developed outside Europe using non-European datasets. European competences should be developed to conduct such analyses with European datasets.

Among the sustainability criteria and indicators, DG ENV saw biomass and biodiversity related indicators increasingly important. Forest biomass links to the general amount, distribution and use of biomass in Europe, and is a key input to various Bioeconomy analyses. Biodiversity indicators are still developing and currently do not provide sufficient means to monitor all aspects of the sustainability of biodiversity, e.g. many aspects related to species composition and primary/old growth forests. Further development of biodiversity and ecosystem services related indicators is ongoing (e.g. Maes et al. 2020), and should align with the new EU Biodiversity Strategy for 2030 (https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm).

2.4 Synthesis of Stakeholder requirements related to Sustainable Forest Management monitoring in Europe

The Stakeholder survey and the virtual workshop provided a wealth of information ranging from broad perspectives on the use of remote sensing for forest monitoring to details on required information and

remote sensing products. These issues have been presented and discussed in detail in the previous chapters. Here we summarize the key points of Stakeholder requirements related to Sustainable Forest Management in Europe:

5. **Need for EO based Sustainable Forest Management approaches:** Sustainable Forest Management is a complex issue with multiple aspects and often contradictory effects on sustainable development goals on forestry. Nevertheless, it is clear that Sustainable Forest Management monitoring is increasingly required in all stakeholder groups, and there is a strong need for new monitoring approaches to meet the increasing requirements. 85% of the respondents to the Stakeholder survey had reporting or monitoring requirements or other interest related to Sustainable Forest Management and 76% of the respondents were already using remote sensing to support their activities. Remote sensing provides tools for transparent and comparable monitoring approaches, but EO approaches will not provide solutions for all requirements.

6. **Thematic requirements:** Stakeholders ranked the 'Forest Resources and their Contribution to Global Carbon Cycles', the 'Forest Ecosystem Health and Vitality' and the 'Biological Diversity in Forest Ecosystems' as the three most significance aspects of sustainability for the coming years, and the aspects where new monitoring approaches were most needed. The usability of EO data for 'Forest Resources and their Contribution to Global Carbon Cycles' and 'Forest Ecosystem Health and Vitality' monitoring was seen promising, but the usability of EO approaches for monitoring the 'Biological Diversity in Forest Ecosystems' was doubted. Forest biodiversity, biomass/carbon and disturbance monitoring were seen as the most important topics. For biodiversity monitoring, EO data was considered potentially suitable for monitoring some key indicators like fragmentation. Methods for more accurate and comprehensive monitoring of the diversity of tree species, deadwood, threatened forest species and old-growth forests were considered particularly important. In disturbance monitoring, the identification and separation of change agents was considered of high importance. Key change agents mentioned included e.g. human induced clearcutting, and thinning/selective logging as well as natural damages caused by pests, storms, floods and fires.

   For thematic products (like land cover maps), the classes would need to match well the Stakeholders requirements. Otherwise, the products were of little use. A good example of a widely used thematic product is the Corine Land Cover map, which was the most used Copernicus product by the Stakeholders for Sustainable Forest Management monitoring purposes. The strength of the Corine Land Cover map is that it is produced using a hierarchical classification structure by national experts, which allows also the production of national versions of the maps, specifically designed for national conditions.

7. **Spatial resolution requirements:** The most used remote sensing data types for Sustainable Forest Management monitoring were airborne LiDAR, aerial imagery and 10-30 m spatial resolution optical imagery. There were requests for regularly updated European wide airborne LiDAR and less than 1 m spatial resolution aerial imagery coverage. These types of datasets were seen particularly necessary for monitoring various biodiversity indicators (e.g. species and diameter distribution, forest structure). However, 10-30 m optical satellite imagery was also found useful for Sustainable Forest Management monitoring purposes e.g. for biomass/carbon as well as forest disturbance and health monitoring. The 10-30 m spatial resolution allows European wide coverage, in high temporal resolution, which is required for many applications.

8. **Temporal resolution requirements:** Although there were several aspects of forest sustainability where annual monitoring was considered to be sufficient (e.g. long term trends in productivity), temporal resolution was currently seen as one of the main limitations in existing Copernicus core products, in the context of Sustainable Forest Management monitoring. For many purposes, the Stakeholders needed monthly or higher temporal resolution. This applied particularly to the change monitoring products that were high in demand among Stakeholders. On the other hand, it was highlighted that some of the existing products, like the Corine Land Cover map, provided valuable information for long term change trends. The trade-off between temporal and spatial resolution guide the usability of EO approaches for various requirements.

For applications where very high resolution (< 1 m) is required, even annual monitoring may not be possible (for Europe-wide products), while 10-30 m analyses can be conducted in 1-3 month intervals except in winter months.

Other issues raised: In addition to the requirements listed above, several related issues were raised. First, the funding and compensation mechanism for forest ecosystem services should be established. Second, the security (an adequate level of raw timber) of future value chains for forest based products would need to be ensured. Remote sensing approaches were seen as one potential tool in supporting this development. The importance of the socio-economic Sustainable Forest Management indicators was also brought up, highlighting that a combination of data sources will always be needed to monitor Sustainable Forest Management. Furthermore, the importance of National Forest Inventory field data, and other field datasets, in Sustainable Forest Management monitoring was highlighted. Related to this, avenues to fully utilize these data for European and National level EO based Sustainable Forest Management monitoring should be found, without compromising the sensitivity of the datasets. The FISE platform is a good example of developments that may facilitate easier data exchange and utilization of National Forest Inventory and other *in situ* data in the future. And finally, some respondents highlighted the fact that their organization does not have the equipment, knowledge, and experience required to utilize EO products. They would require support from European institutes and faculties to use the Copernicus products more productively.

3 Copernicus and National Forest Inventories in Europe

3.1 Overview of National Forest Inventories in Europe

Europe has a long history of systematic National Forest Inventories (NFI). Europe also has the most advanced NFI systems in the world. The National Forest Inventories implemented in Europe are comprehensive, reliable, large-scale forest monitoring systems. The European National Forest Inventory Network (ENFIN) is a European network to promote National Forest Inventories, harmonise forest information and support decision makers in a broad range of forest related policies. Most of the information presented in this section is derived from the ENFIN website (http://www.enfin.info/).

National Forest Inventories are in key roles to support forest policies with harmonised forest information. Therefore, some of the major tasks of ENFIN include provision of a platform for the harmonisation of forest inventory information at European scale, promotion of new methods and optimization of synergies between European National Forest Inventories. By default, the field data and results from European National Forest Inventories are not necessarily comparable. Different countries have designed systems that best suit national resources and conditions. Yet, numerous international programs and target groups from the environmental, wood processing, and energy sectors require comparable information from National Forest Inventories as reliable basis in decision-making processes. The increasing Sustainable Forest Management monitoring requirements further add the pressure for National Forest Inventory harmonization across Europe. Similarly, the usability of National Forest Inventory data as field reference data in European wide EO based approaches greatly benefits from standardized format of data. The harmonisation process initiated by ENFIN maintains the framework of existing National Forest Inventory methods and achieves comparability through the development and application of harmonisation procedures for National Forest Inventory target variables.

The National Forest Inventories of all ENFIN members are based on field measurements, collected though varying sampling designs (Table 3). Typically, each country measures from thousands to tens of thousands of field plots for each National Forest Inventory cycle. In most countries, National Forest Inventories are nowadays conducted in a continuous fashion, annually measuring around x/n field plots, where x is the total number of National Forest Inventory plots and n is the number of years in each cycle. This enables updating the results on annual basis. In addition, it provides valuable up-to-date field reference data for various remote sensing based forest monitoring activities on annual basis.

In most countries, the National Forest Inventory field measurements are not openly available data. There may be numerous reasons for this, ranging from technical complexity of the datasets and privacy issues

of forest owners to general sensitivity of the forest information and location details of permanent sample plots, to name just a few. For instance, if the locations of permanent forest inventory plots are publicly disclosed and marked on the ground, forest owners may treat these areas differently (either logging them ahead of normal schedule or saving them in logging operations) in logging operations just out of ignorance on what should be done with these forest stands. This can lead to biases in the National Forest Inventory. However, increasing number of countries (including e.g. the Netherlands, Spain and Sweden) are providing their National Forest Inventory field data openly. Furthermore, approaches could be developed (e.g. through online processing platforms) to enable the use of National Forest Inventory field measurement data as reference material without fully releasing the data to users.

Table 3: Basic designs of European National Forest Inventorys (http://www.enfin.info/)

Country	Latest inventory		Method	
	Name	Years	Sample plots (n, if available)	Field Assessments
Austria	NFI8	2016-2021	Permanent (22 236)	Continuous
Bosnia and Herzegovina	NFI3	2008-2028	Permanent	Continuous
Belgium	RFI4 (Wallonia)	2008-2018	Permanent and temporary	Continuous
Switzerland	NFI4	2009-2017	Permanent	Continuous
Czech Republic	NFI3	2016-2021	Permanent (14 300)	Continuous
Germany	NFI3	2012	Permanent (195 630)	Periodic
Denmark	NFI4	2017-2022	Permanent and temporary	Continuous
Estonia	NFI3	2009-2013	Permanent and temporary	
Spain	NFI4	2008-2018	Permanent	Continuous
Finland	NFI12	2014-2018	Permanent and temporary	Continuous
France	NFI6	2010-2014	Permanent	Continuous
Croatia	NF1	2006-2009	Permanent (6 235)	
Hungary	NFI1	2010-2014	Permanent	Continuous
Iceland	NFI2	2010-2014	Permanent (814)	Continuous
Ireland	NFI3	2015-2017	Permanent (1800)	Discontinuous
Italy	NFI3	2013-	Temporary	Discontinuous
Lithuania	NFI4	2013-2017	Permanent (16 349)	Continuous
Latvia	NFI2	2009-2013	Permanent and temporary	Continuous
Netherlands	NFI6	2012-2013	Permanent and temporary	Discontinuous
Norway	NFI11	2015-2019	Permanent	Continuous
Poland	NFI3	2015-2019		
Portugal	NFI6	2015	Temporary (12 000)	Discontinuous
Romania	NFI2	2013-2018	Permanent and temporary	Continuous
Serbia	NFI1	2004-2006	Permanent (19 3719)	n.a.
Sweden	NFI8	2003-	Permanent and temporary	Continuous
Slovenia	NFI2	2015-2016		Discontinuous
Slovakia	NFI1	2005-2006		

Although the National Forest Inventories in Europe are based on field plot measurements, and the official nationwide results are derived from the field data, remote sensing datasets are used in several countries at various stages of the process. Table 4 provides an extensive sample of remote sensing datasets used in European National Forest Inventories, according to the Sustainable Forest Management monitoring survey replies from National Forest Inventory organizations. The list does not cover all European countries, but only the ones that replied to the survey. In any case, it gives a good overview of the types of remote sensing datasets typically used in National Forest Inventories in Europe. There is no possibility to go into details on how the remote sensing datasets are used in various National Forest Inventories here. In general level, the two most common ways of utilizing remote sensing datasets relate to: 1) pre-field measurement operations (e.g. multi-phase sampling design with stratification, masking forest areas) and 2) post-field measurement propagation and analysis of results (e.g. creation of wall-to-wall maps and/or calculating results for sub-regions).

Table 4: Remote sensing datasets used in selected European National Forest Inventories (based on the Stakeholder survey)

Country	Remote sensing data used
Bosnia and Herzegovina	• 10-30 m resolution, optical satellite
Belgium	• Airborne LiDAR • Airborne imagery • <10 m resolution optical satellite • 10-30 m resolution optical satellite • 10-30 m resolution radar satellite
Switzerland	• Airborne LiDAR • Airborne imagery • 10-30 m resolution optical satellite • 10-30 m resolution radar satellite • Analysis ready imagery • Thematic products
Czech Republic	• Airborne LiDAR • Airborne imagery • <10 m resolution optical satellite • Thematic products
Denmark	• Airborne LiDAR • Airborne imagery • 10-30 m resolution optical satellite • 10-30 m resolution radar satellite • Analysis ready imagery
Finland	• 10-30 m resolution optical satellite
Croatia	• Airborne LiDAR • 10-30 m resolution optical satellite
Hungary	• <10 m resolution optical satellite
Iceland	• Airborne imagery • 10-30 m resolution optical satellite
Ireland	• Airborne imagery • <10 m resolution optical satellite • <10 m resolution radar satellite
Lithuania	• Orthophoto maps
Netherlands	• Airborne imagery
Norway	• Airborne LiDAR • Airborne imagery • Analysis ready imagery
Poland	• Airborne LiDAR • Airborne imagery
Romania	• Airborne LiDAR • Airborne imagery • <10 m resolution optical satellite • 10-30 m resolution optical satellite
Serbia	• -
Sweden	• Airborne LiDAR • 10-30 m resolution optical satellite
Slovenia	• Airborne LiDAR • Airborne imagery
Slovakia	• Airborne LiDAR • Airborne imagery

	• 10-30 m resolution optical satellite

It can be expected, that the use of remote sensing approaches in European National Forest Inventories will increase in the future. With the increasing availability of different types of remote sensing datasets, and increasing number of variables to monitor, combined use of remote sensing and field measurements can offer significant cost savings and improvements e.g. in the timeliness of the results (Kangas et al. 2018). However, it needs to be remembered that many important forest variables do not correlate with remote sensing data, and very high spatial resolution data is required for many purposes. This limits particularly the use of 10-30 m spatial resolution EO data (e.g. Sentinel-1 and 2) in National Forest Inventories. The frequency of observations and the possibility to cover large geographical areas can be seen as the main strength of EO data. In the context of National Forest Inventories, EO data can be considered particularly suitable for derivation of information on landscape patterns and large area changes (Kangas et al. 2018).

3.2 Perspectives from the National Forest Inventory Organizations' Answers to the Stakeholder Survey

Interesting perspectives to the use of EO to support Sustainable Forest Management aspects in National Forest Inventories were derived also from the Stakeholder survey presented earlier, by restricting the analysis to respondents from organizations leading National Forest Inventories. Responses were received from altogether 20 organizations responsible for National Forest Inventories in their respective countries. Firstly, nearly all (95%) or respondents have reporting or monitoring requirements related to Sustainable Forest Monitoring. Regarding the general views on the importance of different aspects of sustainability and the necessity for new monitoring needs, the views of the National Forest Inventory contact points agreed rather well with the overall survey results. The clearest difference was that the productive functions of forest were seen as more important monitoring topic than biological diversity. But the top two most important Sustainable Forest Management aspects remained to be the carbon and health issues also from the perspective of people working with National Forest Inventories.

Among the National Forest Inventory respondents, 84% said they were using some sort of remote sensing to support their activities related to Sustainable Forest Management monitoring. Perhaps slightly surprisingly, airborne datasets were more dominating in the National Forest Inventory organizations than in the overall survey results, with over half of the twenty respondents declaring that they were using airborne LiDAR and Airborne imagery (Figure 9). In comparison, eight respondents say they were using 10-30 m spatial resolution optical imagery. Just a few respondents were using any other types of remote sensing data.

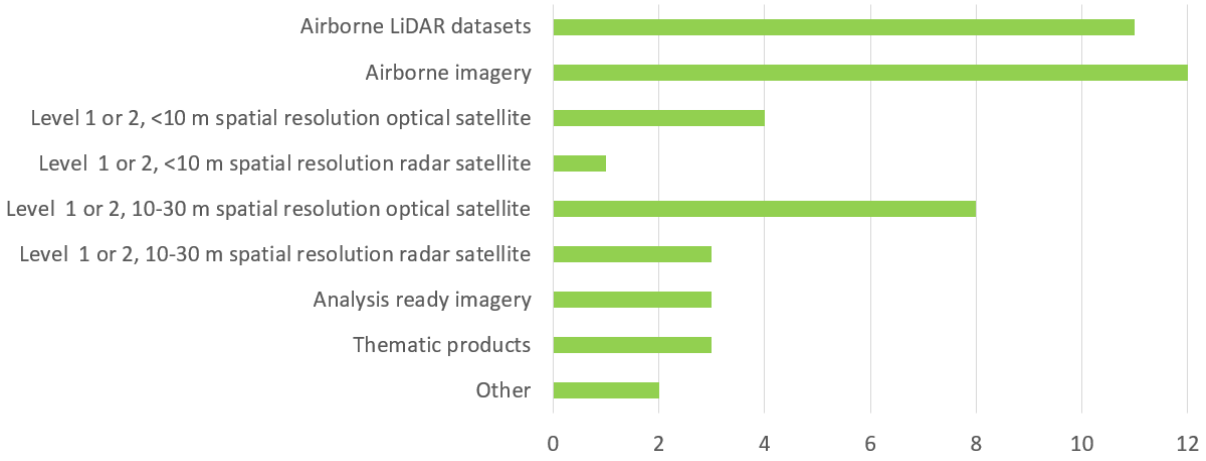

Figure 9: Stakeholder survey, National Forest Inventory organizations: Which type of remote sensing data or products do you currently use?

The use of Copernicus products in the National Forest Inventories was very small. Four respondents said they were using the Sentinel-2 global mosaic and the general Corine Land Cover map, and four were using the national versions of Corine Land Cover. Apart from that, only single users were listed for the Tree Cover Density (TCD) product, EFFIS fire products and FISE. The main reasons for not using Copernicus products were the inadequate accuracy and compatibility for national conditions. As one respondent comments: *"Classifications based on European wide ground truth do not match the details needed in our country context with a highly manipulated forest landscape. To be fully useful, interlinking of monitoring at different scales and time are needed. Otherwise, the monitoring do not provide consistent results and hence monitoring and reporting will be inconsistent leading to misconceptions and erroneous decision support. A huge risk by producing this type of maps is the automation and lacking linking to ground truth, yielding significant risks of false-change estimates. Hence, I would rank large scale change maps to be of high uncertainty, with the subsequent risk of providing erroneous decision support information. Recent publications reveal exactly this risk! But the problem have been known for long time."*

This brings us back to the importance of matching the user requirements, a topic already discussed while analysing the results of the general survey. In order to maximize the uptake of Copernicus products in support of National Forest Inventories, it would be essential to provide products that are flexible enough to be further developed to meet national conditions. The comment above refers also to another important issue, the optimal use of reference data. It would be important to improve the availability and effective utilization of field reference data for production of European wide EO products. Cooperation between national institutes controlling field datasets and institutes responsible for production of European wide EO products should be strongly encouraged to maximize the adaptability of European wide EO products for national conditions.

Alternatively, datasets and tools could be provided in online platforms to enable easy derivation of products for specific interest areas with appropriate data and methods. In this context, the field datasets could remain classified, only accessible to the user using the platform to derive their products. This approach, however, would need to be accompanied with active capacity building efforts. Even with the existing available products, four respondents answered that they do not have the required knowhow to use the products. One respondent synthesized well this problem: "*Except in individual cases by individuals from scientific institutions, the use of Earth Observation on forest ecosystems is not applied in full scale [in our country] due to the lack of equipment, knowledge and experience in interpreting the results etc. Support from European institutes, or Faculties that have knowledge and experience in this field would contribute fully to the implementation of this monitoring system. Knowledge of use of Earth Observation is the main reason for not using the Copernicus images or some other satellite images for the monitoring in the extent that such systems provides.*"

Future products that National Forest Inventory organizations across Europe liked to see (to support their Sustainable Forest Management monitoring needs) were primarily related to forest and land cover change monitoring. Among the products suggested in the survey form, biotic and abiotic damage maps as well as the global 10 m land cover map were the most preferred. In addition, respondents listed specific products such as deforestation map, annual LULC change map, forest cuttings, reforestation and afforestation, all related to forest and land cover changes. From the Sustainable Forest Management perspective, the maps do not necessarily need to be annual products. One respondent raised the usability of the products providing longer change interval as well: "*To support Sustainable Forest Management monitoring in Europe, Land Use change products can be interesting, to see where the changes occurred over the time (for example every 5 years), and clearly make maps of the changes".*

In the free comments, one respondent also raised an important aspect of cost efficiency, and highlighted the benefits of EO in this respect: "*The drawback of forest inventories is that they are most often run for several years before data becomes available. This problem is however solved by the use of continues inventories. After one cycle the new cycle starts immediately so new data is available annually. With respect to developed countries with active forest inventories in place the earth observation data should be used to support the forest inventories, but could also be used to fill gaps that can't be covered by the forest inventory. In that way the forest inventories could become more cost effective and deliver more information than before."*

3.3 Enhancing Synergy between Copernicus Services and National Forest Inventories in Europe and Beyond

The analyses of the Stakeholder perspectives and survey answers presented above reveal a few aspects and key points where synergy between Copernicus Services and National Forest Inventories could be further enhanced in Europe. The findings are also valuable in defining optimal designs for global Copernicus components. In the following, the main findings are discussed under four key points:

1. National Forest Inventory arrangements
2. Field data collection
3. Utilization of EO imagery
4. Utilization of EO products

National Forest Inventory arrangements: As a background, it needs to be remembered that Europe has a long history of forest inventories and most countries have well established National Forest Inventories. Different countries have different institutional and technical arrangements for conducting the inventories. Institutions responsible for conducting the inventories vary from national agencies and state-owned companies to non-governmental organizations and research organizations. Technical approaches vary between countries due to varying forest conditions, but are typically highly developed and optimized, providing high quality and results answering the needs of national users. On one hand, the variability of European approaches complicates the harmonization (and thereby comparability) of the inventories in different countries, but on the other hand, it provides a wide spectum of established examples of National Forest Inventory arrangements that can be used as examples for countries outside Europe. Furthermore, the European National Forest Inventory Network (ENFIN) harmonization approach serves a good example for any regional harmonization ambitions.

Field data collection: All European National Forest Inventories are based on field measurements. Although remote sensing approaches are used in many countries to support the inventories in many stages of the process, the key results are based on extensive field measurement campaigns. This results in an immense, continuously updating, database of field measurements covering nearly all European countries. This source of field measurements should be fully utilized to maximize the synergy with Copernicus EO data. There are two major avenues to utilize this synergy to increase the use of Copernicus data: 1) National level products and 2) European level Copernicus products.

Many countries already utilize Copernicus EO data in combination with their National Forest Inventory field measurements for national level forest monitoring tasks, with ever increasing and improving monitoring approaches (Kangas et al. 2018). However, due to specific temporal or thematic requirements, the countries have set up their own processing systems. This is possible only for the most advanced countries, although many other countries would highly benefit from similar systems. Solutions for enabling production of such analysis based on users own data combined with Copernicus EO data should be developed on online platforms, allowing all countries to fully benefit from the combination of their field data and Copernicus EO data. There are already several existing platforms (like the DIAS platforms and Forestry TEP), that technically allow provision of such Copernicus services. Tools designed for national level analysis can be provided through these platfroms. Capacity building may be needed to ensure optimal usage and service uptake.

For European wide core products, the National Forest Inventory field measurements would form an invaluable training and reference dataset. It would benefit all parties through improved accuracy of the products in the varying forest conditions around Europe. A major complication in the usage of National Forest Inventory field data in production of European wide products is the data secrecy. There are many legitimate reasons why it may not be possible to release National Forest Inventory field measurements in all countries (e.g. forest owner privacy and location details of permanent sample plots). Technical solutions should be sought that would allow utilization of national field measurement datasets for training and accuracy assessment of European wide products, while preserving the confidential aspects of the data. Again, online platforms, or interaction with different platforms (e.g. database/analysis and processing platforms), could provide solutions for creation of such systems.

Utilization of EO imagery: The Copernicus Sentinel satellites (most particularly Sentinel 1 and 2) provide high suitable data for National Forest Inventory purposes, and are already used in several

European countries. Creation of the types of services discussed in the previous chapter, allowing users to produce their own products designed for national level forest monitoring, would further increase the use of Copernicus EO data for national level monitoring. Apart from the 10-30 m spatial resolution data, the National Forest Inventories utilize increasing amount of airborne LiDAR data and Very High Resolution (VHR) satellite imagery. Inclusion of such datasets either in the core offering of Copernicus data, or as auxiliary datasets (e.g. in the above described processing platforms), would be highly advantageous for National Forest Inventories. These datasets could be used either in combination with the 10-30 m resolution Sentinel data, or as the main remote sensing data for specific tasks (e.g. species richness). In long term, continued improvement of the spatial resolution of Copernicus EO data will enable increased usability of EO datasets e.g. for biodiversity and forest health related monitoring tasks. Many of the EO based approaches developed in Europe can also be applied globally, with algorithms tuned to national conditions around the world.

Utilization of EO based products: To increase the use of Copernicus products in National Forest Inventories in Europe and beyond, the key point is to provide products that meet the needs of the users. As described earlier in the document, reasons why Stakeholders had not used existing Copernicus products for Sustainable Forest Monitoring purposes were mainly related to inadequate characteristics (e.g. spatial or temporal resolution) of the products for their needs. A good example of a successful widely used product is the Corine Land Cover map, which is produced by countries themselves and many countries have also national versions of the product. This ensures both the usability of the product for the conditions of a particular country, as well as comparability of the results at European level. This kind of adaptability to national (or any particular interest area) conditions is a key criteria for the success of EO based products.

There are many ways to meet the needs of the users. From products design point of view, products with continuous variables (like tree cover %), are generally more adaptable and allow further development better than products with categorical variables (like land cover classes). It is also important to involve Stakeholders and future users strongly in the design of any future products, like is currently being done in the design of the Copernicus REDD+ component. This will improve the commitment and interest of future users. Due to the improving online data processing capabilities, future EO core products can also include increasing amount of flexibility/adaptability, with provision of platforms and tools that can be used to tune the products for national circumstances. In this respects, appropriate capacity building may be required to ensure that users have the knowledge required to maximize the usability of the products for their national conditions, whether it be in Europe or anywhere else in the world.

4 Preliminary Indications of Research Gaps for European Sustainable Forest Management Monitoring

The Stakeholder requirements and views reported and discussed in the previous sections outline the framework for the analysis of research gaps in European Sustainable Forest Management monitoring. During 2021, the Stakeholder requirements and views will be compared with the status of research and existing Copernicus products. The literature review was first reported in D11.1 (Compendium of R & D Needs for Implementation of European Sustainable Forest Management Copernicus Capacity; v.1), and will be updated during 2021 for the final analysis.

However, some indications of research gaps can already be preliminarily outlined at this point based on the first version of the literature review and the Stakeholder requirements. It became clear during the Stakeholder interaction that they consider the three most important sustainability criteria for their operations in the near future to be: **Forest Resources and their Contribution to Global Carbon Cycles**, **Forest Ecosystem Health and Vitality** and **Biological Diversity in Forest Ecosystems** (in no specific order, as they ranked close to each other). The **Productive Functions of Forests (Wood and Non-Wood)** ranked as the fourth most important, while the **Protective Functions in Forest Management** was considered the least important criterium.

The initial results from the literature review presented in D11.1 highlighted large amount of research ongoing in research themes that support several major aspects of the top three most important criteria listed above. However, research in these thematic areas are in highly different stages from the point of view of Sustainable Forest Management monitoring in European context. Some topics, like 'Forest extent and land cover assessment', that supports monitoring **Forest Resources and their Contribution to Global Carbon Cycles**, is covered by several existing Copernicus Land Monitoring Service products and high level of scientific knowledge. It is believed to require little further research to enable provision of optimal products to support Stakeholders in Sustainable Forest Management monitoring. Biomass and carbon monitoring, that supports the same criteria, is not as ready operationally as forest extent mapping, but there is already intensive research activity ongoing, with several large projects and new sensors implemented or planned. The specifications (spatial and temporal resolution, accuracy *etc.*) of the existing datasets may not satisfy the requirements of the Stakeholders, but the upcoming sensors discussed in D12.2 (Compendium of R&D Needs for the Evolution of the Copernicus Space Component; Version 2) and the new products derived from these sensors are expected to improve the situation to some extent.

'Logging operations monitoring' and 'Abiotic and biotic damages' are perhaps the most interesting thematic areas in the near future from the Copernicus perspective in the context of European Sustainable Forest Management monitoring. The information on these topics support monitoring of several Sustainable Forest Management criteria, including at least **Forest Resources and their Contribution to Global Carbon Cycles**, **Forest Ecosystem Health and Vitality** and **Productive Functions of Forests (Wood and Non-Wood).** Currently, no operational products providing information on many of the sub-topics are available within these areas of interest (*e.g.* thinning, regeneration, biotic damage) but the scientific knowledge has accumulated rapidly over the past few years, particularly related to time series analysis and utilization the Sentinel fleet of satellites. Numerous approaches are available to detect changes from the increasing amount of 10-30 m spatial resolution EO data. The difficulty is to evaluate the magnitude of change and identify the agent behind the change. Practical solutions for providing optimal operational products to support Stakeholder requirements in Sustainable Forest Management monitoring in these areas need to be found in the near future.

The **Biological Diversity in Forest Ecosystems** monitoring is still in early stages of research, trying to define the best practices to utilize EO in support of the biodiversity related Sustainable Forest Management criteria. The challenge is the large variety of parameters of interest, varying (or lacking) practices of biodiversity monitoring by means of remote sensing and the varying definition of some of the concepts (*e.g.* ecosystem functions). Furthermore, monitoring of many of the biodiversity indicators would need very high spatial resolution (< 1 m) data. More research on the usability of 10-30 m resolution data and formulation of best monitoring practices is needed in this topic. In fast evolving topics like this, intensive Stakeholder involvement is important to guide the required research effort into the right direction.

In addition to the directions of interest of the Stakeholders, the interaction brought up a few other major issues affecting the usability and success of any potential future Copernicus products supporting Sustainable Forest Management monitoring. Firstly, the adaptability of Copernicus products into national circumstances around Europe is of crucial importance. Currently, one of the major reasons for not using Copernicus products is the unsuitability of the products for national conditions. It would be essential to design the products so that they could be utilized in varying conditions. Use of continuous variables is one example of the ways to promote adaptability to various definitions and circumstances. Another important aspect, related to the first point, is better utilization of the immense field data reserves that European countries have from their forests. Even though the measurement plots of National Forest Inventories may be smaller than satellite pixel (and the plot data therefore not optimal for analysis of EO data - especially for SAR data suffering from the so called speckle noise) the National Forest Inventory datasets are by far the largest datasets on forest in Europe. A stronger unification and synergy of Copernicus products and national field dataset should be sought, instead of juxtaposing them against each other. This would benefit the quality and usability of the Copernicus products, and make them more suitable for varying circumstances around Europe. Different ways to approach the issue could be sought, varying from traditional core product approach, to more user driven production of on-demand products for defined areas (optionally with user provided field data). The best ways for combined use

of the Copernicus data and national field datasets will need to be found, but the value of such synergy is too large to be overlooked. Many of the most advanced national institutions and other Stakeholders already perform these types of production and analyses in their own systems. It would be very beneficial to make such production/analysis capabilities available for all European Stakeholders.

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Annex 1

Earth Observation for European Sustainable Forest Management – Webinar, 24 Sep 2020, Final Announcement

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Annex 2

European Sustainable Forest Management Stakeholder Survey

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