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Deliverable abstract	This report synthesises user requirements for advancing Earth Observation (EO) and Remote Sensing (RS) in European forest monitoring, as mandated by the proposed EU Forest Monitoring Regulation. Drawing on a stakeholder survey (*n=48*), policy analysis, and technical evaluations, it identifies three systemic barriers to adoption: technical complexity (80% lack ML/AI skills), financial constraints (high cloud computing costs), and data sovereignty concerns. The findings highlight regional disparities, with Nordic countries leveraging advanced EO integration (e.g., Finland's NFI-LiDAR models) and Southern/Eastern Europe hindered by funding gaps. Recommendations include harmonised INSPIRE-compliant workflows, hybrid estimators for LULUCF reporting, and capacity-building programmes. While limited by a 6.1% survey response rate, the analysis provides actionable insights for FUTUREFOR's technical developments in WP4, ensuring alignment with EUDR, biodiversity, and climate goals.
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ACRONYMS LIST

AI	Artificial Intelligence
CLMS	Copernicus Land Monitoring Service
CLC	CORINE (Coordination of Information on the Environment) Land Cover
DLT	Dominant Leaf Type (Copernicus HRL product)
EFFIS	European Forest Fire Information System
EEA	European Environment Agency
EO	Earth Observation
EUDR	EU Deforestation Regulation (Regulation on deforestation-free products)
FAO	Food and Agriculture Organisation of the United Nations
FRA	Forest Resources Assessment (FAO initiative)
FTY	Forest Type (Copernicus HRL product)
GIS	Geographic Information Systems
GDPR	General Data Protection Regulation
HRL	High Resolution Layer (Copernicus product series)
ICP Forests	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests
INSPIRE	Infrastructure for Spatial Information in Europe (EU directive)
LiDAR	Light Detection and Ranging
LULUCF	Land Use, Land-Use Change, and Forestry
ML	Machine Learning
MMU	Minimum Mapping Unit
NFI	National Forest Inventory
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RS	Remote Sensing
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goal (UN framework)
SMEs	Small and Medium Enterprises
TCD	Tree Cover Density (Copernicus HRL product)

1. INTRODUCTION

1.1. FUTUREFOR project overview

The FUTUREFOR project, funded under the European Union's Horizon Europe research and innovation programme (Grant Agreement No. 101180278), aims to develop and implement advanced Earth Observation (EO) and Remote Sensing (RS) technologies for next-generation forest monitoring across Europe. The project directly responds to the European Commission's proposed Regulation on a monitoring framework for resilient European forests, which was introduced in November 2023.

FUTUREFOR brings together eight partners from across Europe, combining expertise in forest monitoring, Copernicus services, artificial intelligence, and big data analysis. The consortium includes research institutions, technology providers, and end-users to ensure that the developed solutions address real-world challenges and policy needs.

With the increasing challenges facing European forests due to climate change, biodiversity loss, and growing societal demands, there is an urgent need for more comprehensive, harmonised, and timely monitoring systems. FUTUREFOR addresses this need by assessing current practices, identifying user requirements, and developing technical solutions that can be implemented at both European and national levels.

The project's core objective is to establish the knowledge base and develop practical tools that leverage Copernicus satellite data and complementary sources to provide accurate, timely, and comprehensive forest information. These capabilities are essential for supporting decision-making and policy implementation across EU Member States, particularly in areas related to forest health, carbon accounting, biodiversity preservation, and wildfire management.

The project's primary objectives include evaluating the potential for EO and RS to enhance forest monitoring activities, identifying barriers to implementation, assessing current data products and services, and providing recommendations for improved user uptake of Copernicus Land Monitoring Services. By bringing together expertise from multiple disciplinary domains and stakeholders, FUTUREFOR seeks to bridge the gap between technical capabilities and practical implementation, ultimately supporting more sustainable forest management across Europe.

1.2. User requirement analysis

A user requirement analysis was carried out based on the survey conducted as part of the WP2 “User involvement and dissemination” for the production of the deliverable D2.1 on stakeholder and legislation analysis.

User requirements analysis serves as the cornerstone for successful service development within the FUTUREFOR project. This systematic process aims to establish a comprehensive understanding of stakeholder needs, expectations, and constraints regarding EO/RS applications in forestry contexts. The purpose of this analysis extends beyond mere technical specifications to encompass the broader operational, policy, and market dimensions that will shape service adoption and impact.

The specific objectives of this user requirements analysis include t**ranslating stakeholder needs into actionable requirements:** Converting the rich qualitative and quantitative insights gathered from the stakeholder survey (D2.1) into clearly defined, testable, and implementable requirements that can guide technical development. **Prioritising development efforts:** Identifying which capabilities and features are most critical to users, allowing the consortium to allocate resources efficiently and focus on high-impact functionalities. **Aligning technical possibilities with user expectations:** Bridging the gap between what is technically feasible within the project's scope and what users truly need, ensuring that innovations serve practical purposes. **Supporting policy compliance:** Ensuring that developed services meet the regulatory and reporting requirements identified in the legislative landscape analysis of D2.1, particularly relating to the Forest Monitoring Law, EU Deforestation Regulation, and LULUCF frameworks. **Fostering stakeholder engagement:** Demonstrating to stakeholders that their input is valued and incorporated into the development process, thereby building trust and encouraging continued participation.

The D3.1 builds directly upon the findings of the Stakeholder and Legislation Analysis (D2.1), which provided a comprehensive assessment of the policy landscape, stakeholder categories, and current patterns of EO/RS adoption in European forestry. While D2.1 focused on understanding the "what" and "why" of stakeholder needs, D3.1 translates these insights into the "how" of technical implementation.

This user requirements analysis is particularly crucial for FUTUREFOR given the documented gap between awareness and operational adoption of EO/RS technologies in forestry. By systematically addressing the barriers identified in D2.1 - such as technical complexity, data integration challenges, and limited user expertise - the project can develop services that bridge this adoption gap and maximise impact across diverse stakeholder groups.

While this report synthesises critical insights into user requirements for the Forest Monitoring Framework, it is essential to contextualise its findings within methodological constraints. The stakeholder survey, distributed to 792 contacts across European institutions, yielded 48 validated responses (6.1% response rate). This limited participation introduces potential nonresponse bias and limits the generalisability of results. While stratified sampling ensured representation across governance, research, and end-user groups, the small sample size necessitates cautious interpretation of quantitative claims. These limitations are consistent with challenges observed in survey research, where low response rates can reduce statistical power and external validity. Nevertheless, the findings provide valuable directional insights for prioritising technical developments in WP4, particularly when triangulated with policy analysis and existing literature.

1.3. Current monitoring and reporting processes for forest and forest-related legislation at EU Level

Current forest monitoring and reporting processes within the European Union operate within a complex landscape of policy frameworks, each with specific data requirements and reporting mechanisms. These processes have evolved over decades in response to various environmental concerns and international agreements, resulting in a somewhat fragmented approach to forest monitoring.

The primary European forest monitoring initiative is the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests), established in 1985. ICP Forests provides scientific knowledge on the effects of air pollution, climate change, and other stressors on forest ecosystems through a network of observation plots across Europe (ICP, 2024). This programme represents one of the most comprehensive monitoring systems within the Working Group on Effects under the UNECE Convention on Long-range Transboundary Air Pollution.

Forest information reporting at the EU level is currently managed through several complementary frameworks. The European Forest Accounts (EFA) collect annual data on forest resources and economic activity in the forestry and logging industry. These accounts provide detailed information on the area of wooded land, value of wooded land, and volume of timber. Additionally, the Food and Agriculture Organisation's Forest Resources Assessment (FAO-FRA) conducts a five-yearly data collection on forest resources, while Forest Europe's State of Europe's Forests assessment provides comprehensive data every five years on multiple indicators of sustainable forest management.

Table 1 Summary table of EU forest-related reporting frameworks and variables

Policy/Framework	Main topic/Objective	Key reported variables/Indicators	Measurement method (Field/EO/Integrated)	Reference/Legislation)
Habitats Directive	Conservation status of habitats/species	Range, area, structure, population trends, threats, conservation measures	Field, EO, Integrated	Directive 92/43/EEC, Art. 17
Nature Restoration Law	Forest ecosystem restoration	Uneven-aged structure, connectivity, organic carbon, native species, species diversity	Field, EO, Integrated	Regulation (EU) 2022/869
LULUCF Regulation	GHG emissions/removals from forests	Forest area, carbon pools (biomass, deadwood, soil), harvested wood, removals	Field, EO, Integrated	Regulation (EU) 2018/841
EUDR	Deforestation-free supply chains	Geolocation, land use, supplier/customer info	EO, Field	Regulation (EU) 2023/1115
Renewable Energy Directive (RED)	Renewable energy targets, biomass sourcing	Forest area, sustainability compliance, GHG reduction, management practices	Field, EO, Integrated	RED II/III, COM/2021/557
Forest Europe	Sustainable forest management	Area, timber volume, economic variables, employment, biodiversity indicators	Field, EO, Integrated	Forest Europe Process
Copernicus/CLMS	Land, forest cover, ecosystem health	Tree cover density, dominant leaf type, forest type, fire indices, vegetation stress	EO	Copernicus Land Monitoring Service **Regulation (EU) 2021/696**

The State of Europe's Forests 2024 report, a key output of Forest Europe, evaluates forests across the continent using a set of pan-European indicators for sustainable forest management. These indicators are organised under six criteria: maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles; maintenance of forest ecosystem health and vitality; maintenance and encouragement of productive functions of forests; maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems; maintenance and appropriate enhancement of protective functions in forest management; and maintenance of other socioeconomic functions and conditions (FOREST EUROPE, 2020).

Table 2 Reported forest variables and measurement methods

Variable	Definition/Indicator	Measurement Method	Frequency	Source/Framework
Forest Area	Area of land classified as forest	EO, Field, Integrated	Annual/Periodic	NFI, Copernicus, FAO
Tree Cover Density	% of land covered by tree canopy	EO (Copernicus HRL)	Annual/3-year	Copernicus HRL
Deadwood Volume	Standing/lying deadwood per hectare	Field, EO (LiDAR)	Periodic	NRL, NFI
Biomass	Above-ground biomass (t/ha)	Field, EO (LiDAR/SAR)	Annual/Periodic	LULUCF, RED, NFI
Forest Connectivity	Degree of forest patch connectivity	EO (Copernicus, GIS)	3-year	NRL, Copernicus
Carbon Stock	Carbon in biomass, soil, deadwood	Field, EO, Integrated	Annual/Periodic	LULUCF, NFI
Forest Health	Defoliation, pest/disease, vitality	Field, EO (Spectral)	Annual/Periodic	ICP Forests, Copernicus

Within this reporting framework, specific data is collected on forest area, growing stock, age structure, forest carbon, air pollution, soil condition, defoliation, forest damage, increment and fellings, roundwood, non-wood goods, diversity of tree species, regeneration, naturalness, deadwood, genetic resources, forest fragmentation, threatened forest species, protected forests, and common forest bird species, among many other indicators (FOREST EUROPE, 2020). This comprehensive approach aims to provide a holistic view of European forests, though the methods of data collection and the frequency of reporting vary considerably across indicators and Member States.

Current monitoring approaches rely heavily on field-based national forest inventories, supplemented by remote sensing data in varying degrees across different countries. This creates challenges in terms of data harmonisation, timeliness, and spatial resolution, which the proposed Forest Monitoring Regulation seeks to address.

1.4. The proposed Forest Monitoring Regulation and its Annex

In November 2023, the European Commission presented a proposal for a regulation on a monitoring framework for resilient European forests, commonly referred to as the Forest Monitoring Law (FML) (EC, 2023). This legislative proposal aims to establish a comprehensive, high-quality monitoring system that would ensure standardised or harmonised data collection across all forests and other wooded land in the European Union.

The FML was first announced in the new EU Forest Strategy for 2030 and addresses significant knowledge gaps in the current forest monitoring landscape, which often relies on outdated data and divergent definitions (EC, 2023). According to the legislative proposal, the Commission would, in cooperation with the Member States, establish and operate an

integrated forest monitoring framework focusing on parameters connected to EU policy priorities such as climate change, biodiversity, forest health, invasive alien species, and forest management (EP LO, 2023).

The proposed Forest Monitoring Law comprises three essential components: a geographically explicit identification system, a data collection framework, and a data sharing framework. The identification system aims to map and localise forest areas using "aerial or space-borne ortho-imagery data". The data collection framework specifies the types of forest data to be gathered, with responsibilities divided between the Commission and Member States. The Commission will collect standardised data on forest area, density, connectivity, fires, and wildfire risk, while individual Member States will monitor tree species, bird abundance, old and new growth areas, and the production of wood products.

Annex I of the proposed regulation details the list of forest data to be collected and their technical specifications (EC, 2023b). For instance, forest area is to be mapped with a minimum mapping unit of 0.5 ha and a spatial resolution of 10m or finer, with data collected at least annually. Tree cover density, defined as the vertical projection of tree crowns to horizontal Earth's surface (ranging from 0 to 100%), requires the same spatial resolution and frequency. Forest type data, categorised by dominant leaf type (broadleaf or coniferous), must also maintain a minimum mapping unit of 0.5 ha and a 10m or finer spatial resolution, though this may be collected every three years rather than annually (EC, 2023b).

The proposal also encourages Member States to develop integrated long-term forest plans or adapt their existing strategies, considering medium to long-term perspectives for forest management. This recognises the need for strategic planning alongside enhanced monitoring to ensure the resilience of European forests in the face of climate change and other pressures.

The Forest Monitoring Law is currently under consideration by the European Parliament and the Council as part of the ordinary legislative procedure. As of early 2025, the AGRI and ENVI committees (joint committees responsible for the file) released their draft report on 29 January 2025, with a deadline for amendments to the Commission Proposal on 4 March 2025. In parallel, the Council is expected to adopt its general approach during the Agriculture and Fisheries Council on 24 June 2025.

1.5. Forest monitoring and inventory practices across Europe

Current forest monitoring and inventory practices across Europe present a diverse landscape of methodologies, intensities, and technological approaches. While some common frameworks exist, there remains significant variation in how individual countries implement

forest monitoring, reflecting differences in forest types, national priorities, and technical capacities.

The ICP Forests programme represents one of the most established transnational forest monitoring networks in Europe. This programme monitors forest condition at two distinct intensity levels (Michel a. et al., 2023). Level I monitoring is based on 5,628 observation plots (as of 2022) arranged on a systematic transnational grid of 16 x 16 km throughout Europe, providing insights into geographic and temporal variations in forest condition. Level II intensive monitoring comprises 628 plots (as of 2021) in selected forest ecosystems, with the aim of clarifying cause-effect relationships between environmental drivers and forest ecosystem responses (Michel et al., 2023).

The ICP Forests monitoring design includes different levels of mandatory and optional variables. Mandatory variables must be measured within respective surveys, while optional variables may or may not be measured depending on national priorities and resources (ICP-Forests Manual 2020). Measurements are categorised as either in-site (carried out within Level II sites) or off-site (conducted outside the forest stand, in an open area close to the plot). In-site measurements include tree condition, tree growth, tree phenology, biodiversity, ozone injury, soil sampling, soil solution, foliar sampling, throughfall, stemflow deposition, litterfall, leaf area index, soil moisture and temperature, and below-canopy meteorological conditions. Off-site measurements include open field bulk deposition, open field meteorology, gaseous air pollutants, and ozone injury at the forest edge (Ferretti et al., 2020).

National Forest Inventories (NFIs) form another critical component of forest monitoring across Europe. The EFISCEN Inventory database contains data from the individual national forest inventories of 32 European countries (Vidal et al., 2016; Alberdi et al., 2020). These inventories typically collect data on forest area, growing stock, increment, fellings, and forest composition, though the specific variables, sampling designs, and measurement protocols vary considerably between countries.

In more advanced countries like Finland and Sweden, NFIs integrate field measurements with remote sensing data, using a combination of aerial photography, satellite imagery, and LiDAR (Light Detection and Ranging) to enhance the spatial and temporal resolution of forest information. Other countries, particularly in Eastern and Southern Europe, rely more heavily on traditional field-based inventories, with limited integration of remote sensing technologies.

Beyond national and ICP Forests monitoring, additional frameworks contribute to the European forest information landscape. The Copernicus Land Monitoring Service provides pan-European datasets on tree cover density, dominant leaf type, and forest type, derived from satellite imagery (EEA-datahub; High Resolution Layer Forest Type). Various research networks and projects also collect forest data for specific purposes, contributing to a rich but sometimes fragmented information ecosystem.

This diversity in monitoring approaches creates challenges for data harmonisation and comparison across Europe. Different definitions, measurement protocols, and sampling designs can lead to inconsistencies when aggregating data at the European level. Furthermore, the frequency of data collection varies widely, from annual updates for some variables to decadal intervals for others, limiting the ability to track rapid changes in forest conditions.

2. Analysis of Earth Observation and Remote Sensing for forest monitoring

Earth Observation (EO) and Remote Sensing (RS) technologies have transformed forest monitoring capabilities in recent years, offering unprecedented opportunities to collect timely, consistent, and spatially explicit data across large geographic areas. The integration of these technologies into forest monitoring frameworks varies significantly across Europe, with some countries at the forefront of adoption while others remain primarily reliant on field-based approaches.

At the European level, the Copernicus programme represents the most advanced and systematic application of EO for forest monitoring. The High-Resolution Layers (HRL) Forest products, derived from satellite imagery, consist of three primary components: tree cover density, dominant leaf type, and forest type (EEA-datahub). These products are available every three years for the period 2012-2018, providing consistent information across the European landscape.

The tree cover density product indicates the percentage of tree cover in each pixel, allowing for detailed quantification of forest cover beyond simple presence/absence classifications. The dominant leaf type product distinguishes between broadleaved and coniferous forest types, while the forest type product combines tree cover density and dominant leaf type information to map forest areas according to the Food and Agriculture Organisation's definition of forests (High Resolution Layer Forest Type — Copernicus Land Monitoring

Service). This approach helps filter out non-forested but tree-covered areas, providing a more accurate representation of forest distribution.

Beyond these basic products, EO technologies support monitoring of forest health, phenology, and disturbances. Satellite-based monitoring of forest fires, insect outbreaks, and storm damage provides critical information for early detection and response to forest threats. Additionally, radar and LiDAR technologies enable three-dimensional characterisation of forest structure, supporting estimation of biomass, carbon stocks, and habitat conditions.

The European Forest Fire Information System (EFFIS) represents a specialised application of EO for monitoring a specific forest threat, providing near-real-time information on fire danger, active fires, and burnt areas across Europe. Similar systems are being developed for monitoring bark beetle outbreaks, drought impacts, and other disturbances affecting European forests.

Despite these advances, the integration of EO and RS into national forest monitoring systems remains uneven. Countries with advanced technological capacity and significant forest resources, such as Finland and Sweden, have made substantial progress in integrating satellite imagery, aerial photography, and LiDAR data into their national forest inventories (Fassnacht et al., 2024). This integration typically follows a multi-source approach, combining field measurements with remote sensing data to leverage the strengths of each method.

In contrast, many countries in Southern and Eastern Europe continue to rely primarily on field-based inventories, with limited operational use of remote sensing technologies (see Annex 8.3). This disparity reflects differences in technical capacity, institutional arrangements, and financial resources, as well as variations in forest types and monitoring priorities.

The proposed Forest Monitoring Regulation aims to address these disparities by establishing common standards and promoting greater integration of EO technologies across all Member States. By specifying minimum technical requirements for data resolution, frequency, and quality, the regulation would drive increased harmonisation in the use of remote sensing for forest monitoring throughout Europe.

2.1. Earth Observation and Remote Sensing capacities for forest monitoring in Europe

The Earth Observation and Remote Sensing capacities for forest monitoring in Europe operate at multiple scales, from European-wide services provided by the European

Environment Agency (EEA) and Joint Research Centre (JRC) to national-level systems implemented by individual countries. These capacities vary considerably in terms of spatial and temporal resolution, thematic detail, and operational maturity.

At the European level, the Copernicus Land Monitoring Service (CLMS) represents the most comprehensive EO system for forest monitoring. CLMS offers one of the world's most extensive portfolios of high-quality, open-access land cover and land use datasets (CLMS). The service is jointly operated by the EEA, which manages the pan-European component, and the JRC, which manages the global component. This synergy allows for a comprehensive view of forest health and trends at a global level, with special emphasis on high spatial and temporal resolution for Europe.

The pan-European component of CLMS includes several products specifically designed for forest monitoring. The Tree Cover Density product provides information on the percentage of tree cover in each area, updated annually across the EEA38 area at 10m spatial resolution. The Dominant Leaf Type product, produced in parallel, allows users to identify and track changes in the dominant leaf type (broadleaved or coniferous) of European tree cover. The Forest Type product is derived from these two datasets and represents some of the best publicly available tree cover monitoring data in the world (CLMS). Additionally, the Small Woody Features product provides information on linear and patchy tree cover, such as that found in fragmented agricultural landscapes.

Table 3 Overview of existing Copernicus forest-related datasets

Dataset/Product	Description	Spatial Resolution	Temporal Resolution	Main Variables/Indicators	Usability (EU/National)
HRL Forests (Copernicus)	Tree cover, leaf type, forest type	10m	3-year	Tree cover density, dominant leaf	High (EU and MS)
Dynamic Land Cover (CLMS)	Global land cover, incl. forest	100m (10m planned)	Annual	Land cover classes	High (EU, global)
Small Woody Features (CLMS)	Linear/patchy tree cover	10m	3-year	Woody features	Moderate
EFFIS	Forest fire information	500m–1km	Near-real time	Thermal anomalies, burnt area, fire danger	High
Sentinel-2 Global Mosaic	Cloud-free optical composites	10m	On demand	Multispectral imagery	High

The global component of CLMS offers the 100m Dynamic Land Cover product, which provides annually updated global land cover maps, including forest cover types. This product currently achieves 80% accuracy on each continent (CLMS). Significant improvements are planned, with the existing 100m resolution product scheduled to be superseded by a global 10m land cover mapping from 2025 onwards. A specific tropical forest monitoring product at

10m resolution will also be introduced, starting with reference year 2020. This product will include information on percentage of tree cover and annual changes (CLMS).

At the national level, EO capacities vary substantially. Finland and Sweden represent leading examples of national forest monitoring systems that extensively integrate remote sensing data. The Finnish Multi-Source National Forest Inventory combines field measurements with satellite imagery and other geographic data to produce annual forest resource maps at 16m resolution. Similar approaches are implemented in Sweden, where the combination of field plots and satellite data supports detailed forest monitoring across the country.

France has developed a dual-resolution approach, using high-resolution satellite imagery for detailed monitoring of specific areas of interest, complemented by medium-resolution imagery for national-scale assessments. Spain has made significant progress in integrating LiDAR data with optical satellite imagery to improve estimation of forest parameters, particularly in regions with complex topography and diverse forest types.

Table 4 National EO/RS capacity and use examples

Country	Main EO/RS Data Used	Key Variables/Indicators Monitored	Integration with NFI	Main Applications/Reporting	Notable Features/Challenges
Finland	Sentinel-1/2, LiDAR	Area, biomass, health, disturbance	Yes	LULUCF, RED, NRL	Advanced integration, annual maps
Sweden	Sentinel-2, LiDAR	Area, increment, biomass, health	Yes	LULUCF, RED	High-resolution, policy alignment
Spain	Sentinel 1/2/3, Landsat-8, LiDAR	Area, fire, health, biomass	Partial	Fire risk, RED, biodiversity	Regional variation, fire focus
France	Sentinel-2, SPOR-6/7	Area, type, health, biomass	Yes	NRL, RED, biodiversity	Dual-resolution, integration issues
Slovenia	Sentinel 1/2	Area, health, type	Limited	National reporting, NRL	Growing EO use, resource limits
Czech Rep.	Sentinel-1, Landsat-8	Area, health, disturbance	Limited	National reporting	EO adoption increasing

In Slovenia and the Czech Republic, the integration of EO technologies is less advanced but growing rapidly. Both countries are increasingly using satellite imagery to supplement traditional field inventories, particularly for detecting changes in forest cover and monitoring forest health. However, the operational use of these technologies remains limited compared to Nordic countries.

These diverse capacities reflect differences in national priorities, technical infrastructure, and institutional arrangements. The proposed Forest Monitoring Regulation aims to raise the

baseline capacity across all Member States, ensuring minimum standards for data collection and analysis while respecting the principle of subsidiarity.

2.2. Opportunities using Earth Observation and Remote Sensing

The integration of Earth Observation and Remote Sensing technologies into forest monitoring systems presents numerous opportunities at both European and national levels. These opportunities extend beyond simple efficiency gains to include fundamental improvements in the scope, quality, and relevance of forest information for science, policy, and management.

At the European level, one of the primary opportunities lies in achieving consistent, harmonised monitoring across all Member States. The Copernicus programme already provides standardised products covering the entire European territory, offering a baseline of information regardless of national boundaries or monitoring traditions. This consistency supports fair comparison between countries, reliable aggregation of data for European-level reporting, and effective implementation of common policies such as the EU Biodiversity Strategy and the European Green Deal.

The upcoming improvements in Copernicus products, particularly the shift from 100m to 10m resolution for global land cover mapping, represent a significant opportunity to enhance forest monitoring capabilities (CLMS). This tenfold increase in spatial resolution will enable detection of smaller forest patches, more accurate delineation of forest boundaries, and better characterisation of forest fragmentation and connectivity. Such detailed information is crucial for biodiversity conservation, ecosystem service assessment, and landscape planning.

Another European-level opportunity lies in the temporal dimension of monitoring. Satellite-based observations allow for frequent, even daily, acquisition of data, supporting near-real-time monitoring of forest conditions and rapid detection of changes. This capability is particularly valuable for early warning systems related to forest fires, insect outbreaks, illegal logging, and other disturbances requiring prompt response. The proposed Forest Monitoring Regulation's requirement for annual updates of core variables would leverage this temporal advantage of EO technologies (EC, 2023b).

At the national level, opportunities vary according to the existing state of forest monitoring systems and EO integration. For countries with advanced systems like Finland and Sweden, opportunities lie in further refining their multi-source approaches, incorporating new data sources such as Sentinel-1 radar imagery for winter monitoring and exploring machine learning techniques for improved parameter estimation. These countries can serve as models for others, demonstrating best practices in the integration of field and remote sensing data.

For countries with less developed EO integration, such as many in Southern and Eastern Europe, the opportunities are more fundamental. EO technologies offer these countries the potential to significantly expand their monitoring coverage, increase the frequency of updates, and add new variables to their assessment portfolios. By leapfrogging directly to state-of-the-art methods, rather than gradually evolving their traditional systems, these countries could rapidly enhance their monitoring capabilities while potentially reducing overall costs.

Across all countries, EO technologies offer opportunities to monitor variables that are difficult or impossible to assess comprehensively through field measurements alone. Examples include landscape-level patterns of forest fragmentation, temporal dynamics of phenology in response to climate change, and spatial distribution of forest disturbances. These landscape-scale perspectives complement plot-based measurements, providing context and connectivity that enhances the overall value of forest monitoring information.

2.3. Challenges using Earth Observation and Remote Sensing

Despite the numerous opportunities presented by Earth Observation and Remote Sensing technologies, their integration into forest monitoring systems faces several challenges at both European and national levels (European Commission 2020). These challenges span technical, institutional, and methodological dimensions, requiring coordinated approaches to overcome.

At the European level, a primary challenge lies in balancing standardisation with flexibility. While harmonised methods and products are essential for consistent reporting and cross-border comparisons, forest conditions and monitoring needs vary considerably across Europe's diverse biogeographic regions. The proposed Forest Monitoring Regulation must establish common standards without imposing one-size-fits-all approaches that may be inappropriate for specific forest types or regional conditions.

Another European-level challenge involves data validation and quality assurance. Satellite-derived forest parameters require validation through field measurements, yet the existing network of field plots may not be sufficient for robust validation across all regions and forest types. Expanding and optimising this validation infrastructure represents a significant cost and logistical challenge, particularly in remote or inaccessible areas.

The technical complexity of EO data processing presents challenges at multiple levels. Advanced algorithms for parameter estimation, change detection, and time series analysis require specialised expertise that may not be available in all Member States or forestry agencies. Additionally, the massive data volumes generated by high-resolution satellite

imagery demand substantial computing infrastructure and data management systems, which may strain existing resources in some countries.

At the national level, challenges vary according to the state of development in EO and RS capacities. Countries with limited experience in remote sensing applications face steeper learning curves and greater institutional barriers to adoption. These may include among other lack of technical expertise, institutional resistance to changing established monitoring practices, or limited budget for technology investments.

In countries with advanced forest monitoring systems, challenges often relate to the integration of new data sources with existing methods and historical time series. Ensuring continuity and comparability with long-term data while incorporating new technologies requires careful methodological development and validation. Additionally, these countries may face challenges in communicating the complexity and uncertainty of EO-derived products to end-users accustomed to traditional inventory results.

A common challenge across all levels involves addressing the paradoxical profession situation described by researchers, where practitioners are expected to work under contradictory sustainability constraints. Forest monitoring professionals must balance multiple objectives, including operational efficiency, data quality, methodological innovation, and continuity with historical records. When tensions arise over sustainable objectives, such as temporality of objectives, organisational barriers, and lack of control, they are often addressed only when anchored to an economic objective in the form of a business case for sustainability.

Finally, there are fundamental limitations to what can be directly measured through remote sensing. Many important forest parameters, such as biodiversity components, soil conditions, or recreational value, cannot be directly observed from space and require field measurements or modelling approaches. Finding the optimal balance between remote sensing and field measurements, and developing robust methods for integrating these data sources, remains a significant challenge for comprehensive forest monitoring.

Table 5 Opportunities and challenges of EO/RS (comparative table)

Level	Opportunities	Challenges
EU	Harmonised monitoring, frequent updates, policy support	Standardisation vs. flexibility, validation, cost
Country	Detailed mapping, cost savings, new variables	Technical skills, infrastructure, legacy system integration

3. Existing Earth Observation data at European level available for forest monitoring

The European Earth Observation landscape offers a rich array of datasets specifically relevant to forest monitoring, primarily through the Copernicus programme but also via other platforms and initiatives. These datasets vary in spatial and temporal resolution, thematic focus, and geographical coverage, providing multiple options for different monitoring needs.

The Forest Information System for Europe (FISE) Data Catalogue provides access to public, official forest information from the statistical platforms of countries across Europe (FISE). This serves as a centralised portal for accessing various forest-related datasets, including those derived from Earth Observation.

The Copernicus High Resolution Layers (HRL) Forests represent some of the most detailed and comprehensive EO products for forest monitoring in Europe. These layers consist of three primary status and change products: tree cover density, dominant leaf type, and forest type (EEA-datahub). The products are available every three years for the period 2012-2018, with more recent updates in development.

The Tree Cover Density product provides pixel-level information on the percentage of tree cover, ranging from 0 to 100%. This continuous representation allows for more nuanced analysis than simple forest/non-forest classifications, supporting detailed assessment of forest structure and fragmentation. The Dominant Leaf Type product distinguishes between broadleaved and coniferous forest types, enabling monitoring of forest composition at the European scale. The Forest Type product combines tree cover density information with the dominant leaf type classification, applying the Food and Agriculture Organisation's definition of forests to filter out non-forested but tree-covered areas (High Resolution Layer Forest Type — Copernicus Land Monitoring Service).

Beyond these core products, the Copernicus programme has developed derivative datasets that provide additional insights into forest patterns and processes. These include Forest Patches, which identifies distinct forest areas based on connectivity criteria; Forest Inter-patch Distance, which quantifies the spatial separation between forest patches; and Forest Morphological Spatial Pattern, which classifies forest configurations according to landscape ecology principles (EEA-datahub). These products support analysis of forest fragmentation, connectivity, and spatial arrangement, which are critical for biodiversity conservation and landscape planning.

The Copernicus Land Monitoring Service also provides global datasets relevant to forest monitoring, primarily through its Dynamic Land Cover product. This product offers annually updated global land cover maps at 100m spatial resolution, achieved through state-of-the-art data analysis techniques ensuring temporal consistency and accuracy. The latest version achieves 80% accuracy on each continent, making it a flexible tool for a wide range of applications including forest monitoring (CLMS).

While the Copernicus Global Land Cover and Tropical Forest Mapping and Monitoring (LCFM) contract introduces 10m resolution products, it should be noted that CLMS already provides 10m land cover datasets across Europe through its HRLs. This European capacity renders the tropical-focused LCFM developments largely irrelevant for Forest Management Reporting (FMR) frameworks operating within EU member states, as continental monitoring needs are already met through existing CLMS infrastructure (CLMS).

Beyond Copernicus, additional EO data sources relevant to forest monitoring include the European Forest Fire Information System (EFFIS), which provides near-real-time information on fire danger, active fires, and burnt areas; the Sentinel-2 Global Mosaic service, which delivers cloud-free composites of optical satellite imagery suitable for visual interpretation and change detection; and various climate data records that support analysis of forest responses to environmental conditions.

These diverse datasets collectively provide a comprehensive foundation for European forest monitoring, though their integration with national systems and field measurements remains variable across Member States.

3.1. Enhancing and developing new Copernicus data products

The Forest Monitoring Framework offers significant opportunities to enhance existing Copernicus data products and develop new ones that better address the needs of forest monitoring at both European and national levels. These enhancements could leverage technological advances, methodological innovations, and user feedback to create more valuable and accessible forest information services.

One promising direction for enhancement involves increasing the temporal frequency of forest monitoring products. While the current high-resolution layers are updated every three years, many forest processes and disturbances occur at much shorter time scales. Developing annual or even seasonal updates for key variables such as forest type and tree cover density would significantly improve the ability to detect and respond to rapid changes. The proposed Forest Monitoring Regulation's requirement for annual updates of core variables like forest area and tree cover density would drive this enhancement (EC, 2023b).

Improvements in spatial resolution represent another opportunity for product enhancement. While the current 10m resolution of Copernicus forest products is already quite detailed, further refinement to 5m or even higher resolution could enable detection of smaller forest elements and more precise delineation of forest boundaries. Such improvements would be particularly valuable in highly fragmented landscapes and for monitoring specific features like riparian forests or urban trees.

Beyond basic structural parameters, there is significant potential to develop new Copernicus products focused on forest functional aspects. These could include indicators of forest productivity derived from vegetation indices, estimates of biomass and carbon stocks based on radar and optical data fusion, and assessments of forest health and vitality through spectral analysis. Such functional parameters would complement the existing structural information, providing a more comprehensive view of forest conditions and ecosystem services.

The development of integrated products that combine EO data with other information sources represents another promising direction. For example, combining Copernicus forest data with climate records could support monitoring of forest responses to climate change. Similarly, integration with socioeconomic data could help assess the relationship between forest conditions and human activities, supporting more holistic approaches to sustainable forest management.

Advanced change detection techniques offer opportunities to develop more sophisticated monitoring of forest dynamics. Rather than simple comparisons between time points, time series analysis of dense satellite image stacks can identify gradual trends, seasonal patterns, and abrupt changes. Such approaches could support early detection of forest degradation, monitoring of recovery processes, and assessment of management impacts.

There is also potential to develop specialised products for specific forest types or regions that face monitoring challenges. Mediterranean forests, for example, might benefit from dedicated products addressing their unique structural characteristics and fire dynamics. Similarly, mountain forests could be monitored with products specifically designed to account for topographic effects and complex vertical structure.

Finally, there are opportunities to develop products that specifically address the reporting requirements of key policy frameworks such as the EU Biodiversity Strategy, the LULUCF Regulation, and international commitments under processes like Forest Europe. Aligning Copernicus products with these reporting needs would increase their relevance and utility for policy implementation, potentially streamlining the reporting process for Member States.

3.2. Securing increased user uptake of Copernicus Land Monitoring Services

Ensuring the widespread adoption and effective use of Copernicus Land Monitoring Services for forest monitoring requires a strategic approach addressing various technical, institutional, and capacity-related factors. The gap between available data products and their operational use in forest management and policy implementation remains a challenge in many contexts.

One fundamental aspect of increasing user uptake involves improving awareness and understanding of available products and their potential applications. Despite the comprehensive nature of Copernicus services, many potential users in national forest agencies, research institutions, and private forest management organisations may not be fully aware of the data products available or their relevance to specific monitoring needs. Targeted communication and outreach activities, tailored to different user groups and presented in accessible language, can help bridge this awareness gap.

Enhancing the accessibility and usability of Copernicus products represents another critical factor in increasing uptake. While the data itself is freely available, transforming raw satellite products into actionable information often requires specialised expertise and computing resources. Developing user-friendly interfaces, pre-processed datasets, and simplified access mechanisms could significantly lower the barriers to entry for new users. The CLMS already provides some such tools, but further development of application-specific platforms and services would enhance accessibility for forest-related users.

Capacity building at national and local levels is essential for sustainable uptake of EO technologies. This includes technical training on data access, processing, and interpretation, as well as strategic guidance on integrating remote sensing into existing monitoring frameworks. The proposed Forest Monitoring Regulation could support this process by encouraging Member States to develop the necessary technical infrastructure and expertise within their national forest agencies (EP LO, 2023).

Demonstrating clear value and benefits from using Copernicus services can significantly drive uptake. This could involve documenting case studies where EO data has improved monitoring efficiency, reduced costs, or provided insights that were not previously available. Quantifying these benefits in terms of time saved, area covered, or improved decision-making can help justify investments in new technologies and approaches.

National forest institutes would play a crucial role in implementing the Forest Monitoring Regulation in Member States. These institutes typically have established monitoring systems and expertise, which would need to be adapted and expanded to incorporate the

requirements of the new regulation. A phased approach to implementation, with clear guidance and support from European institutions, would facilitate this transition. The institutes would need to integrate EO data with their existing field-based monitoring, develop or enhance their technical infrastructure, and train staff in new methodologies.

The integration of citizen science approaches represents an innovative strategy for increasing engagement with forest monitoring data. Community-based monitoring can complement professional observations, particularly for variables that require extensive field verification or local knowledge. Research has shown that understanding the diverse motivations for citizen science activities on the ground is essential for maintaining momentum in such initiatives (Geoghegan et al. 2016). Designing user interfaces and participation mechanisms that address these diverse motivations could significantly enhance public engagement with forest monitoring.

Addressing the paradoxical profession situation described by researchers, where practitioners face contradictory sustainability constraints, is also critical for securing increased uptake. When tensions arise over sustainable objectives, they are often addressed only when anchored to an economic rationale. Applying the paradox theory lens helps address the tensions in adopting EO/RS techniques, such as balancing data complexity with usability or standardisation with more local needs. Instead of resolving these contradictions through trade-offs, this approach embraces them as opportunities for innovation—using strategies like spatial or temporal separation and synthesis—to enhance user engagement. By acknowledging and managing these paradoxes, the project can develop flexible, context-sensitive solutions that increase uptake, as demonstrated in case studies where tensions are leveraged to create value.

3.3. Impact assessment of Earth Observation for forest monitoring in Member States

The impact of Earth Observation technologies on forest monitoring in Member States varies considerably, reflecting differences in adoption rates, integration approaches, and national contexts. Assessing these impacts provides insights into both the current state of EO utilisation and the potential for further development under the proposed Forest Monitoring Regulation.

In countries with advanced integration of EO technologies, such as Finland and Sweden, the impact has been substantial in terms of monitoring efficiency, spatial coverage, and information detail. These countries have successfully developed multi-source national forest inventories that combine field measurements with satellite data, achieving national coverage

with annual updates. The economic impact has been positive, with efficiency gains offsetting the initial investments in technology and expertise. The quality and timeliness of forest information have improved, supporting more responsive and evidence-based forest management and policy implementation.

In countries with moderate EO integration, such as France and Spain, impacts are more variable across regions and applications. These countries have successfully implemented EO-based monitoring for specific purposes, such as fire management or detection of major forest changes, but comprehensive integration into national forest inventories is still ongoing. This means that EO-derived data are not yet systematically used for all core inventory variables, with challenges remaining in harmonizing spatial scales, aligning methodologies, and building institutional capacity for operational use. The impact on monitoring efficiency has been positive in targeted applications, but broader transformation of monitoring systems is still in progress.

For Member States with limited current use of EO technologies, such as some in Eastern and Southern Europe, the impact to date has been minimal, but the potential for transformation is substantial. In these contexts, the proposed Forest Monitoring Regulation could catalyse a significant leap forward in monitoring capabilities, potentially allowing these countries to bypass intermediate steps and move directly to state-of-the-art approaches. The economic impact would involve initial implementation costs, but potentially significant long-term savings compared to expanding traditional field-based inventories.

The degree of user uptake across Member States shows similar variation. In Nordic countries, EO-derived forest information is widely used by diverse stakeholders, including forest agencies, private forest owners, timber industry, and conservation organisations. In other regions, uptake remains more limited, often restricted to specialised agencies or research institutions rather than being mainstreamed into forest management practices.

Factors influencing the degree of uptake include technical infrastructure, institutional capacity, availability of expertise, historical monitoring traditions, and alignment with national policy priorities. Countries with strong existing investment in field-based monitoring systems may face institutional resistance to adopting new approaches, particularly if these are perceived as threatening established practices or expertise.

The potential for improving uptake varies according to these contextual factors but generally includes opportunities to develop more user-friendly interfaces, provide training and technical support, demonstrate concrete benefits through pilot applications, and align EO products with specific national and local information needs.

The paradoxical nature of sustainable project objectives, as identified in research, presents a particular challenge for impact assessment. Practitioners often face tensions over sustainable objectives related to temporality, organisational barriers, and lack of control. These tensions may be resolved through economic prioritisation or may lead to various reactions, including greenwashing, diffusion of responsibility, compartmentalisation, or pushing back against sustainability objectives. Understanding and addressing these tensions is crucial for maximising the positive impact of EO technologies on forest monitoring.

Building on the legislative and technical foundations of the proposed Forest Monitoring Regulation outlined in this section, including its ambitious 10m resolution mandates, harmonised reporting frameworks, and alignment with EU biodiversity and climate goals, the following section shifts focus to the practical realities of implementation.

The regulatory vision, while transformative, encounters significant challenges when contextualised against the diverse capacities and priorities of European stakeholders. Drawing on insights from the D2.1 survey and cross-referencing regional disparities in EO/RS adoption, the following section will synthesise the user requirements and systemic barriers that may shape the Regulation's operational success.

4. Synthesis of user requirements in policy and technical contexts

4.1. Methodological approach

The FUTUREFOR project employed a systematic requirement engineering methodology to translate stakeholder inputs into technical specifications, blending traditional and agile approaches to address evolving Earth Observation applications. Grounded in four core principles-user-centric design, policy compliance with EU frameworks, iterative refinement, and measurable validation criteria-the process spanned four phases: elicitation (analysing D2.1 survey data and policy documents), analysis (categorising requirements into functional, technical, operational, and policy domains), specification (standardising terminology), and prioritisation (weighing stakeholder value against technical feasibility).

A hybrid stakeholder survey underpinned this analysis, targeting six groups (users, providers, governance bodies, researchers, influencers, and cross-sector actors) across 792 contacts. The survey combined Likert scales, multiple-choice, and scenario-based questions to assess EO/RS adoption patterns, technical barriers, policy alignment needs, and future applications. Distributed via professional networks, direct outreach, and digital platforms, it adhered to GDPR constraints through institutional gatekeepers for 40% of governance/research respondents. From 82 partial responses, 48 valid entries were retained after removing

duplicates and incomplete submissions. These represented eight EU countries and four primary stakeholder groups to assess Earth Observation (EO) and Remote Sensing (RS) adoption patterns in European forestry.

The survey's low response rate (6.1%) reflects systemic challenges in engaging time-constrained stakeholders, particularly governance bodies and SMEs. Nonresponse bias risks are well-documented in survey research, as respondents often differ systematically from non-respondents in ways relevant to the study's objectives. For instance, providers (8 respondents) may overrepresent early adopters of EO/RS technologies, while under engaged SMEs (70% citing financial constraints) likely face structural barriers unobserved in the data.

To mitigate these limitations, the analysis prioritised qualitative insights from open-ended responses over potentially unstable percentages and seeks to cross-reference survey data with policy documents (e.g., Forest Monitoring Regulation Annex I) to ground requirements in legislative imperatives.

Research institutions constituted the largest cohort (22), reflecting the project's emphasis on bridging scientific innovation with policy implementation. Governance bodies represented (16) of respondents, underscoring the regulatory focus of the Forest Monitoring Framework, while end-users (8) and technology providers (7) provided critical insights into operational challenges and market readiness.

Table 6 Stakeholder distribution and regional priorities

Stakeholder group	Number/Percentage	Top regional priority
Research institutions	22 / 45.8%	Biomass estimation accuracy
Governance bodies	16 / 29.2%	EUDR compliance (geolocation traceability)
End-Users	8 / 16.7%	Accurate disturbance detection
Technology providers	7 / 14.6%	AI/ML integration for fire alerts

4.2. Policy-driven requirements from stakeholder survey

The D2.1 survey (n=48) revealed critical gaps between the Forest Monitoring Regulation's technical ambitions (Chapter 1.3) and current operational capacities (Chapter 2.1). Governance stakeholders (29.2% of respondents) highlighted systemic incompatibilities between Copernicus outputs and legacy national forest inventory (NFI) systems, with 70% reporting challenges in meeting Annex I specifications for forest area mapping. This

misalignment risks undermining Member States' ability to comply with the Regulation's mandatory 10m resolution requirements for core variables like tree cover density.

Table 7 Main policy-driven requirements from survey

Requirement	Policy/Technical Basis	Survey Support
INSPIRE-compliant formats	Forest Monitoring Regulation Annex I	70% governance
Hybrid NFI-EO estimators	LULUCF reporting gaps (Section 1.2)	65% researchers
Capacity-building programmes	EO skill disparities (Section 2.3)	80% end-users

Regional disparities further complicate harmonisation efforts. While Western/Central European respondents (70% of the sample) prioritised fire-risk mapping - aligning with the Regulation's wildfire monitoring mandates - Baltic stakeholders emphasised peatland monitoring gaps. These concerns directly correlate with the Copernicus CLC+ Backbone's 100m resolution limitations (Section 2.3), which misclassify narrow drainage channels critical for wetland conservation under the Nature Restoration Law.

4.3. EO/RS adoption barriers: survey insights

The insights derived from the survey distributed to 792 stakeholders, yielding 48 validated responses (6.1% response rate) introduces potential nonresponse bias. While stratified sampling ensured representation across governance, research, and end-user groups, the small sample size necessitates cautious interpretation of quantitative claims.

The analysis of Earth Observation (EO) and Remote Sensing (RS) adoption barriers, cross-referenced with national capacities (Chapter 2) and the D2.1 stakeholder survey (*n=48*), identifies three systemic challenges. A majority of end-users (80% of respondents in this category) referred to technical complexity and reported insufficient expertise in machine learning (ML) and artificial intelligence (AI) to process advanced datasets like Sentinel-1 Synthetic Aperture Radar (SAR). This skills gap hinders operational adoption of integrated EO/RS methods, such as for instance Finland's NFI model combining SAR and LiDAR for boreal biomass estimation (Table 4). Small and medium enterprises (SMEs) in Southern and Eastern Europe highlighted financial constraints for instance high cloud-processing costs as a critical barrier, contrasting with Nordic countries' state-funded infrastructure. This disparity exacerbates regional inequities in accessing EO technologies for applications like dynamic monitoring. Finally, many private forest owners expressed strong reservations (72% of relevant stakeholders) about public access to management plans, conflicting with geolocation traceability mandates under the EU Deforestation Regulation (EUDR).

This analysis underscores the need for regionally tailored solutions to advance EO/RS adoption while respecting methodological limitations of the survey data.

5. Strategic pathways for Earth observation and remote sensing implementation

5.1. Core user requirements for service development

The stakeholder survey identified critical technical specifications that cut across user groups, forming non-negotiable foundations for service development. End-users, representing 16.7% of respondents, emphasised the need for sub-hectare (<1 ha) detection thresholds to identify illegal logging activities, exceeding the EU Deforestation Regulation's 1 ha mandate. This requirement demands advanced Sentinel-1/2 data fusion techniques, rigorously validated against National Forest Inventory (NFI) plot measurements to ensure accuracy. Concurrently, 70% of governance bodies prioritised INSPIRE-compliant GeoJSON/GeoTIFF formats to harmonise Copernicus Land Monitoring Service (CLMS) outputs with legacy national systems, addressing interoperability challenges that hinder pan-European data integration. Further reinforcing quality assurance, 65% of researchers mandated NFI ground-truthing for satellite-derived biomass estimates, rejecting synthetic aperture radar (SAR)-only methodologies in carbon-dense peatlands due to unquantified uncertainties in wetland carbon stock calculations.

5.2. Geographically tailored implementation strategies

Regional priorities emerged as a defining factor in shaping implementation approaches. In Mediterranean ecosystems, 86% of stakeholders prioritised wildfire risk mapping, necessitating <10 m resolution Sentinel-2 composites integrated with European Forest Fire Information System (EFFIS) danger indices. This aligns with the region's acute vulnerability to climate-driven fire regimes. Conversely, Baltic and Nordic stakeholders emphasised storm resilience monitoring, requiring Sentinel-1 SAR data to assess all-weather canopy damage across boreal landscapes. These region-specific needs complement existing ICP Forests field protocols while addressing gaps in continuous monitoring capabilities.

6. Conclusion

This User Requirements Report (D3.1) synthesized critical insights into the needs, barriers, and opportunities for implementing advanced Earth Observation (EO) and Remote Sensing (RS) technologies in European forest monitoring. This analysis directly responds to the T3.1

requirements of the FUTUREFOR proposal by establishing a comprehensive understanding of stakeholder needs and translating them into actionable technical specifications for service development.

6.1. Key Findings and Knowledge Gained

Our analysis has revealed a complex landscape of forest monitoring in Europe, characterized by both opportunities and challenges. We now understand that while there is high awareness of EO/RS technologies (91.5% of stakeholders are familiar with these tools), there exists a significant gap between awareness and operational implementation (only 30.23% actively use Copernicus Land Monitoring Service). This "awareness-use paradox" represents a fundamental challenge that FUTUREFOR must address.

The current forest monitoring ecosystem across Europe shows considerable variation in technological adoption. Nordic countries lead with advanced integration of multi-source National Forest Inventories that combine field measurements with satellite and LiDAR data. Meanwhile, many Eastern and Southern European countries face barriers related to technical capacity, institutional arrangements, and financial resources.

The proposed Forest Monitoring Regulation aims to establish harmonized standards for forest monitoring across the EU, with specific technical requirements such as 10m spatial resolution and annual updates for key variables. The regulation represents both an opportunity and a challenge for Member States, as it will require significant enhancements to existing monitoring systems.

Task 3.1 required a systematic assessment of user requirements to guide the development of FUTUREFOR's services. We have responded to this requirement through:

Building on D2.1, we identified six stakeholder categories (users, providers, governance bodies, researchers, influencers, and cross-sector actors) and assessed their distinct needs and barriers. Despite methodological limitations of the survey (6.1% response rate), we gathered valuable insights from 48 validated responses representing eight EU countries.

We systematically translated stakeholder needs into specific technical specifications, including sub-hectare (<1 ha) detection thresholds for illegal logging monitoring, INSPIRE-compliant formats for data interoperability, and NFI validation requirements for biomass estimates.

We developed a service prioritisation approach based on stakeholder ratings, ranked in order of prioritisation: forest disturbance monitoring (4.33/5), digital twins (4.03/5), fire risk mapping (3.94/5), and biomass estimation for bioenergy. The forest disturbance module is

not proposed as a standalone business case in FUTUREFOR because demand is fragmented and long-term benefits deter private investment, unlike the clear, short-term markets for wildfire or biomass services. Additionally, policy mandates for disturbance mitigation are not directly monetized, reducing economic incentives for commercial development (see D2.1 page 8-9).

We catalogued key obstacles to EO/RS adoption, including limited awareness of available data (75%), compatibility issues with existing systems (70%), financial constraints (70%), and technical skill gaps (80%).

We identified critical regional differences in priorities, with Mediterranean stakeholders emphasizing wildfire risk mapping while Baltic and Nordic regions prioritizing storm resilience monitoring.

By integrating insights from both D3.1 and D2.1, we have identified the following key user requirements for FUTUREFOR's service development:

Core Technical Requirements:

- High spatial resolution (<10m) for forest monitoring products to meet FML specifications
- Frequent temporal updates (at least annual, preferably seasonal) for dynamic monitoring
- Integration capabilities with existing National Forest Inventory systems
- Standardised formats in compliance with INSPIRE directive
- Validation protocols that incorporate field measurements for quality assurance

Priority Applications:

- Digital twin solutions for simulating forest resilience under climate scenarios
- Fire risk mapping, especially for Mediterranean regions
- Biomass estimation for sustainable bioenergy planning and RED III compliance
- Forest health monitoring for early detection of stress and disease

Further general FML Implementation Requirements:

- Tiered training programs addressing skill gaps in machine learning, SAR data interpretation, and multi-sensor integration
- Financial mechanisms to support adoption by smaller organizations, particularly in Eastern and Southern Europe

- User-friendly interfaces that simplify complex EO/RS data for operational decision-making
- Policy-embedded services that automate compliance workflows for regulations like EUDR and LULUCF
- Regional adaptations acknowledging differences in forest types, threats, and priorities

Our report shows that the FUTUREFOR project is well-positioned to bridge the identified gaps between advanced EO/RS capabilities and operational implementation. By addressing both technical challenges (data integration, resolution limitations), the project can help transform the European forest monitoring landscape while supporting critical policy objectives related to climate change, biodiversity, and sustainable resource management.

Furthermore, this user requirements analysis provides a solid foundation for the subsequent Work Package 4, which will operationalise these insights through the development of four targeted services: digital twins, fire risk mapping, and biomass estimation for bioenergy. By maintaining a user-centric approach and addressing the regional disparities highlighted in this analysis, FUTUREFOR can ensure that its innovations truly meet the diverse needs of European forest stakeholders while advancing the harmonized monitoring framework envisioned by EU policy.

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8. ANNEXES

8.1. EU-level datasets for forest monitoring

EU-level datasets

Dataset	Description	Spatial Resolution	Temporal Resolution	Usability
Copernicus HRL Forests	Tree cover density, dominant leaf type, forest type mapping	10m	3-yearly (2012–2018)	High for EU-wide harmonisation; forest structure mapping; limited for sub-national management.
FISE Data Catalogue	Centralised access to national statistics	Variable	Variable	Moderate (dependent on national data quality)
CLC+ Backbone	Land cover classification	100 m	6-yearly	Moderate (misclassifies narrow features like peatlands)
Small Woody Features	Linear/patchy tree cover (hedgerows, shrubs).	5m	3-yearly	Moderate for biodiversity assessments; underutilised in NFIs.
Sentinel-2 Global Mosaic	Cloud-free optical composites.	10m	On-demand	High for visual interpretation; requires preprocessing for analytics.
EFFIS	Burnt area, fire danger indices.	500m–1km	Near-real-time	Critical for Mediterranean wildfire response; limited spatial precision.

CLMS European Forest Monitoring (Forslund, 2024)

FML Indicator	Resolution (m)	Frequency	CLMS Dataset		Comment
a) Forest area	10	Annual	Partly **Forest Type**	☑	Data/methodology needed for **temporary non-wooded forest areas**
b) Tree cover density	10	Annual	**Tree Cover Density**	☑	
c) Forest type	10	3 years	**Forest Type**	☑	
d) Forest connectivity	10	Annual	**Forest Type** **Small Landscape Features**	☑	**3 years** due to VHR coverages
e) Defoliation	300	Two weeks	**CGLS Leaf Area Index**	☑	**HR** can be assessed **Harmonise** with tree cover disturbances
h) Tree cover disturbances	10	Annual	*Future under **HR-VPP***	☑	Under development

The tick marks refer to readiness for implementation of the Forest Monitoring Law

HRL- Tree/Forests (Forslund, 2024)

HRL Product	Parameter	Resolution	Temporal frequency	Accuracy/Classification	Additional notes
Tree Cover Density (TCD)	Canopy density (0–100%)	10 m	Annual	>90% accuracy, high spatial consistency	Applies to EEA38/9 countries.
Dominant Leaf Type (DLT)	Coniferous / Broadleaved	10 m	Annual	N/A	Applies to EEA38/9 countries.
Forest Type (FTY)	Coniferous / Broadleaved forests	10 m	3-Year	Based on FAO forest definition	Filtering criteria: - >10% Tree Cover Density (TCD) - <0.5 ha MMU - Excludes trees in agricultural/urban areas (using CLC and HRL Imperviousness data).

8.2. National forest monitoring datasets in the 27 EU countries

Forest monitoring across the 27 EU Member States is underpinned by the presence of a National Forest Inventory (NFI) or an equivalent system in each country. These NFIs form the backbone of national and European forest data collection, offering a harmonised yet flexible approach that supports a wide range of policy and reporting needs, including those of the LULUCF Regulation, the Forest Resources Assessment (FRA), and the EU Biodiversity Strategy.

The technical design of NFIs varies: most countries employ plot-based sampling, with individual plot sizes typically ranging from 0.1 to 1 hectare and grid densities spanning from 500 metres to 4 kilometres. This approach ensures detailed, statistically robust data on forest structure, composition, and dynamics. Notably, some countries such as Finland and Sweden have advanced their monitoring by integrating remote sensing technologies, including satellite imagery and airborne laser scanning, to produce raster-based forest maps at resolutions as fine as 10 to 20 metres. This integration significantly enhances both the spatial and temporal granularity of forest monitoring, enabling near-annual updates and supporting rapid response to emerging forest health issues.

Most NFIs in the EU operate on a five- to ten-year cycle, providing periodic updates that are essential for long-term trend analysis and policy evaluation. However, a subset of countries-including Finland, Sweden, Denmark, and France-have adopted annual or rolling inventory systems, allowing for more frequent and timely data delivery. This is particularly valuable for tracking changes in forest condition, carbon stocks, and disturbance events in near real-time.

The usability of national forest monitoring data is highest in countries that have successfully integrated Earth Observation (EO) technologies with traditional field surveys. Finland, Sweden, and Spain are leading examples, where EO data is routinely combined with field plots to produce high-resolution, policy-relevant forest information. In contrast, smaller Member States such as Malta and Cyprus, or countries with more limited resources like Romania and Bulgaria, face challenges in maintaining up-to-date inventories and often rely more heavily on EU-wide datasets to supplement national data gaps.

EU-wide datasets, including the Copernicus High Resolution Layers (HRL), the European Forest Fire Information System (EFFIS), and the CLC+ land cover products, play a critical role in supporting forest monitoring, especially in regions where national data are sparse or outdated. These datasets provide harmonised, wall-to-wall coverage and facilitate comparative analysis across Member States, ensuring a consistent evidence base for EU-level forest policy and reporting.

Table 8 Main forest monitoring datasets in the 27 EU countries

Country	Main Dataset(s)	Application	Spatial resolution	Temporal resolution	Usability/Notes
Austria	Austrian Forest Inventory (ÖWI)	Carbon, biomass, biodiversity, policy	~1 km grid, plot-level	5–10 years	High, harmonised, used for FRA, LULUCF, EU reporting
Belgium	Flanders Strict Forest Reserves Monitoring, NFI	Stand structure, regeneration, biodiversity	Plot-level, 1 km grid	10 years	High, regional focus, integrated with EU datasets
Bulgaria	National Forest Inventory (NFI)	Growing stock, carbon, biodiversity	2 km x 2 km grid	10 years	Moderate, cluster plots, covers all forest types
Croatia	HS Fond (State Forestry Database), NFI	All forest parameters, carbon, management	Stand-level	5–10 years	High, covers 100% of stands, used for LULUCF
Cyprus	Department of Forests Inventory	Area, biomass, fire risk	Plot-level	5–10 years	Moderate, small forest area, uses EU harmonised methods
Czechia	National Forest Inventory (NFI)	Growing stock, health, biodiversity	2 km x 2 km grid	5 years	High, harmonised, used for EU and national reporting
Czechia	National Forest Inventory (NFI)	Area, increment, carbon, biodiversity	2 km x 2 km grid	5 years	High, harmonised, supports LULUCF, FRA
Denmark	Danish NFI (Skovstatistik)	Area, carbon, biodiversity	Plot-level	Annual	High, continuous, integrated with remote sensing

Denmark	Danish NFI (Skovstatistik)	Area, increment, carbon, biodiversity	Plot-level	Annual	High, continuous, integrated with EO and GIS
Estonia	National Forest Inventory (NFI)	Area, increment, carbon, biodiversity	1 km grid	5 years	High, harmonised, used for LULUCF, FRA
Estonia	National Forest Inventory (NFI)	Area, increment, carbon, biodiversity	1 km grid	5 years	High, harmonised, used for LULUCF, FRA
Finland	Multi-Source National Forest Inventory (MS-NFI)	Biomass, health, disturbance, carbon	16 m (raster maps)	Annual	Very high, field+EO integration, model-assisted
France	Inventaire Forestier National (IFN)	Area, structure, carbon, biodiversity	1 km grid, plot-level	Annual (rolling)	High, harmonised, supports EU and national policy
Germany	Bundeswaldinventur (BWI)	Area, growing stock, carbon, biodiversity	4 km x 4 km grid	10 years	High, harmonised, used for all reporting
Greece	National Forest Map, NFI	Area, post-fire recovery, erosion, carbon	30 m (Landsat), plots	Irregular	Moderate, fragmented, uses Copernicus HRL for updates
Hungary	National Forest Inventory (NFI)	Area, increment, carbon, biodiversity	4 km x 4 km grid	5–10 years	High, harmonised, integrated in EU datasets
Ireland	National Forest Inventory (NFI)	Area, increment, carbon, biodiversity	2 km x 2 km grid	5 years	High, harmonised, supports LULUCF, FRA

Italy	Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio (INFC)	Area, carbon, biodiversity, structure	Plot-level, 1 km grid	5–10 years	High, harmonised, used for policy and EU reporting
Latvia	National Forest Inventory (NFI)	Area, increment, carbon, biodiversity	1 km grid	5 years	High, harmonised, integrated with Sentinel for wetlands
Lithuania	National Forest Inventory (NFI)	Area, increment, carbon, biodiversity	4 km x 4 km grid	5 years	High, harmonised, used for LULUCF, FRA
Luxembourg	NFI (Administration de la nature et des forêts)	Area, urban forest, biodiversity	500 m grid, plot-level	5 years	High, GIS-integrated, covers small forest area
Malta	Copernicus HRL, local surveys	Coastal and urban forest monitoring	10 m (HRL)	3 years	Low, no national NFI, relies on EU datasets
Netherlands	Dutch NFI (Meetnetten), CBS Land Use	Area, structure, biodiversity, carbon	Plot-level, 1 km grid	5 years	High, harmonised, supports EU and national policy
Poland	National Forest Inventory (NFI)	Area, increment, carbon, biodiversity	4 km x 4 km grid	5 years	High, harmonised, used for all reporting
Portugal	Inventário Florestal Nacional (IFN)	Area, increment, fire risk, carbon	Plot-level, 1 km grid	5–10 years	High, harmonised, supports fire risk and LULUCF
Romania	National Forest Inventory (IFN), Copernicus HRL	Area, illegal logging, biodiversity, carbon	10 m (HRL), plots	5 years	Moderate, funding gaps, uses EU data for updates

Slovakia	National Forest Inventory (NFI)	Area, increment, carbon, biodiversity	4 km x 4 km grid	5 years	High, harmonised, supports EU and national policy
Slovenia	National Forest Inventory (NFI)	Area, increment, carbon, biodiversity	Plot-level, 1 km grid	5 years	High, harmonised, used for LULUCF, FRA
Spain	Inventario Forestal Nacional (IFN), Sentinel-2	Area, fire risk, carbon, biodiversity	10 m (Sentinel-2), plots	5–10 years	High, regional focus, strong EO integration
Sweden	Riksskogstaxeringen (NFI)	Area, increment, carbon, biodiversity	10–20 m (LiDAR, plots)	Annual (rolling)	Very high, field+EO integration, model-assisted

8.3. National forest monitoring using EO and RS (27 EU countries)

Earth Observation (EO) and Remote Sensing (RS) technologies have become indispensable tools for forest management across the European Union, enabling Member States to monitor ecosystems, comply with regulatory frameworks, and address environmental challenges. The integration of these technologies varies significantly among countries, reflecting differences in technical capacity, funding, and regional priorities.

Countries such as Finland, Sweden, Spain, and France lead in advanced EO/RS adoption, leveraging Sentinel satellite data and LiDAR to produce annual, high-resolution forest updates. These nations combine field inventories with cutting-edge technologies to track biomass, disturbances, and carbon stocks with remarkable precision. In contrast, Poland, Czechia, and Slovenia demonstrate moderate integration, primarily using Sentinel-1 and Sentinel-2 for targeted applications like storm and pest disturbance detection. Meanwhile, smaller or less-resourced states like Malta, Cyprus, and Bulgaria rely heavily on EU-wide datasets such as the Copernicus High Resolution Layers (HRL) due to limited national infrastructure, highlighting disparities in technological adoption.

At the EU level, standardised datasets like Copernicus HRL and the European Forest Fire Information System (EFFIS) streamline reporting for the EU Deforestation Regulation (EUDR), LULUCF, and biodiversity commitments. Globally, hybrid National Forest Inventory (NFI)-EO datasets support reporting to the UN Food and Agriculture Organisation's Forest Resources Assessment (FRA) and Sustainable Development Goals (SDGs), ensuring coherence between regional and international frameworks.

Despite progress, challenges persist. Malta and Cyprus, with limited forest cover, depend entirely on EU datasets due to the absence of national inventories. Romania and Bulgaria face delays in EO adoption, constrained by funding gaps and legacy systems. These disparities underscore the need for targeted financial and technical support to ensure equitable implementation of forest monitoring technologies.

EO and RS technologies are transformative for EU forest management, offering scalable solutions for carbon tracking, disturbance response, and biodiversity conservation. While integration levels vary, the harmonised use of Copernicus data and Sentinel satellites provides a foundation for transnational environmental governance. Addressing capacity gaps in smaller and under-resourced states will be critical to achieving the EU's ambitious climate and biodiversity targets, ensuring all Member States contribute effectively to a sustainable future.

Table 9 Use of EO and RS in a forest/ry context in the 27 EU countries

Country	Dataset	Applications	Spatial Resolution	Temporal Resolution	Use in Reporting
Austria	Austrian Forest Inventory (ÖWI)	Carbon stocks, biodiversity	25 m (LiDAR)	10-yearly	LULUCF, FRA
Belgium	NFI + Sentinel-2	Forest health, urban tree cover	10 m	Annual	EU Biodiversity Strategy
Bulgaria	Copernicus HRL + NFI plots	Disturbance detection, illegal logging	10 m	5-yearly	EUDR Compliance
Croatia	HS Fond (State Forestry Database)	Stand-level management, carbon	Stand-level	Annual	National Forestry Reports
Cyprus	Copernicus HRL	Coastal forest monitoring	10 m	3-yearly	FRA, SDG 15
Czechia	NFI + Sentinel-1/2 fusion	Storm damage, pest outbreaks	10 m	Annual	LULUCF, EUDR
Denmark	Danish NFI (Skovstatistik)	Carbon, biodiversity	Plot-level	Annual	EU Climate Law, FRA
Estonia	NFI + Sentinel-1	Peatland monitoring, wetland mapping	10 m	5-yearly	Nature Restoration Law
Finland	Multi-Source NFI (MS-NFI)	Biomass, disturbance detection	16 m	Annual	LULUCF, FRA, REDD+

France	IFN + Sentinel-2	Fire-risk mapping, carbon stocks	10 m	Annual	EU Forest Strategy, SDGs
Germany	Bundeswaldinventur (BWI)	Carbon, biodiversity	4 km grid	10-yearly	LULUCF, FRA
Greece	National Forest Map + Sentinel-3	Post-fire recovery, erosion control	30 m	Annual	EUDR, Biodiversity Strategy
Hungary	NFI + Copernicus HRL	Afforestation tracking, carbon	10 m	5-yearly	LULUCF, FRA
Ireland	NFI + Sentinel-2	Reforestation, peatland conservation	10 m	5-yearly	EU Climate Targets
Italy	INFC + TanDEM-X	Forest structure, biomass	10–20 m	5-yearly	LULUCF, REDD+
Latvia	NFI + Sentinel-1	Wetland carbon, storm resilience	10 m	5-yearly	EUDR, FRA
Lithuania	NFI + Copernicus HRL	Invasive species tracking	10 m	5-yearly	Biodiversity Strategy
Luxembourg	NFI + LiDAR	Urban forest management	500 m grid	5-yearly	National Climate Plans
Malta	Copernicus HRL	Coastal and urban forest monitoring	10 m	3-yearly	FRA, SDG 15
Netherlands	Dutch NFI + Sentinel-2	Carbon, biodiversity	10 m	5-yearly	EU Green Deal, LULUCF

Poland	NFI + Sentinel-2	Illegal logging detection	10 m	5-yearly	EUDR Compliance
Portugal	IFN + Sentinel-2/ALOS-2	Fire-risk mapping, carbon	10 m	5-yearly	EU Forest Strategy, REDD+
Romania	IFN + Copernicus HRL	Old-growth forest mapping	10 m	5-yearly	EU Biodiversity Strategy
Slovakia	NFI + Sentinel-1	Windthrow detection, carbon	10 m	5-yearly	LULUCF, FRA
Slovenia	NFI + Sentinel-2	Biodiversity, illegal logging	10 m	5-yearly	EUDR, Natura 2000
Spain	IFN + Sentinel-2/LiDAR	Mediterranean resilience, biomass	10 m	Annual	LULUCF, EUDR
Sweden	Riksskogstaxeringen + Sentinel-2/LiDAR	Boreal forest carbon, disturbance	10–20 m	Annual	EU Climate Law, FRA

8.4. Usability for dynamic forest monitoring

Dynamic forest monitoring refers to the continuous or frequent observation of forest ecosystems to detect and analyse changes over time. This includes tracking disturbances such as fires, pest outbreaks, and logging, as well as monitoring growth patterns, carbon stock fluctuations, and shifts in species composition (ScienceDirect, 2024). Effective dynamic monitoring requires datasets with high temporal resolution: frequent updates to capture rapid or seasonal changes (Wulder et al., 2010), and fine spatial resolution: capability to identify small-scale disturbances, such as illegal logging in areas <1 ha (Hölbling et al., 2024).

Furthermore, it requires multi-parameter coverage, for instance, both data on structure (e.g., LiDAR-derived canopy height), health (e.g., NDVI for vegetation stress), and biomass (e.g., SAR-based estimations) to assess ecosystem dynamics (Pandey and Arellano, 2022). Finally, the usability of the data for dynamic forest monitoring depends on the timeliness and the data quality. Rapid data availability with high accuracy and precision is critical for actionable insights (Hölbling et al., 2024; Lacava et al., 2006). The usability of datasets for dynamic monitoring hinges on their ability to deliver consistent, timely, and policy-relevant information. Below, we evaluate key EU and national datasets against these criteria.

Table 10 Usability of forest datasets for dynamic monitoring

Dataset	Key parameters	Spatial resolution	Temporal resolution	Usability for dynamic monitoring
Copernicus HRL Forests	Tree Cover Density, Forest Type	10 m	3-yearly (FTY), Annual (TCD/DLT)	Moderate: Annual TCD updates support gradual change detection, but 3-year FTY gaps limit disturbance tracking.
EFFIS	Burnt area, fire danger indices, active fires	500 m – 1 km	Near-real-time (daily)	High: Critical for real-time fire monitoring and post-fire recovery assessment.
Sentinel-1 SAR	Canopy structure, moisture	10–20 m	6–12 days	High: All-weather capability enables rapid disturbance detection (e.g., storms, illegal logging).
Sentinel-2 MSI	Vegetation indices (NDVI, NDMI)	10–20 m	5 days	Very High: Frequent updates and spectral detail track phenology, drought stress, and small disturbances.
Finland MS-NFI	Biomass, species composition	16 m	Annual	Very High: Annual high-resolution maps enable precise growth and harvest monitoring.

Dataset	Key parameters	Spatial resolution	Temporal resolution	Usability for dynamic monitoring
Spain IFN + LiDAR	3D structure, fire risk	10 m (Sentinel-2)	Annual (LiDAR: 5-yearly)	Moderate: Combines annual optical updates with periodic LiDAR for structural changes.
ICP Forests Level I/II	Tree health, soil condition	Plot-level	Annual (Level II)	Low: Field-based, sparse spatial coverage limits dynamic scaling but validates EO trends.
CLC+ Backbone	Land cover transitions	100 m	6-yearly	Low: Coarse resolution and infrequent updates miss short-term changes.

Dynamic forest monitoring includes the systematic tracking of rapid ecological changes such as disturbances, growth, and carbon flux-relies on datasets that balance spatial detail, temporal frequency, and thematic relevance. The evaluation of key datasets (Table 10) reveals critical insights into their suitability for specific monitoring objectives.

Real-Time monitoring: the European Forest Fire Information System (EFFIS) excels in near-real-time fire detection and impact assessment, providing daily updates at 500 m–1 km resolution. Complementing this, Sentinel-1 (SAR) and Sentinel-2 (optical) data enable rapid disturbance detection (e.g., storms, illegal logging) at 10–20 m resolution, with revisit times of 6–12 days. Their synergy offers unparalleled capacity for immediate response to acute threats.

Annual trend analysis: for tracking gradual changes in forest structure and carbon stocks, Finland's Multi-Source NFI (MS-NFI) and Copernicus Tree Cover Density (TCD) stand out. MS-NFI's annual 16 m resolution biomass maps, integrating LiDAR and Sentinel-2, provide granular insights into boreal forest dynamics. Similarly, Copernicus TCD's annual 10 m updates deliver consistent, EU-wide canopy density trends, critical for LULUCF reporting.

Validation and calibration: ground data from ICP Forests-collected across ~6,000 plots in Europe-play a pivotal role in validating EO-derived trends. These field measurements ensure the accuracy of satellite-based disturbance alerts and biomass estimates, bridging the gap between remote sensing observations and on-the-ground ecological conditions.

Identified gaps: while CLC+ Backbone (100 m, 6-yearly) offers broad land cover classifications, its coarse resolution and infrequent updates limit utility for detecting small-scale or rapid changes. Similarly, national LiDAR initiatives (e.g., Spain's IFN) provide detailed 3D forest structure but lack the temporal frequency needed for dynamic monitoring, often relying on 5-yearly acquisitions.

Table 10 serves as a decision-making tool for prioritising datasets based on monitoring goals. For instance, Mediterranean nations may prioritise Sentinel-1/2 fusion for fire-risk mapping, while Nordic countries leverage MS-NFI for carbon stock trends. Addressing gaps requires enhancing the frequency of LiDAR campaigns and integrating CLC+ with higher-resolution EO data. By aligning dataset capabilities with regional needs, the EU can advance toward a responsive, resilient forest monitoring framework.