

Perspectives: State of national forest damage survey programmes in Europe and ways toward improved harmonization and data sharing

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ABSTRACT

Recent increases in forest damage across Europe have challenged national forestry sectors and threatened progress toward Europe's climate and bioeconomy goals. Although developments in remote sensing now allow large-scale wall-to-wall monitoring of forest conditions, reliable damage assessments still require robust terrestrial data. Yet, existing data often remain inconsistent and fragmentarily distributed across institutions and countries. Based on consultations with national experts, we here provide an evaluation of national forest damage survey programmes in 19 European countries, identify obstacles that hinder more effective use of data, and formulate recommendations to overcome these barriers. We examined five aspects of national forest damage surveys: (i) legal and institutional frameworks, (ii) data acquisition methods, (iii) damage attribution, (iv) data quality and consistency, and (v) data accessibility. We found that half of the examined programs have changed protocols since 2000 and only 53 % of countries currently have survey programs covering their entire forest area.

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In 26 % of countries, legal constraints hamper data accessibility to the broader international community, while in 89 % data are available only in the respective national languages. In 84 % of countries, the absence of adequate metadata hinders the usability of the data without inside knowledge. Some of Central European countries operate the most consistent and open systems, while western and northern countries generally exhibited lower levels of openness and consistency. The implementation of coordinated structural changes in national programs that would enable consistent monitoring of forest damage at European level is unrealistic in the foreseeable future. However, certain critical gaps in data coverage, completeness, and consistency can be addressed through extensive data post-processing and integration with remote sensing. Overcoming barriers, such as limited awareness of the importance of transnational assessments, requires improved communication efforts and targeted funding programs. Establishing a coordination unit by leveraging existing policy processes in Europe appears essential to advancing these efforts.

1. Introduction

Forest damage caused by windthrows, wildfires, insects, and diseases has substantially increased in recent decades (Patacca et al., 2023). As climate change continues to accelerate, disturbance dynamics may intensify even further, though these effects can exhibit significant geographical variability and different responses between individual agents (Seidl et al., 2017). Continental-scale increases in forest mortality will have pervasive and long-lasting effects on forests and the ecosystem services they provide (Das et al., 2025; Lecina-Diaz et al., 2024; McDowell et al., 2020). In Europe, the scale of recent impacts was unprecedented and caused large-scale forest cover losses, triggered large fluctuations in timber prices, and revealed bottlenecks in forestry logistics and timber processing chains (Asada et al., 2023; Hlásny et al., 2021a; Kärvelo et al., 2023; Washaya et al., 2024). This pulse of disturbance presents a critical challenge for many regions and for the European forestry sector as a whole, and threatens progress in reaching climate and bioeconomy goals (Hetemäki et al., 2022; Korosuo et al., 2023).

Managing forests under these rapidly changing conditions requires timely and precise data on forest disturbance levels and trends at national or subnational scales. Implementation of European forest-related policies also demands EU-wide harmonization of data collection and open accessibility (Forzieri et al., 2023; Patacca et al., 2023; Schelhaas et al., 2003). These needs are also recognized by the EU Forest Strategy for 2030, which aims to enhance collaboration on monitoring of forest diseases and pests across Europe (European Commission, 2021) as well as by the Ministerial Conference on Forest Protection in Europe, which highlighted the urgency of establishing a coordinated pan-European Forest Risk Knowledge Mechanism (Forest Europe, 2020). These political intentions are also echoed by the scientific community. Hartmann et al. (2018), for instance, suggested a framework for coordinated tree mortality monitoring, which has been used within the IUFRO Task Force on monitoring patterns and trends of global tree mortality. Building upon these ideas, a comprehensive framework for integrating ground inventories, remote sensing data, and modelling has recently been proposed by Senf et al. (2025) to support a consistent assessment of tree mortality and address limited data completeness and coverage in existing damage inventories. Patacca et al. (2023) further proposed an Artificial Intelligence (AI)-based gap-filling algorithm and applied it to extensive ground data reported by national forestry agencies (Schelhaas et al., 2020), consistently reconstructing forest damage trends across Europe since 1950.

The monitoring program ICP Forests (Lorenz, 1995), which maintains a network of permanent forest plots throughout Europe, makes an important contribution to estimating tree vitality (i.e., crown transparency) and forest mortality across Europe (George et al., 2022; Jaime et al., 2022; Neumann et al., 2017). However, the network operates on a plot grid of sparse spatial density (16 km x 16 km), potentially limiting some applications, and has not been designed to establish causality in tree death. Plot-scale damage assessments may also be limited in their ability to capture long-term trends in disturbance agents that affect large forest areas, often resulting in the removal of trees at entire monitoring

plots. Remote sensing-based monitoring has significantly advanced during the last years, potentially resolving some of the limitations of plot-based assessments (Senf et al., 2017; Forzieri et al., 2023). Recent advances in AI in integrating ground and remote sensing data hold significant potential for overcoming some of these limitations and enabling more comprehensive and scalable disturbance monitoring (Gao et al., 2020; Hislop et al., 2019). However, establishing consistent frameworks for integrating ground data on agent-specific damage levels and trends still depends on progress in international agreements that enable seamless information flows from the field to regional and global assessments (International Tree Mortality Network, 2025).

Existing disturbance datasets such as the Database of Forest Disturbances in Europe (Patacca et al., 2023; Schelhaas et al., 2020) and the Database of European Forest Insect and Disease Disturbances (Forzieri et al., 2023), partly drew their results from damage survey programs operated by various national forestry agencies. These data also have supported different national studies (e.g., Klapwijk et al., 2013; Hlásny et al., 2021a; Usbeck et al., 2010; Thom et al., 2013) and, in some cases, informed broader Europe-wide evaluations (e.g., Forest Europe, 2020; FAO, 2020). These databases are typically based on data collected during salvage and sanitary logging, which are management measures aimed to contain the spread of pest species and mitigate economic losses following disturbances (Dobor et al., 2020; Hlásny et al., 2021b). On the one hand, these national data sources are a unique collection of data and their validation and processing often involve national experts with an in-depth understanding of local disturbance dynamics. On the other hand, these surveys lack international coordination and data harmonization, have unclear data access rules, do not follow transparent quality control procedures and are generally available in national languages only. For example, Kautz et al. (2017) found that European country-wise forest damage data were not easily available at annual resolution and that data quality varied between countries due to different monitoring standards and protocols—unlike more consistent and accessible U.S. and Canadian disturbance databases. Nevertheless, national damage survey data may be essential for informing policy development in Europe and play a critical role in detecting and understanding of emerging disturbance dynamics. It is thus disconcerting that institutional and legal frameworks of national damage survey programs in Europe—as well as their protocols of data collection, pre-processing, reporting, and provision—have never been systematically analysed. Additionally, a clear strategy for utilizing these valuable yet underexploited data repositories at the EU level is lacking, despite their potential to support the European climate, biodiversity, and bioeconomy policies.

Here, we aimed to provide the first comprehensive assessment of national forest damage survey programs across Europe and formulate recommendations for better data use and sharing. To outline a path forward, we assembled a team of national experts responsible for or familiar with data collection and management in their respective countries. Based on a questionnaire survey and iterative individual consultations, we conducted a comprehensive analysis of the current state of forest damage survey programs, focusing on aspects essential for improving continent-scale data harmonization and sharing. We aimed to identify the main obstacles limiting the establishment of a European-

wide forest damage monitoring system and propose strategies for overcoming them. These findings are intended to support efforts toward more coordinated forest damage assessment, as well as improved data and knowledge sharing across national forest agencies in Europe.

2. Questionnaire

In 2023 and 2024, we distributed an online questionnaire to national experts from 19 European countries. The participating experts represented national forestry agencies responsible for conducting forest damage surveys or institutions engaged in data analysis and processing. Our objective was to receive one completed questionnaire per country; however, we did not place any restriction on the number of experts who could participate in filling out a single questionnaire. In total, 25 experts contributed to the responses and participated in follow-up individual consultations.

The participating countries span across a wide geographical, ecological, and forest management gradient, ranging from Central and Western European countries (Austria, Germany, France, Belgium, United Kingdom) through Central and Eastern European post-socialist countries (Slovakia, Czechia, Poland, Hungary, Bulgaria, Romania, Slovenia, Croatia, Serbia), Southern Europe (Italy) to Nordic (Sweden, Norway, Finland) and Baltic (Lithuania) countries. Taken together, the countries included in our analysis comprise 144 million hectares of forest area, which constitutes 71 % of Europe's forested land cover (without Russia, Belarus and Ukraine).

The questionnaire addressed five interconnected areas to characterize damage surveys in terms of: (i) legal and institutional settings, (ii) data acquisition procedures, (iii) damage attribution detail, (iv) data quality and consistency, and (v) data accessibility (Fig. 1). Each thematic area was addressed with several questions; altogether, the questionnaire included 16 questions (Appendix A). Each question allowed respondents to select from multiple choices or to provide an open-ended answer, if needed.

A two-step evaluation procedure was used: first, all national experts completed an online questionnaire detailed in Appendix A. Then, the collected data were analyzed within a smaller team and all issues hampering consistent data analysis were identified. This initial assessment was shared with the entire team and the identified issues were solved through individual consultations. Then, an online meeting was held aimed (i) to enhance consistency and ensure a common understanding of individual questions, and (ii) to collectively identify major obstacles to improved data sharing and use as well as to discuss possible ways forward. Based on these consultations, some initial responses were adjusted, and the evaluation was revised accordingly.

To rank the performance of the national programmes across the five thematic areas, we assigned scores to survey responses. These were either binary (e.g., whether data are available only in the national

language or not) or on a continuous scale from 0–1 (e.g., the proportion of a country's forest area that is surveyed) (Appendix A). A score of 1 (or close to 1) was given to responses that reflected the most desirable state in terms of data quality, thoroughness, and broader applicability. These scores were used for comparing the systems across countries.

Next, we summed the scores within each thematic area (Fig. 1) and calculated the fraction of the maximum possible value—representing the case where all responses within that area received a score of 1 (for example, the thematic area 'Data acquisition and coverage' reaches 1 if each out of four questions reached score 1; Appendix A). To rank the countries by their overall performance across the five thematic areas, we summed the scores across these areas, with the maximum reachable value of 5.

We examined the questionnaire results using Principal Component Analysis (PCA) and K-means clustering. Country-level responses to individual questions were used as input variables for the extraction of principal components. Within this ordination space, clusters of countries with similar performance across the investigated thematic areas were identified and interpreted. Finally, we explored whether differences between countries could be explained by factors such as the contribution of forestry to national Gross Domestic Product (GDP) and the proportion of forest land (%).

3. Differences among national forest damage surveys in Europe

The vast majority (84 %) of programmes in the investigated countries are mandatory, meaning that forest owners are obliged to collect and provide data on forest disturbances based on national forestry legislation (Fig. 2). The exceptions are Belgium, Finland, and Sweden, where these activities are conducted voluntarily. Institutional settings are more variable: In 42 % of the countries, programmes are decentralized and their individual parts (e.g., assessment of biotic and abiotic damage) are inconsistent (e.g., Belgium, Sweden, Serbia, Croatia, Italy, Romania, and Germany), whereas in another 37 %, they are operated by multiple organizations yet with a higher degree of consistency (Fig. 2). Finally, in four countries (Bulgaria, Finland, Norway, and Slovakia), programmes are supervised by a single organization.

Regarding data acquisition, 42 % of the countries collect data in the field during management operations (including salvage and sanitary harvests), while two countries, Norway and France, rely on damage estimates obtained from a network of monitoring plots as part of the national forest inventory. A combined approach—using both data from management operations and monitoring plots—is applied in 47 % of the countries. In 89 % of the countries, data are collected and reported annually (or more frequently), whereas Norway uses a 5-year interval. A different approach is practiced in Belgium, where the data acquisition interval differs depending on damage agent.

The forest area covered by the surveys varies across countries: 63 % of the countries conduct surveys over more than 70 % of their forested area, while Belgium, Italy, Lithuania, Germany, and Romania limit coverage to 30–50 %. Finland and Norway employ a plot-based survey or focus on regions where damage has been observed. A specific approach is practiced in Belgium, where the reporting varies depending on the species and between regions.

Regarding data quality and spatial and temporal consistency, 84 % of countries reported that surveys are conducted by trained personnel. However, only 47 % of countries employ an independent quality control procedure, such as field revisits. Furthermore, survey programmes in 42 % of the countries experienced changes in survey and reporting protocols in the last 20 years (typically represented as changes in the reported variables), potentially compromising the quality and temporal consistency of the data. Finally, 79 % of countries reported that the survey, assessment, and reporting are conducted consistently (i.e., using the same protocol) across the entire surveyed area. Hence, most of the inspected programmes suffer from temporal inconsistencies (i.e., surveys protocols changed over time), whereas their spatial consistency is

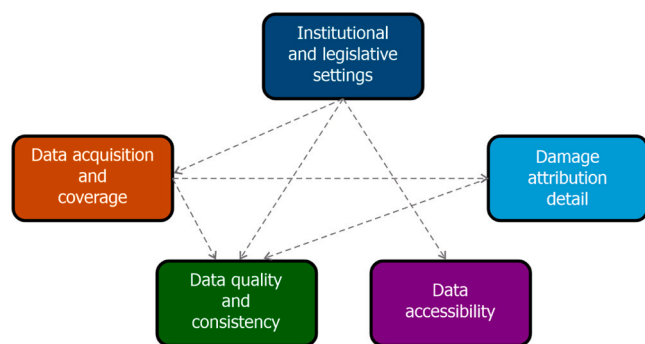


Fig. 1. Organisation of the questionnaire on forest damage surveys operated in different European countries. Each thematic area was covered by several questions. The arrows indicate ways how individual areas determine each other.

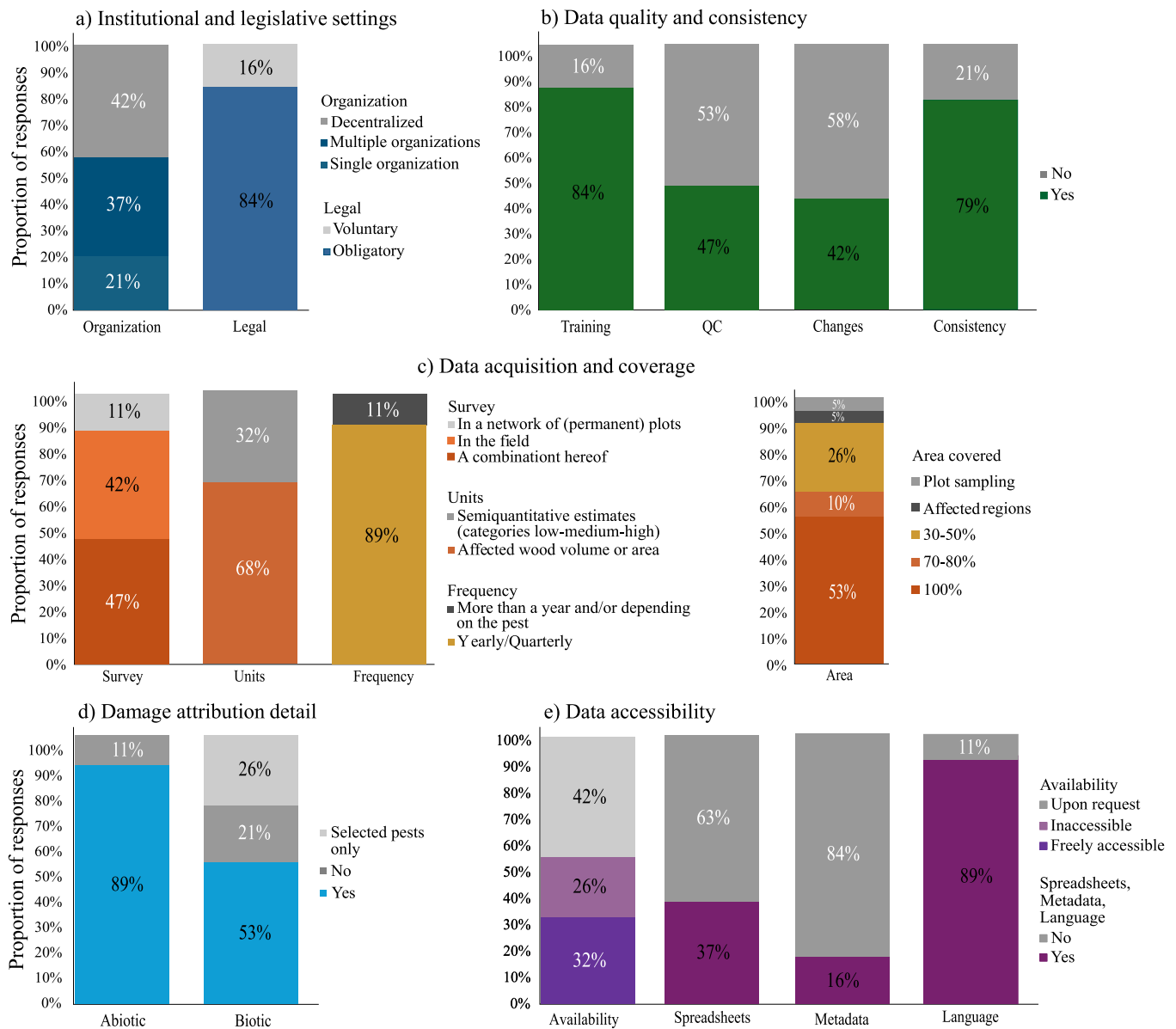


Fig. 2. Summary results of a questionnaire-based assessment of national forest damage surveys in 19 European countries. Proportions of responses to the questions listed in Appendix A are indicated. Legend labels are also detailed in Appendix A.

relatively higher (i.e. survey protocols remain uniform across different regions within countries).

The detail of damage attribution to agents differs depending on whether biotic or abiotic agents are surveyed (Fig. 2). For abiotic damage, 89 % of countries attribute damage to individual agents, such as wind, drought, fire, or ice, whereas the remaining countries report abiotic damage without distinction. In the case of biotic damage, 21 % of countries do not attribute biotic damage to individual agents (insect and disease species, wildlife), and 26 % attribute biotic damage only to a small number of most important agents (such as spruce bark beetle *Ips typographus*). The remaining 53 % of countries attribute biotic damage to a larger number of individual insect and pathogen species.

As for data accessibility, 32 % of the countries make data freely available through a dedicated website, while another 42 % provide data only upon request. In the remaining 26 % of countries (Belgium, Bulgaria, Serbia, Croatia, and Poland), data are not publicly accessible at all. Consistently formatted and documented data spreadsheets that allow direct data analysis are provided by 37 % of countries only. Metadata on data acquisition, preprocessing, and quality control are

available only in Slovakia, Slovenia and the UK. Finally, Finland and the UK are the only countries that make the data directly accessible in English.

4. Country rankings

Based on the aggregated scores for all five thematic areas (Appendix B), Slovakia, Slovenia, and the UK were the top-ranked countries (Fig. 3). Slovakia (receiving score 4.5 out of 5, representing maximum possible performance across the five thematic areas, Fig. 1, Appendix A) and Slovenia (4.4) both exhibited high performance across all five areas, whereas the UK (4.0) scored notably lower in data quality and consistency. At the opposite end, Belgium ranked last with a total of 1.7, having received a zero score in legislative settings. The remaining 15 countries scored between 2.6 and 3.9, with varied performance across the thematic areas (Fig. 4).

Damage survey programmes are operated mandatorily in all examined countries except Belgium, Finland, and Sweden (Fig. 4). The systems are centrally managed by a single organization in Bulgaria,

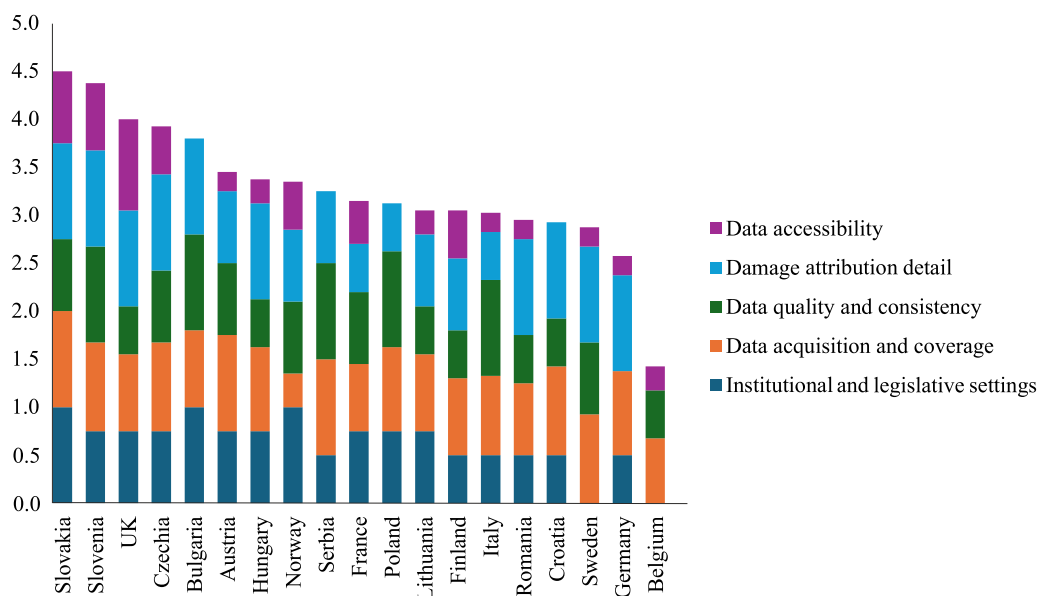


Fig. 3. Ranking of countries based on the performance of their national forest damage survey programmes across five thematic areas. Each area was assessed through multiple questions that were scored on a 0–1 scale by national experts (see Appendix A for details). The fractional values in the graph represent the proportion of the maximum possible score achieved within each category, summed across all categories. Because there are five thematic areas, the maximum combined score is 5.

Norway, Finland, and Slovakia, while more institutions are involved in the remaining countries. For data acquisition and coverage, Serbia, Slovakia, and Austria were the highest-ranking countries in all categories. Norway underperformed compared to other countries with respect to data acquisition and coverage. This was due to the use of plot sampling for damage recording and a long 5-year survey interval. Concerning data quality, Bulgaria, Italy, Poland, Slovenia, and Serbia scored high in all aspects, including spatial and temporal consistency of survey protocols, personnel training, and data quality control. On the other hand, Germany ranked lowest in terms of data quality and consistency, largely due to variability in survey protocols among its federal states. Most countries attribute both biotic and abiotic damage to individual agents. The exceptions are France, Italy, and Belgium, where biotic damage is reported collectively for all agents. Survey data are freely available or available at request in Czechia, Slovakia, Hungary, Austria, the UK, France, Italy, Finland, Romania, Slovenia, Lithuania, Sweden, Norway and Germany. On the other hand, Bulgaria, Poland, Serbia, and Croatia scored zero in all aspects of data accessibility—making it the area with the highest incidence of zero scores (Fig. 3).

5. Classification of countries by forest damage survey characteristics

The ordination space defined by the first two PCA components highlights certain groupings of countries based on data quality, legal frameworks, data availability, acquisition, and damage attribution to causal agents (Fig. 5). Cluster 1 comprises countries such as Belgium, France, Italy, and Norway. It is positioned along the positive principal axis 2 and slightly negative axis 1. These countries are characterized by relatively high data quality but limited data availability and less efficient legal and institutional settings. Belgium is a distinct outlier within this cluster, with significant limitations in data acquisition and availability.

Cluster 2 includes Finland, Sweden, Germany, Romania, Croatia, and the UK, and is located near the origin, extending slightly into negative axis 2. These countries exhibit moderate performance across most variables, with Finland and the UK showing better data availability. Germany is located at the negative end of the axis 1, showing considerably lower levels of data quality and legal and institutional settings.

Cluster 3, consisting of Austria, Slovakia, Slovenia, Czechia, Poland,

Serbia and Bulgaria, is positioned along the positive axis 1 and positive axis 2, characterizing high data quality and favourable legal and institutional settings. Austria and Bulgaria are closely associated with the quality axis 2. Poland and Serbia, by contrast, are located on the negative part of axis 1, largely due to low data availability.

Overall, Cluster 3 involves countries ranking high in terms of quality and legal and institutional settings, Cluster 1 reflects higher data quality but gaps in availability. Cluster 2 represents a more balanced yet moderate performance across the evaluated criteria. The clusters did not show a clear pattern in relation to geographical or forest-related characteristics. However, the concentration of several Central European countries (e.g., Slovakia, Czechia, Austria, Bulgaria) in the upper left quadrant may indicate a higher degree of forestry organization and centralization, potentially influenced by both the Austro-Hungarian administrative legacy and the centralized planning systems of the socialist era.

A complementary analysis of potential drivers behind differences in country-level performance revealed no significant effect of either the relative contribution of forestry to national Gross Domestic Product or the proportion of forested area within countries (Appendix C).

6. Acknowledged limitations and ways forward

Through a questionnaire survey and consultations with national experts, we identified key limitations hindering progress toward the improved sharing and utilization of forest damage data managed by national forestry agencies across Europe. In the following, we describe these limitations and develop recommendations to address them. We note that several initiatives towards continental to global disturbance assessment have been initiated recently, focusing on different data components and institutional frameworks, and addressing different objectives (e.g., Forzieri et al., 2023; Hartmann et al., 2018; International Tree Mortality Network, 2025; Kautz et al., 2017; Patacca et al., 2023). A shared narrative among these initiatives is the integration of existing data, spanning various sources as well as spatial and temporal scales, rather than the creation of a single, unified system. National forest damage survey systems can make an important contribution to these efforts, while also benefiting from such integration.

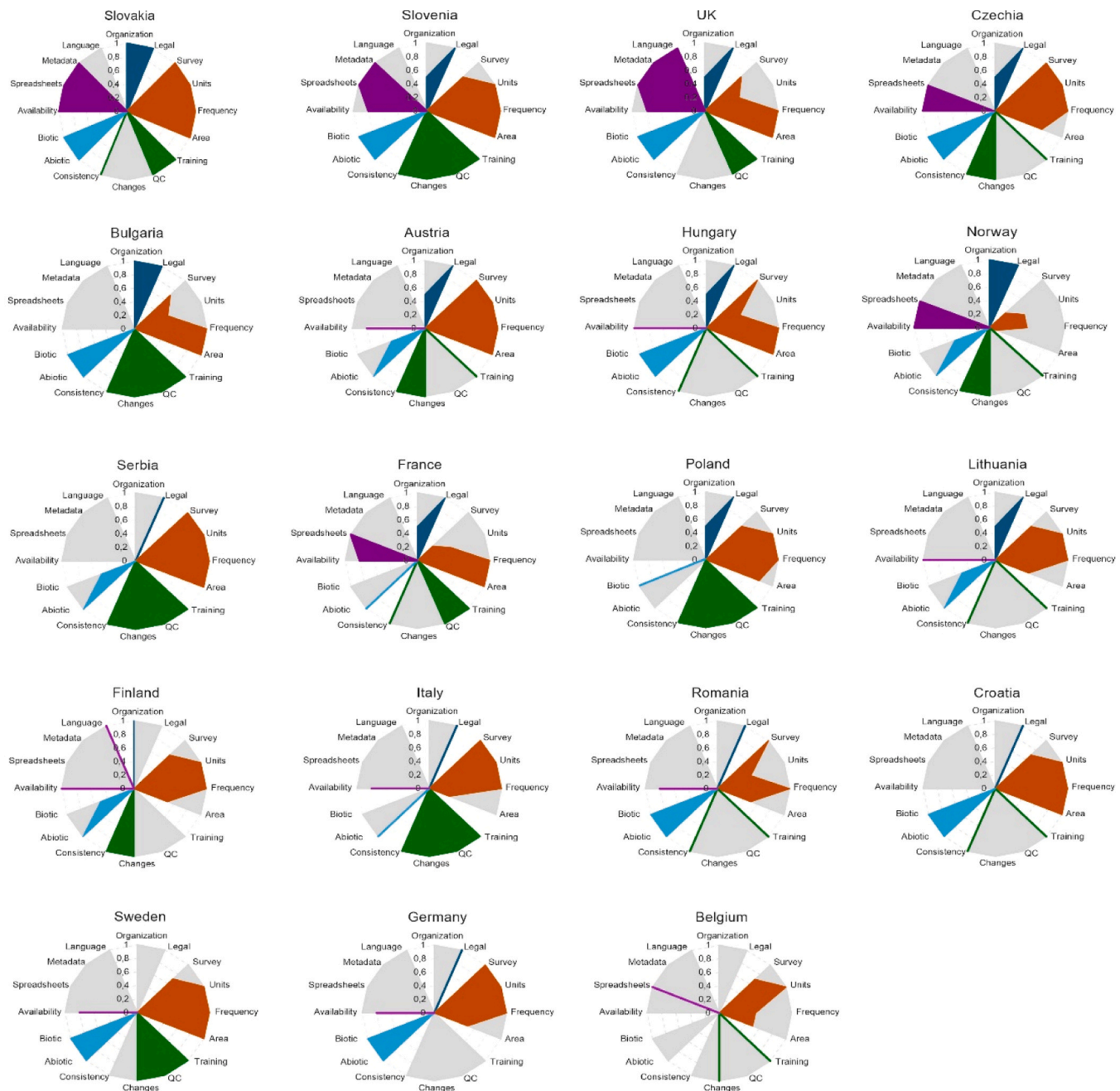


Fig. 4. Performance of forest damage surveys in 19 European countries evaluated through a questionnaire distributed to national experts. The plots show responses to 16 questions (represented as spikes), organized into five thematic areas (colours) (Appendix A). Grey areas denote the hypothetical maximum possible within each thematic area. The questions, graphs labels and scores assigned to different responses are detailed in Appendix A. Higher scores reflect better survey performance.

6.1. Define common objectives and data structure

The overarching challenge stems from the absence of clearly defined policy and research objectives that specify how the data should be used and for what purpose. Identifying common objectives may require a sustained dialogue between science and policy; here we propose several directions in which these efforts could be developed.

Establish common geographical units and time steps for reporting

As a minimum requirement, we propose that the spatial and temporal resolution of reported data aligns with prevailing reporting standards (Fig. 2), specifically by using standardized administrative regions as defined by The Nomenclature of Territorial Units for Statistics (NUTS) (European Commission, 2024) and reporting at annual time step. This spatial and temporal resolution aligns with current data reporting

routines in most countries; exceptions include France, Belgium, Norway, Italy, and Poland. This structure would thus comply with the requirements of national damage assessment and strategic planning, while also enabling consistent transnational assessments. It is noteworthy, however, that administrative regions as geographical unit are inadequate for tasks requiring higher spatial resolution, such as detailed disturbance mapping, operational forest management planning, or ground-truthing data for remote sensing applications. As previously mentioned, addressing a wider set of research and policy objectives requires the assimilation of multiple data sources on tree mortality, beyond the data source addressed here.

Include causal agent and host tree attribution in reporting

To allow a comprehensive risk assessment, provide novel insights into emerging disturbance dynamics and formulate adaptation

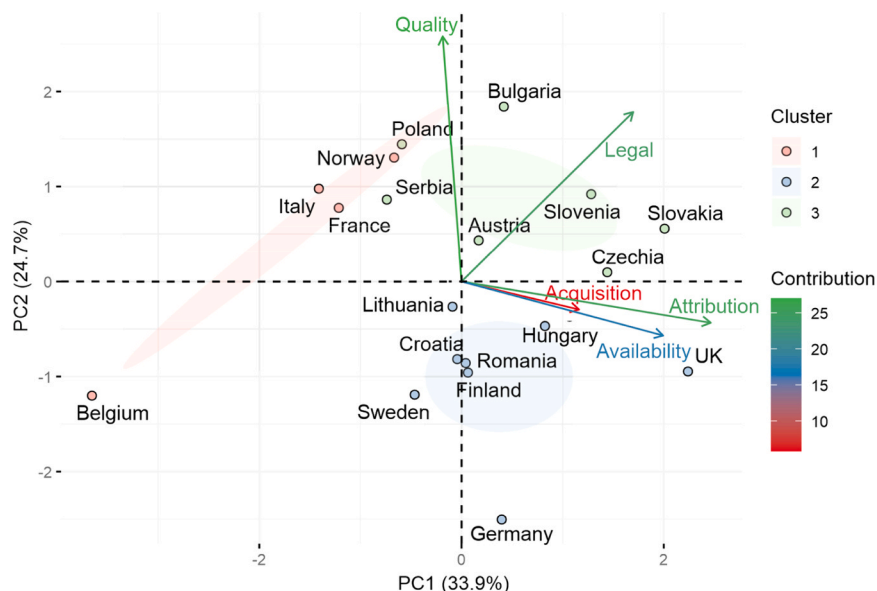


Fig. 5. Principal Component Analysis of countries based on criteria characterizing national forest damage survey systems. The first two principal components, explaining a combined 58.6 % of the total variance are shown. Arrows represent the most influential variables, with direction and length indicating the strength and contribution to the principal components. The colour gradient indicates variable contribution levels, with green showing the highest contributions. Groups of countries identified by K-means clustering are also shown. Higher positive values on each axis represent higher scores reached by each country. Variable codes: Quality: Data quality; Legal: Legal and institutional settings; Attribution: Detail of damage attribution to causative agents; Acquisition: Quality of data acquisition procedures; Available: Level of data availability.

strategies (Bastit et al., 2023; Gardiner et al., 2008; Lindner et al., 2010), data must provide causality attribution to specific agents (including wind, fire, insect pests, pathogens, and wildlife) and to particular forest type or tree species being affected. This enables the identification of emerging trends in disturbance dynamics, like increases in the activity of previously harmless biotic agents, rising damage to previously resistant tree species, or geographical shifts in the activity of different agents (e.g., Jaime et al., 2022; Patacca et al., 2023; Hartmann et al., 2025). Given the substantial differences among national survey systems, adopting common protocols for damage attribution is essential to enable broader data integration.

Agree on common metrics for reporting

To support economic, environmental and carbon-related impact assessments, it is desired to obtain damage estimates in terms of either affected area (e.g., for defoliating insects or regeneration damage by ungulates) or the volume of growing stock impacted. This is only partly feasible using plot-scale forest monitoring programmes (e.g., ICP Forests and National Forest Inventories) and remote sensing-based surveys and thus remains the domain of damage survey systems. Most—but not all—national survey programs focus on collecting data on total damage (though attribution to agents remains variable), typically derived from salvage harvesting records, and other management operations. Nevertheless, inconsistent assessment metrics across countries and agents (including the use of semi-quantitative scales, Fig. 2b) together with variable sampling designs and levels of attribution require significant post-processing to achieve a basic level of consistency in transnational assessments. To support meaningful data integration, standardized metrics for different damage agents should be adopted at international level.

6.2. The need for systemic changes in forest damage survey programmes and ways forward

Major limitations arise from the fact that damage survey systems are designed to primarily support national policy and management needs, rather than for ensuring spatial and temporal consistency or for providing a basis for large-scale assessments and scientific research

across national boundaries. For instance, 8 out of 19 evaluated countries reported changes in data acquisition and processing protocols over the past 20 years, in response to new national needs or changes in availability of funds. While such adjustments may not limit data use for estimating damage levels and management operation planning, they can compromise cross-border comparability and analysis of long-term trends. Regarding data coverage, most countries collect data exclusively for state-owned forests (Fig. 4), which reduces the value of the monitoring at both national and international scales. Expanding the monitoring to all forested land would allow substantial progress towards a pan-European forest damage assessment.

Until such changes are implemented we recommend taking advantage of recent advances in remote sensing and AI (Liu et al., 2021) to address the described limitations. These technologies can help identify correlation patterns between various agents and environmental conditions across different European countries, potentially filling gaps in existing terrestrial data and extrapolate damage estimates to unsurveyed areas (e.g. Patacca et al., 2023). As an early detection mechanism, we propose identifying exemplary countries with advanced capacities for detecting emergent damage patterns. Their assessments can inform surrounding countries about evolving disturbance dynamics until they develop such capacities themselves. Our country rating does not provide clear guidance in this regard (Fig. 3), hence this aspect requires further exploration.

While limitations arising from the idiosyncrasies of national programs can only be overcome in the mid- to long-term, we underscore the need for improved data accessibility as an important initial step to a coordinated transboundary assessments. This can be achieved by promptly publishing collected data on the websites of national forestry agencies, using a common data format, and including information on the most common damage agents, ideally accompanied by metadata in English.

6.3. Raise the awareness of the importance of coordinated international damage assessments

Despite an increasing transnational impact of natural disturbances

on forest resources, such a broader context remains insufficiently considered at the national level. Moreover, national forestry planning typically relies on locally collected data, which are considered trustworthy and sufficient for domestic needs. As a result, the potential of international data sharing and knowledge exchange remains underutilized, with limited motivation to engage in harmonized cross-country assessments. Furthermore, national experts often face multiple reporting obligations without clear mutual benefits, making them reluctant to engage in further activities, particularly in the absence of additional funding. During our interviews, we also noted concerns that reporting highly-detailed forest damage data might be seen as a risk of revealing inadequate management practices—such as insufficient outbreak prevention and containment, or misuse of salvage logging.

Although some of these concerns are deeply rooted, overcoming them may not require extensive structural changes to make progress possible. In particular, a combination of improved communication across national agencies and collaborative efforts towards co-production rather than unilateral reporting can address these challenges. While improved communication and knowledge sharing may yield some progress, providing financial support for the adoption of improved practices is likely to have a greater impact. Regularly informing national agencies about forest damage levels and trends across participating countries, for example, through synthesis assessment reports, involving national experts in pan-European projects that utilize shared data and lead to research papers can further motivate engagement in international initiatives.

6.4. Coordination and funding

To facilitate the improvements discussed earlier, we propose to establish an international coordination centre that channels momentum from existing initiatives, such as the Ministerial Conference on Forest Protection in Europe (Forest Europe), the Forest Risk Facility (FORISK) under the European Forest Institute, or capacities of the International Union of Forest Research Organizations (IUFRO). Such a centre should involve representatives of national forestry agencies, research bodies, and international organizations to collectively define priorities and objectives of coordinated forest damage assessment, formulate a roadmap, communicate it back to national policy makers and oversee its implementation. Establishing a dedicated funding program, for example, through a targeted EU-financed project call or tender, appears essential to incentivize these activities.

7 Conclusions

During recent decades, forests in Europe and in many other regions of the world have faced a combination of rapidly changing climate and increasingly severe natural disturbances, a trend that is likely to continue. Forest management agencies can develop effective countermeasures against forest damage only if occurring damage can be assessed and analysed in a timely manner. However, current national

damage monitoring systems are often incomplete in spatial coverage, making wall-to-wall assessments impossible even at the national scale. Moreover, because disturbances are not constrained by national boundaries, an international perspective is invaluable for developing mitigation measures. Given the already huge challenges in protecting forest against abiotic and biotic threats related to climate warming, forest management agencies and policy makers should foster international cooperation and data sharing. Effort in this direction, whether monetary or in terms of cooperation, will provide substantial returns by increasing the chances of maintaining functional forest ecosystems and the services they provide.

CRediT authorship contribution statement

Tomáš Hlásny: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Conceptualization. **Michaela Perunová:** Visualization, Formal analysis. **Roman Modlinger:** Writing – review & editing, Resources, Formal analysis. **Max Blake:** Writing – review & editing, Resources. **Gediminas Brazaitis:** Writing – review & editing, Resources. **György Csóka:** Writing – review & editing, Resources. **Maarten de Groot:** Writing – review & editing, Resources. **Mihai-Leonard Duduman:** Writing – review & editing, Resources. **Massimo Faccoli:** Writing – review & editing, Resources. **Margarita Georgieva:** Writing – review & editing, Resources. **Georgi Georgiev:** Writing – review & editing, Resources. **Wojciech Grodzki:** Writing – review & editing, Resources. **Henrik Hartmann:** Writing – review & editing, Resources. **Anikó Hirka:** Writing – review & editing, Resources. **Gernot Hoch:** Writing – review & editing, Resources. **Hervé Jactel:** Writing – review & editing, Resources. **Mats Jonsell:** Writing – review & editing, Resources. **Marija Kolšek:** Writing – review & editing, Resources. **Paal Krokene:** Writing – review & editing, Resources. **Markus Melin:** Writing – review & editing, Resources. **Slobodan Milanović:** Writing – review & editing, Resources. **Bjørn Økland:** Writing – review & editing, Resources. **Milan Pernek:** Writing – review & editing, Resources. **Gilles San Martin:** Writing – review & editing, Resources. **Martin Schroeder:** Writing – review & editing, Resources. **Rupert Seidl:** Writing – review & editing, Resources. **Jozef Vakula:** Writing – review & editing, Resources. **Tiina Ylioja:** Writing – review & editing, Resources.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. A questionnaire

Table A1

Main thematic areas and individual questions covered by the questionnaire. Scores were assigned to enable a semi-quantitative analysis of the responses. A score of 1 (or close to 1) indicates response options with the highest level of data quality, thoroughness, and accessibility. The keyword in brackets following each question is used for labelling in the graphs throughout the text.

(continued on next page)

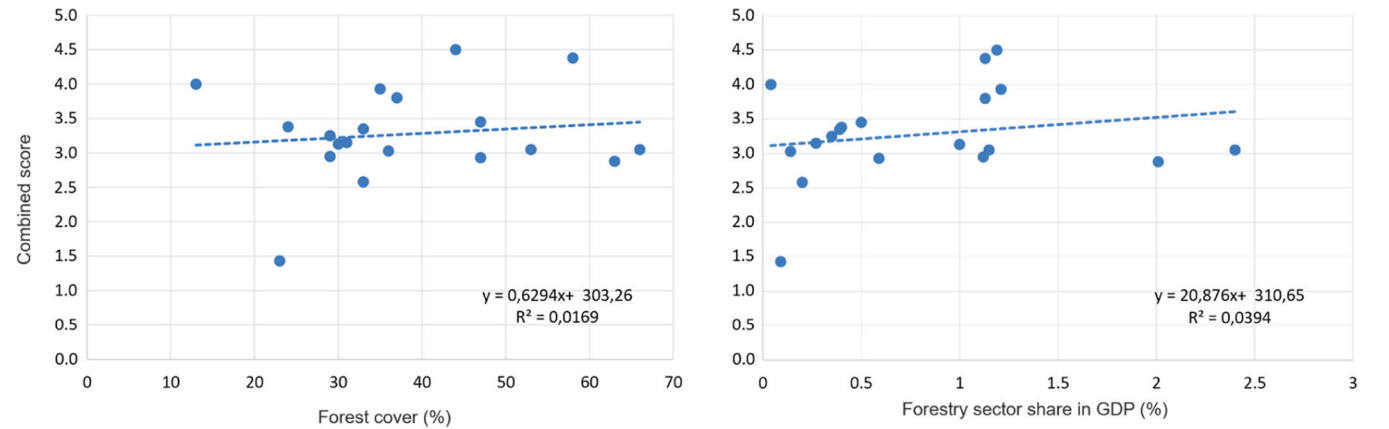
Table A1 (continued)

Domain	Question	Response options	Score
Institutional and legislative settings	1.1. What are the institutional settings underlying the operation of damage survey systems? (Organization)	A single organization is responsible for the operation of national forest damage monitoring, assessment, and reporting.	1
		Multiple organizations are responsible for different activities (e.g., data collection, processing, and reporting) and/or different kinds of forest land (e.g., administrative regions, ownerships, etc.) but following a consistent methodology.	0.5
		The system is decentralized, and data are fragmentarily managed and reported, possibly plagued with consistency issues.	0
	1.2. Is the reporting obligatory, e.g. set by law, or is it voluntary? (Legal)	Obligatory	1
		Voluntary	0
Data acquisition and coverage	2.1. Damages are recorded (Survey):	In the field during harvesting and other operations	1
		In a network of (permanent) plots	0.3
		A combination thereof	0.7
	2.2. Damages are recorder in terms of (Units):	Affected wood volume, area or number of trees	1
		Semiquantitative estimates, such as damage categories (low-medium-high, etc.)	0.5
	2.3. What is the frequency of data collection? (Frequency)	Yearly or quarterly	1
		More than a year and/or depending on the pest	0.5
	2.4. What proportion of forest land in the country is covered by the reporting? (Area)	0-100%	0-1
		All affected regions	0.5
Data quality and consistency	3.1. Are the data acquired by qualified and trained personnel able to attribute damages to specific agents? (Training)	Yes	1
		No	0
	3.2. Is a quality-control procedure applied, such as field revisits by experts, confrontation of reported damages with remote sensing data, or an independent monitoring system? (QC)	Yes	1
		No	0
	3.3. Have any substantial changes been made to the monitoring and reporting procedures during the last	Yes	0
	20 years that would compromise the spatial and temporal consistency of the data? (Changes)	No	1
	3.4. Are the data consistently reported across the entire country, using the same data acquisition, pre-processing, and reporting methodology? (Consistency)	Yes	1
		No	0
Damage attribution detail	4.1. Is abiotic damage recorded at the level of individual agents (wildfire, snow, windthrows, etc.)? (Abiotic)	Yes	1
		No	0
	4.2. Is most biotic damage attributed to individual species (insects, diseases, wildlife)? (Biotic)	Yes	1
		No	0
		For selected pests only	0.5
Data accessibility	5.1. Are source data (i.e., not only summary reports and graphs) made publicly available? (Availability)	No, the data are inaccessible	0
		Yes, data can be provided by the respective authority subject to a formal request	0.8
		Yes, data can be freely downloaded from a website	1
	5.2. Are data available as consistently formatted spreadsheets that allow for direct analysis? (Spreadsheets)	Yes	1
		No	0
	5.3. Are metadata, including data collection and processing procedures, quality control, and other aspects, published alongside the data? (Metadata)	Yes	1
		No	0
	5.4. Are data reported in national language only? (Language)	Yes	0
		No	1

Appendix B. The relative performance of national forest damage survey systems across five thematic areas

Country	Institutional and legislative settings	Country	Data acquisition and coverage	Country	Data quality and consistency	Country	Damage attribution detail	Country	Data accessibility
Bulgaria	100%	Serbia	100%	Bulgaria	100%	Bulgaria	100%	UK	95%
Norway	100%	Slovakia	100%	Serbia	100%	Sweden	100%	Slovakia	75%
Slovakia	100%	Austria	100%	Italy	100%	Slovakia	100%	Slovenia	70%
Poland	75%	Sweden	93%	Poland	100%	Croatia	100%	Czechia	50%
Slovenia	75%	Croatia	93%	Slovenia	100%	Slovenia	100%	Finland	50%
Hungary	75%	Slovenia	93%	Sweden	75%	Hungary	100%	Norway	50%
Austria	75%	Czechia	93%	Norway	75%	Romania	100%	France	45%
Lithuania	75%	Poland	88%	Slovakia	75%	Germany	100%	Hungary	25%
Czechia	75%	Hungary	88%	Austria	75%	Czechia	100%	Lithuania	25%
UK	75%	Germany	88%	Czechia	75%	UK	100%	Belgium	25%
France	75%	Italy	83%	France	75%	Norway	75%	Sweden	20%
Serbia	50%	Bulgaria	80%	Belgium	50%	Serbia	75%	Italy	20%
Croatia	50%	Lithuania	80%	Croatia	50%	Austria	75%	Austria	20%
Italy	50%	UK	80%	Hungary	50%	Lithuania	75%	Romania	20%
Romania	50%	Finland	80%	Lithuania	50%	Finland	75%	Germany	20%
Germany	50%	Romania	75%	Romania	50%	Poland	50%	Bulgaria	0%
Finland	50%	France	70%	UK	50%	Italy	50%	Serbia	0%
Belgium	0%	Belgium	68%	Finland	50%	France	50%	Croatia	0%
Sweden	0%	Norway	35%	Germany	0%	Belgium	0%	Poland	0%

Appendix C. Relationship between the performance of national forest damage survey systems across five thematic areas (combined score on the Y-axis), forest cover (%), and the contribution of forestry to Gross Domestic Product in each country (n = 19)



Data availability

Data will be made available on request.

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