# D5.1 Stakeholders' opinion

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## Key take-away messages

- All FORSAID's targeted forest insect and pathogen species were identified as priority pests by at least one respondent, confirming the relevance of focusing on these organisms to address a variety of geographic and environmental contexts.
- The European spruce bark beetle *Ips typographus* and pine wood nematode *Bursaphelenchus xylophilus* were considered the main biotic threats to European forests by most respondents, due to their current or anticipated impact on key tree species in the forest-wood industry.
- These pests affect (or have the potential to affect) forests, biodiversity and society in various ways and to different extents. But all such impacts are important to be considered when designing monitoring and control strategies, depending on the target environment (*e.g.*, urban areas, productive forests, biodiversity hotspots).
- The questionnaire offers an overview of the methods currently in use, highlights areas for improvement, and identifies gaps that have not yet been considered for detection, identification and monitoring methods. FORSAID aims to address some of these deficiencies while also exploring some underestimated topics such as citizen science, AI applications, as well as emerging challenges including ethical issues in AI.
- Remote sensing, ground-based sensors, eDNA and insect smart traps emerged as the most promising tools for enhancing forest pest surveillance. The members of the CoS will closely follow the progress of FORSAID and have expressed willingness to implement field trials.
- Stakeholders prioritized specific environmental settings, *i.e.*, entry points of invasive species, productive forests and tree nurseries, for trials of innovative technologies.
- Citizen science initiatives were perceived ambivalently by stakeholders: while considered promising, they were also seen as lacking sufficient relevance for integration into routine monitoring of the prioritized pest species. WP4 therefore plays a key role in demonstrating the added value of citizen science and providing practical solutions to integrate these initiatives into the range of monitoring tools already in use.
- Major barriers to adoption include technical complexity, limited expertise and knowledge, and high costs. Developing efficient, comprehensive and affordable solutions should therefore be the priority to ensure broad adoption of the newly developed technologies.

## Summary

The FORSAID Work Package 5 utilizes a multi-actor strategy to facilitate transformative change in forest quarantine pest surveillance via digital technologies, engaging stakeholders from various backgrounds to collaboratively produce knowledge, best practices, and novel solutions. A survey targeting European stakeholders was conducted to assess their needs, expectations, and constraints regarding the adoption of digital technologies for monitoring nine regulated forest pests; 18 people from 10 countries answered the questionnaire.

The European spruce bark beetle (*Ips typographus*) and the pine wood nematode *(Bursaphelenchus xylophilus)* were identified as the most impactful species, particularly in relation to bioeconomy and host tree viability and outbreak susceptibility. Other pest species were also noted for their significant and widespread impacts, raising concern for transboundary risks.

Conventional monitoring methods such as visual inspection, molecular diagnostics, and trapping remain widely used. Stakeholders expressed the need for technological advancement through tools like AI-powered smart traps and model-based image analysis. These priorities strongly align with FORSAID objectives, particularly in advancing automated trapping systems, AI-assisted remote sensing, and eDNA analysis for early detection and risk assessment. Standardized laboratory protocols will be developed for lesser-known species to enable broader and more consistent application. In contrast, 3D machine vision and phone-based citizen science tools received mixed responses, with the latter struggling to convince practitioners of its relevance for detecting and monitoring pests in their specific contexts. This reveals a gap in stakeholder engagement and perception which needs to be given particular attention at the next Committee of Stakeholders (CoS) meeting.

Furthermore, the establishment of insect trap networks and the integration of citizen science data from mobile apps are planned as key operational components beyond the project's duration. Stakeholders identified priority environments for monitoring tool deployment, including border inspection points, commercial forests, tree nurseries, and urban forest areas—facilitating the progression of these technologies toward higher readiness levels and broader operational and market uptake.

Barriers to digital tool adoption were primarily technical complexity, limited user knowledge, and cost—particularly for tools such as remote sensing, insect traps, molecular diagnostics, and their associated AI models. These findings highlight the importance of developing more user-friendly, cost-effective, and adaptable tools, along with integrated data platforms and networks, to support efficient, scalable, and economically viable forest pest surveillance.

## List of abbreviations

AI – Artificial Intelligence
CoS – Committee of Stakeholders
EU – European Union
RS – Remote Sensing
WP – Work Package

# 1 Introduction

FORSAID (FORest Surveillance with Artificial Intelligence and Digital technologies) is a project funded by the EU Horizon research and innovation programme to harness innovative technologies to ensure plant health in Europe's forests. As a consequence of globalisation, climate and global changes, EU's Forest health is increasingly threatened by biotic pressures, including both larger-scale, long-lasting pest outbreaks and the introduction of new alien species with high damage potential. The European Union's response to address the issue is mainly legislative. The 2016 Regulation on protective measures against pests of plants, the classification of harmful species covered by EU emergency measures and the structuration of Plant Protection Organization help identify priority pests in the EU and support effective detection and eradication measures. The main objectives of the FORSAID project are to focus on the early stage of forest quarantine pest introduction and improve their detection by developing new technological solutions combined with AI.

To maximise impact and achieve transformative change towards a comprehensive monitoring system using digital technologies, a multi-actor approach has been set up as a backbone of the research project. Although the FORSAID consortium includes some industrial partners in the field of remote sensing and insect trapping and forest pest network managers, the majority of the partners are academic research institutions. Thus, it is crucial to ensure that the research and innovations developed within FORSAID go beyond the academic world and benefit a wide range of practitioners in the EU. The WP5 overall objective and method is therefore to adopt a multi-actor approach, which involves all relevant stakeholders with complementary backgrounds and expertise to co-create and share knowledge on best practices and innovative solutions. The identified stakeholders are gathered in FORSAID's Committee of Stakeholders (CoS) and will be engaged at various stages of the project.

To ensure the project's success, it is important to fully understand the needs and expectations of the forestry and tree health stakeholders, their perception of the panel of digital technologies suitable for forest pest detection, identification and monitoring, and their feedback on the innovations that will be provided by FORSAID.

This deliverable has been developed by IEFC with input from other project partners. IEFC is an organization managing European collaborative networks in the field of planted forests and forest health. This deliverable describes the creation and the composition of the CoS, and the methodology applied to learn more from the stakeholder's opinion on the main focal points of the FORSAID project, *i.e.*, the targeted pest species and the digital technologies. The results will help better understand their concerns regarding the main regulated forest pests, the pros and cons identified for every digital technology considered in FORSAID and their current routine application by the forestry and plant health stakeholders. We can then identify the gaps between the stakeholder's expectations and FORSAID's objectives, consolidate planned actions that can meet their interests and adjust other research actions to better fit their needs.

# 2 FORSAID's Committee of Stakeholders

Setting up the stakeholders' committee was the first activity of the WP5 and the priority of the first months of the project (late 2024-early 2025). The stakeholders were defined as any practitioners who are affected by forest pests and pathogens and are involved in their detection, surveillance and control. They must have an interest in R&D in the field of new digital technologies and be sufficiently fluent in English to be able to easily contribute to the engagement activities.

The invitation to join the FORSAID CoS complied with the following criteria in priority order:

- At least one NPPO from each of the represented EU countries of the FORSAID consortium.
- Organizations that have sent letters of commitment and expressed their interest since the preparation of the proposal.
- Representatives of each of the following sectors at the European scale: tree nursery, forest owner, forest manager, forest industrials, customs officer in charge of good inspection at entry points (port, airport), policy maker, urban tree manager, etc.
- Large distribution of stakeholders across EU member countries.
- Avoid researcher profiles to contrast with the project consortium background and offer broader perspectives.

The recruitment process resulted in a 23-member committee, meeting the above conditions as closely as possible (Fig. 1, Table 1).

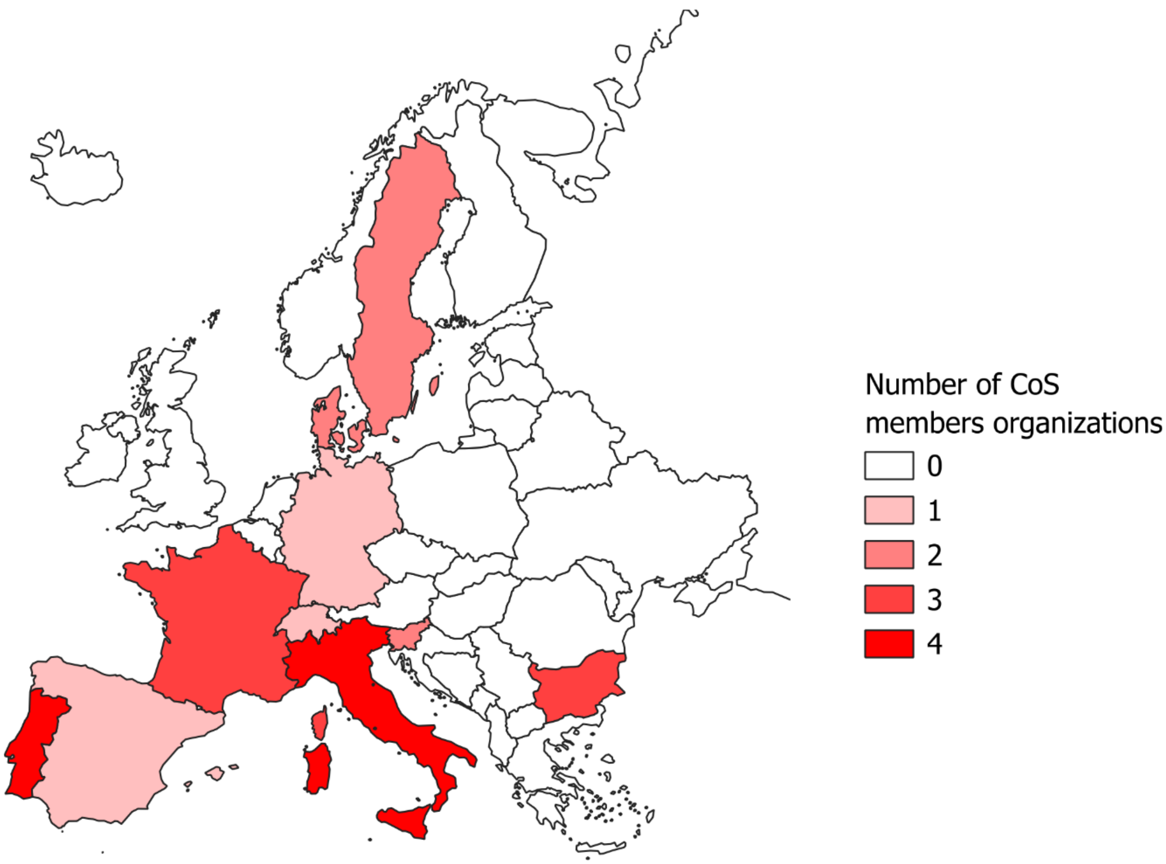


**Figure 1: Geographical distribution of the CoS members.**

**Table 1: Breakdown by country of the activities of the first members of FORSAID's Stakeholder Committee.**

| Country | NPPO | Forest owner | Forest manager | Nursery | Customs officer | Policy maker | Other |
|---|---|---|---|---|---|---|---|
| Bulgaria | X | | | | | X | X |
| Denmark | X | | X | X | | | X |
| France | X | X | | X | | | |
| Germany | X | | | | | | |
| Italy | X | | X | | X | | |
| Portugal | X | | X | X | X | | |
| Slovenia | X | | X | | | | |
| Spain | X | | | | | | |
| Sweden | | X | | X | | | |
| Switzerland | | | X | | | | |
| EU/International | | | | | | X | X |

However, this committee is not set in stone, and may need to evolve depending on the interest of new actors or the needs of the FORSAID project for specific profiles.

# 3 Survey methodologies

As a first engagement activity with the stakeholders, and to facilitate the collection of standardized data, especially qualitative data, we decided to explore our topic by using a questionnaire.

## 3.1 Stakeholder survey design

The survey was implemented via the EUSurvey platform of Europa (Annex A) and officially launched on March 31. By May 5th, 18 responses were received, from 10 European countries and 1 international non-governmental organization. The survey was developed in alignment with FORSAID Research Action 5.1.1, with the objective of assessing stakeholder needs, expectations, and priorities concerning the deployment of advanced digital technologies for the detection, identification, and surveillance of quarantine forest pests. The semi-structured survey includes multi-choices, scaling and open written answers; divided into 2 major parts. The first part captures stakeholders' knowledge and perceptions of high-risk forest pest species currently relevant to the scope of the FORSAID project. The second part further evaluates stakeholders' perspectives on the operational effectiveness and applicability of digital technological tools in monitoring these pests and solicits expert input on strategies to optimize or augment the performance and integration of such technologies in quarantine forest pest management.

To shorten the questionnaire processing time, the respondents were sometimes asked to answer the questions only for their top 3 most threatening species. Thus, some answers are dependent on the selected top 3 most threatening species by the respondents, which is itself highly dependent on participants' geographical origin and professional activity.

The analysis is performed by describing the responses and visualizing them in the form of diagrams and maps. Regarding open written questions, the answers were first assessed and then grouped into shared or strong opinions.

## 3.2 Survey reference and concepts

The selection of target regulated forest pests to be included in the FORSAID project as model species was based on current legislative frameworks, identified research priorities, and the geographic distribution of threats across European forest biomes. The chosen taxa encompass pest categories relevant to both forest and urban trees, including fungi, insects, and nematodes. During the stakeholder survey, these species—along with other potential species of concern identified by stakeholders—were considered targets for the use of digital tools for detection, identification, and monitoring. The list consists of nine species in total (3 fungi, 5 insects, and 1 nematode), hereby referred as pests throughout this report (Table 2):

- *Agrilus anxius*, *Agrilus planipennis*, and *Bursaphelenchus xylophilus* from the list of priority pests in the Commission Implementing Regulation 2019/1702.
- *Agrilus anxius* and *Agrilus planipennis* from the list of part A of Annex II to Commission Implementation Regulation 2019/2072.
- *Bursaphelenchus xylophilus*, *Ceratocystis platani*, and *Fusarium circinatum* from the list of part B of Annex II to Commission Implementing Regulation 2019/2072.
- *Cryphonectria parasitica, Ips typographus, Thaumetopoea pityocampa*, and *Thaumetopoea processionea* from the list of Annex III (Protected Zones) to Commission Implementing Regulation 2019/2072.

**Table 2: 9 target regulated pests included in FORSAID project, and Stakeholder's survey (FORSAID submitted, 2022).**

| Category | Scientific name | Host plant genus | Common name EPPO | EPPO code | Present in EU |
|---|---|---|---|---|---|
| Fungus | *Ceratocystis platani* | *Platanus* | Canker stain of plane | CERAFP | FR, GR, IT |
| Fungus | *Cryphonectria parasitica* | *Castanea* | Chestnut blight | ENDOPA | Protected zone |
| Fungus | *Fusarium circinatum* | *Pinus* | Pitch canker of pine | GIBBCI | PT, SP |
| Insect | *Agrilus anxius* | *Betula* | Bronze birch borer | AGRLAX | Absent |
| Insect | *Agrilus planipennis* | *Fraxinus* | Emerald ash borer | AGRLPL | Absent |
| Insect | *Ips typographus* | *Picea* | Spruce bark beetle | IPSXTY | Protected zone |
| Insect | *Thaumetopoea pityocampa* | *Pinus* | Pine processionary moth | THAUPI | Protected zone |
| Insect | *Thaumetopoea processionea* | *Quercus* | Oak processionary moth | THAUPR | Protected zone |
| Nematode | *Bursaphelenchus xylophilus* | *Pinus* | Pine wood nematode | BURSXY | PT, SP |

The open-ended questions provided relatively exhaustive information on the methods used to detect, identify and monitor the FORSAID targeted species. The respondents only had to provide answers for their top 3 threatening species; therefore, the robustness of the analysis can only be reached for the most mentioned species.

The second part of the survey was dedicated to the potentials and constraints of digital tools for forest pest detection, identification and monitoring. Within the scope and objectives of FORSAID, the terms Detection, Identification and Monitoring were specifically defined as following phases:

- **Detection**: detect the presence of damage or dieback on trees or forest stands, or the presence of the agent.
- **Identification**: identify the cause of the damage and the identity of the pest or pathogen.
- **Monitoring**: monitor the evolution and expansion of pests and pathogens on a regional, national or European scale.

# 4 Results and discussion

## 4.1 Concerns regarding forest pests and pathogens

- **Presence of targeted pests (question 1.1: To your knowledge, are the quarantine or regulated forest pests and pathogens listed below present in your country?)**

The answers to this first question were in line with current knowledge of quarantine species (Fig. 2). The two priority quarantine pests that are absent from EU member states' territory (*Agrilus anxius* and *Agrilus planipennis*) were not mentioned by the respondents. The three priority pests (*Bursaphelenchus xylophilus*, *Fusarium circinatum* and *Ceratocystis platani*) were only mentioned by a limited number of stakeholders. Finally, the protected zone regulated pests (*Cryphonectria parasitica*, *Ips typographus*, *Thaumetopoea pityocampa* and *Thaumetopoea processionea*) were reported to be present in the majority of respondents' countries.

- **Levels of threat of targeted pest (question 1.2: From the list of quarantine species that you are aware of, what are the 3 most threatening to the forests in your country?)**

Beyond the absence or presence of these targeted pests, many other aspects (*i.e.*, host trees, type and severity of damages, existence of control measures) may affect the concerns of forest stakeholders. The respondents were therefore asked to indicate and rank their perceived three most threatening pest species for the forests of their country among FORSAID's list of targeted species. The aggregated answers are displayed in Fig. 2 in descending order of priority. **The comparison of the ranking with the abundance of each species in the CoS countries can help weigh the risk represented by each organism**.

The European spruce bark beetle *Ips typographus*, is widely present in the countries of the CoS members, and is also considered by far as the most threatening pest from our list of targeted species, gathering a third of all votes as first and second most threatening species. Not only its geographical range is very broad, extending from central Europe to the Scandinavian countries, but it causes extensive damage to Norway spruce and other coniferous species of high economic value. The pine wood nematode *Bursaphelencus xylophilus*, while being restricted to Portugal and Spain, is raising high concerns in neighbouring countries with important share of pine trees like France, Italy, Germany and Slovenia. The PWN accounts for another third of all votes for the first most threatening species. At the bottom of the graph, the bronze birch borer and canker stain of plane were less of a priority for CoS members. This could be explained by the relatively low economic interest of the host tree species, the former targeting birch species which lacks a processing industry while the latter affects plane trees that are mainly found in urban areas. In between are organisms of moderate threat to the respondents. This includes the widely distributed oak and pine processionary moths and the chestnut blight. The pitch canker of pine and the emerald ash borer are raising a relatively high share of concern given the limited expansion of these pests.

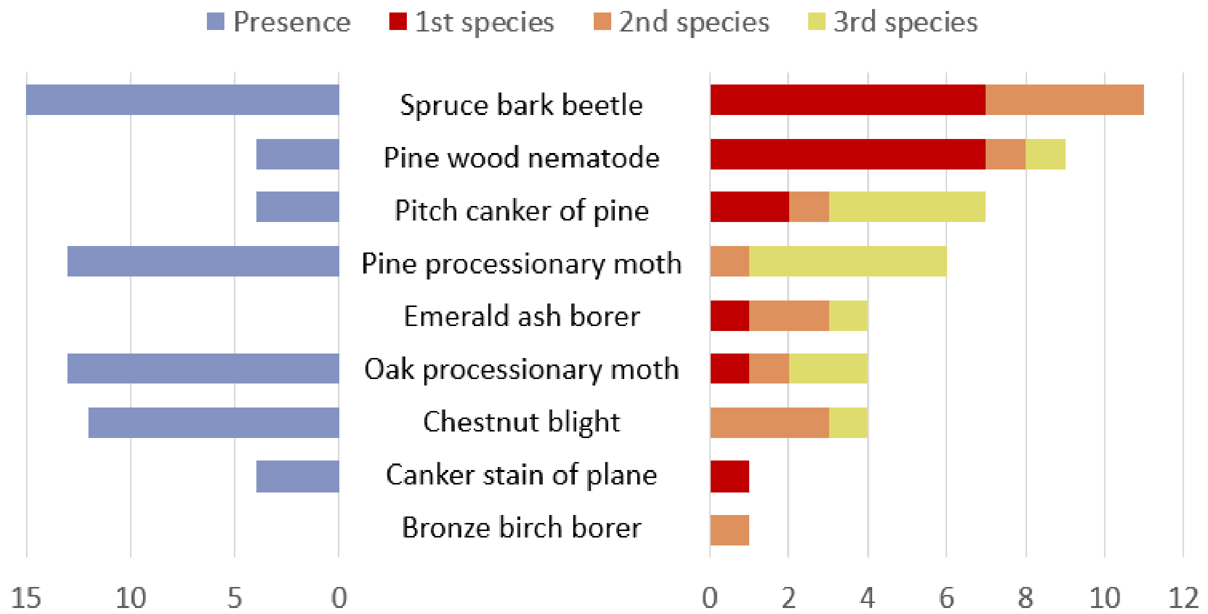


**Figure 2: Number of responses regarding the presence in Europe and the ranking of the top 3 most threatening pests by the respondents.**

The origin of the respondent is of course the main factor explaining the ranking of the pests whose current and future spatial distribution is known. Maps showing the geographical distribution of stakeholder's concerns about each pest are provided in the Appendix (Annex B).

**All FORSAID's targeted species were mentioned as a priority pest by at least one respondent, which confirms the interest in studying these species**. It also ensures that information will be available for each species in the following questions but without the same robustness.

In addition, the respondents were offered the possibility to suggest additional organisms that would deserve special attention. The few responses included:

- *Bretziella fagacearum*, an EU quarantine fungus that is only present in the USA and that causes important dieback on oak tree species.
- *Phytophthora*, an oomycete disease that affects needles, leaves or trunks and roots to hundreds of forests and ornamental tree species for *Phytophthora ramorum* (particularly aggressive against Japanese larch and American oaks) or root rots for *Phytophthora cinnamomi*.

- *Anoplophora glabripennis*, a xylophagous longhorn beetle causing serious damage to many hardwood species including birch, maple, ash, elm, chestnut, poplar and willow.
- Non-European Scolytinae.
- *Xylella fastidiosa*, a priority pest (bacterium) that is already present in some southern EU member countries and causes damage to a large range of plant hosts (especially on olive trees in Italy but also almond trees in Spain).

❖ **Main impacts of the most threatening species (question 1.3: What are the main impacts of these 3 most important quarantine pests and pathogens on the forests in your country?)**

Since targeted FORSAID pest species do not affect the forest and society in the same way, stakeholders were asked to describe the main impact of their top 3 pest species. The results of question 1.3 are shown in Table 3. They help to understand the reasoning behind the ranking of the most threatening species in the previous question. The analysis was carried out individually for each pest species because the absolute values in the table depend on the answers to the previous question: for example, the table summarizes 11 contributions for the European spruce bark beetle against only one for the bronze birch borer and the canker stain of plane.

Overall, the target pests have compound impacts on economy (killing host trees, affecting bioeconomy), on ecosystem stability (increased vulnerability to hazards, biodiversity), and on human health or well-being. The total number of votes per column was very similar, indicating that all of these impacts were relevant for stakeholders. However, some impacts stand out particularly for certain pests. For example, the pine wood nematode was mainly identified as a threat to the survival of host trees but was surprisingly less commonly recognized as a concern for bioeconomy despite the drastic eradication measures or trading restrictions that have to be implemented in an infected area. On the other hand, both processionary moth species were identified as public health problems because of their urticating hairs, but rarely as a threat to the survival of host trees. It is finally reassuring to see that the impact of pests on the vulnerability of trees to biotic and abiotic hazards is well considered by the participants. Trees are under increasing pressure from multiple and combined hazards (*i.e.*, pest attack combined with drought, storm, and fire) and a pest outbreak might indirectly lead to the dieback of some host tree species despite the low aggressiveness of some pests.

**Table 3: Heatmap of the main impacts of the 3 most threatening pests according to the respondents.**

| Pests | Number of respond-ents | It kills host trees | It affects bio-economy | It increases vulnerability to hazards | It affects biodiver-sity | It affects human well-being |
|---|---|---|---|---|---|---|
| *Spruce bark beetle* | 11 | 8 | 10 | 7 | 6 | 3 |
| *Pine wood nematode* | 9 | 9 | 6 | 6 | 5 | 3 |
| *Pitch canker of pine* | 7 | 5 | 5 | 5 | 4 | 4 |
| *Emerald ash borer* | 4 | 4 | 3 | 3 | 3 | 3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| ***Chestnut blight*** | 4 | 4 | 2 | 3 | 3 | 3 |
| ***Pine processionary moth*** | 6 | 0 | 3 | 3 | 4 | 6 |
| ***Oak processionary moth*** | 4 | 1 | 0 | 3 | 2 | 4 |
| ***Canker stain of plane*** | 1 | 1 | 1 | 1 | 1 | 1 |
| ***Bronze birch borer*** | 1 | 0 | 1 | 0 | 1 | 0 |

Understanding the range of impacts of each pest can help design tailored monitoring and control strategies in the most relevant environments, including urban areas, protected areas, and productive forests, and help to anticipate the consequences of outbreaks. Oak or pine processionary moth outbreaks do not require the same control strategy depending on whether they take place in urban vs. forest environments. These results will be used to guide the development of decision-support tools to help stakeholders choose the best detection or monitoring methods for their environment and priorities.

## 4.2 Forest pest detection, identification and monitoring methods

- **Existing methods and their opportunities for improvement (question 2.1: In your opinion, what are the best methods to effectively <u>detect</u>, <u>identify</u> and <u>monitor</u> *your top 3 most threatening pests*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

FORSAID aims to improve the early detection, accurate identification and territory surveillance to prevent and contain the damage caused by quarantine forest pests. Each of these phases requires different methods, technologies and protocols that combine innovation and practitioner & scientific knowledge. The question 2.1 gathered the stakeholder's knowledge about the best methods and their need for improvement for each of the surveillance phases. The analysis focuses on reviewing the diversity of the methods implemented and their maturity level divided into 3 categories:

- **Mature methods**: when a practice has been mentioned as the best method without any mention of improvement opportunities by the respondents.
- **Methods to improve**: when a practice has been mentioned as the best method but with at least one suggestion for improvement.
- **New solutions to be developed**: when a practice has not been mentioned as an effective method but appeared as a suggestion for improvement.

The maturity level is always downgraded to the most critical response to highlight opportunities for improvement.

Similarly to the previous question, respondents were asked to provide answers for their 3 most threatening species, so the species at the bottom of the ranking received few opinions. In addition, as the question was open-ended, respondents were not asked to express their views on all the tools listed in the result table, but only on the one that spontaneously came to mind. However, the analysis of the stakeholder responses gives a good overview of the currently used and best-known methods, the room for improvement identified by the stakeholders but also the gaps that have not yet been considered to improve detection, identification and monitoring (Table 4).

**Table 4: List of existing methods and their readiness level for the detection, identification and monitoring of the target FORSAID forest pests according to the stakeholders.**

| | | *Canker stain of plane* | *Chestnut blight* | *Pitch canker of pine* | *Bronze birch borer* | *Emerald ash borer* | *Spruce bark beetle* | *Pine processionary moth* | *Oak processionary moth* | *Pine wood nematode* |
|---|---|---|---|---|---|---|---|---|---|---|
| **I - Detection** | Drone images | | Mature | | | | To improve | Mature | To improve | New solutions |
| | Visual observation by experts | Mature | Mature | To improve | Mature | To improve | Mature | Mature | To improve | To improve |
| | Traps (pheromone, spore, …) | | | Mature | | Mature | New solutions | To improve | | To improve |
| | Citizen science apps | | | | | | Mature | | Mature | To improve |
| | AI | | | | | | | | To improve | New solutions |
| **II – Identification** | Visual observation by experts | | Mature | To improve | Mature | To improve | Mature | Mature | Mature | |
| | PCR test in the field | | | To improve | | | | | | To improve |
| | Sample analysis in the lab | Mature | Mature | To improve | Mature | To improve | To improve | | Mature | To improve |
| **III - Monitoring** | Satellite images | | Mature | | | To improve | To improve | Mature | | To improve |
| | Drone images | | Mature | | | To improve | To improve | Mature | | To improve |
| | GIS systems | Mature | | Mature | | | Mature | | New solutions | |
| | DST (risk map; predictive modelling) | | New solutions | To improve | | To improve | To improve | | New solutions | To improve |
| | Traps, Environmental genetics | | New solutions | | To improve | Mature | To improve | Mature | New solutions | Mature |
| | Ground survey | | | To improve | | Mature | Mature | Mature | To improve | To improve |
| | Citizen science apps | | | | | | | Mature | To improve | |
| | Networking collaboration | New solutions | Mature | | | | | Mature | New solutions | |

**Legend**
- Mature method
- Methods to improve
- New solutions to be developed

- Visual observation on trees is by far the most commonly used approach for the detection of symptoms (holes in the bark, shape of the gallery, tree crown discolouration, stressed or dead trees…) and the identification of the agent causing damage. However, it is still highly time-consuming and requires a high degree of expertise and many human resources in the field to be able to be responsive to any new pest introduction. This approach can be supported by the development of training modules to maintain and update taxonomic expertise, and the development of operational, reliable AI applications to compensate for the lack of taxonomic services observed in some countries. However, these two solutions are potentially contradictory, as the use of AI could ultimately undermine the conservation of human expertise. This dilemma will be addressed in the study on AI and ethics in WP4.
- Traps, whether they intercept insects with pheromones, UV lights and other lures or pathogens through spores and other environmental DNA, traps are essential tools in the detection phase, in longer term monitoring design, but also indirectly in the identification phase by providing samples. The latter could be greatly improved by the use of smart traps combining AI for the automatic identification and notification of catch data. Chemical lures can always be improved for better efficiency of the trapping.
- Molecular methods based on DNA are applied for the identification of organisms using genetic materials performed whether in a laboratory or directly in the field. They rely on DNA amplification techniques like PCR and LAMP. Room for improvement stands in the simplification of the protocols, the rapidity of the process and the adaptation of the tool for use in the field. It also needs to be broadened to a larger range of symptomatic and asymptomatic tree species.
- Satellite, LiDAR and drone images can be used in a large range of contexts from large to proximal scale remote sensing. The training of AI can improve the performance of remote sensing image analysis and its ability to discriminate the cause of the trees' dieback. Advances are possible to improve detection in complicated forest contexts such as mixed, irregular stands.
- Decision Support Tools (DST) encompass a large range of more or less sophisticated solutions to facilitate the work of practitioners. The tool most often cited by the stakeholders is mechanistic model to predict the dynamics of pest populations. The suggested improvement includes the development of better local climate models to forecast the emergence of insect pests, a better map of host trees and a better understanding of pest behaviour in order to model the most likely risk of occurrence. This can also be supported by studies to better identify epidemiological factors involved in pest and pathogen distribution and spread.
- Citizen science driven by the voluntary use of crowd source platforms or smartphone applications on insects and other organisms can provide a great amount of data and general surveillance, supporting the work of plant health experts. Stakeholders suggest the use of information campaigns to improve the detection skills of end-users and direct their attention to a limited number of priority species during targeted campaigns. Questions remain about the type of profiles to be approached, between users close to the forest environment and involved in forest health (*i.e.*, forest owners and managers) or the more general public with a naturalistic interest and a desire to contribute to a better understanding and protection of local forests.
- GIS systems can help collect, store and process pest presence data from all possible sources (ground surveys, smart traps, citizen science, private or public databases). These platforms need strong networking and national and cross-border collaborations, and could

in turn support the creation or adjustment of DST. The more geolocated and dated data we collect, the better we will understand the phenology of regulated pests and the more we will be able to improve predictive models and monitoring strategies.

Each of the 3 surveillance phases is interconnected and influences each other, which makes it tricky to classify the digital technologies and their maturity level. DST used to monitor or predict the occurrence of a pest can in turn lead to the design of detection protocol and ground survey. The detection of a pest or the capture of biological material (spores, insects or plant tissues) is also the first step of any identification process. Improving one of these phases can directly or indirectly improve the other.

New areas of innovation and technical development were mentioned for a few additional forest pests. In particular, stakeholders mention the need to improve the process of identifying *Fusarium circinatum* on seeds (including asymptomatic seeds) or on insect vectors. They also suggested developing traps for *Thaumetopoea pityocampa* females, and not only the males who are already captured using sexual pheromones. Such innovations are not planned in FORSAID.

- **Alignment of the planned FORSAID innovations with stakeholder's expectations**

In general, there are shortcomings in pest detection, identification and monitoring methods, which are acknowledged by both stakeholders and researchers. The main stakeholders' expectations are to improve the early detection of quarantine species by using more versatile traps, learning equipment for visual inspection, and aerial remote sensing to detect and delineate physiological changes in the forest. For monitoring methods, AI models should be more generic and applicable to mixed forests and under climate change scenarios.
FORSAID will not be able to meet all the gaps and explore every suggested idea. However, the planned activities fit quite nicely with some of the needs that were expressed for each of the targeted pests (Table 5).

Nevertheless, some species are better documented than others, which allows for the development of more advanced detection methods. For example, extensive research on bark beetle infestations and pine wood nematode detection using remote sensing has contributed to improving large-scale detection accuracy and timeliness (Kautz et al., 2024). These efforts are often complemented by a wide range of laboratory-based tests combined with visual inspection (Tahir et al., 2024). In such cases, the integration of artificial intelligence offers promising opportunities to automate inspections while making the tools more accessible and versatile. However, for newly identified or less-studied quarantine species, there is still a need to develop comprehensive protocols and adopt or innovate new methods to gather relevant information, which can then support more targeted surveillance efforts.

**Table 5: Summary table of stakeholders' perspectives on tool enhancement, aligned with FORSAID's provisional research actions for nine targeted species.**

| | **Stakeholder expectations** | **FORSAID objectives** | |
|---|---|---|---|
| **Spruce bark beetle** | Qualified observation networks for adequate calibration and validation data | Improvement of automatic identification of bark beetles<br><br>Development of robotized sorting and image analysis to | **<u>For all species:</u>**<br><br>A network of traps established in |

| | | | |
|---|---|---|---|
| | Improvement of insect trapping for the detection and monitoring phases<br><br>Better remote sensing early detection and monitoring on larger surfaces<br><br>New models to process catch data, epidemiological factors and improved local climate models | sort insect specimens from bulk samples obtained from generic traps<br><br>Risk map accounting future climate scenarios and forest management practices at the European scale from satellite images | more than 35 entry/export points to identify native/ exotic beetles<br><br>Developing AI model and efficacy test on Entomoscope |
| **Pine wood nematode** | Assist visual inspection with AI, intelligent traps (aimed at vectors) or less expensive, quicker molecular techniques<br><br>Generative AI models for remote sensing analysis to distinguish the role of the PWN in declining trees<br><br>Studies on identification of epidemiological factors<br><br>Improve the asymptomatic area monitoring (sample strategy) | Enhancing eDNA test and analysis by collecting real-time liquid samples to access the presence of agent<br><br>Developing generative AI models using aerial and satellite remote sensing to improve detection and define potential entry points<br><br>RS models concentrated on NIR spectra to detect infected trees | Evaluating and verifying the accuracy and maximizing the utility of Citizen Science data to integrate and improve pest surveillance |
| **Pitch canker of pine** | More reliable, rapid and easy field diagnostics for detection, identification and monitoring<br><br>Ground survey methods integrated with models for monitoring | Advanced image analysis software to monitor the pathogens' symptoms or identify tree stress markers | |
| **Emerald ash borer** | Skills in visual inspection to differentiate from other similar stressors<br><br>Knowledge and facilities demanding<br><br>Generative models for monitoring | Adoption of Entomoscope for automatic and faster identification of 12 Agrilus species using AI<br><br>A protocol for the agent's detection in greenhouses using quantitative, droplet digital PCR and metabarcoding techniques | |
| **Chestnut blight** | Improve risk modelling<br><br>Explore the use of environmental genetics | Developing protocols for the agent's detection and its parasitic mycovirus | |

| | | | |
|---|---|---|---|
| | | RS models concentrated on NIR spectra to detect infected trees | |
| **Pine processionary moth** | Traps capable of capturing both sexes<br><br>RS methods in monitoring | Development and optimization of automatic traps based on image recognition in Trapview, to be tested in forest and urban settings<br><br>Developing AI models using satellite images to assess the level of defoliation, and change detection techniques for long-term monitoring | |
| **Oak processionary moth** | High-resolution remote sensing models for detection in mixed stands<br><br>Improve maps of pest distribution (collecting reports) | Development and optimization of automatic traps based on image recognition in Trapview, to be tested in forest and urban settings | |
| **Canker stain of plane** | Early detection and network collaboration | Enhancing eDNA test and analysis by collecting real-time liquid samples to detect the presence of agent<br><br>Aerial images and AI models for early detection of disease | |
| **Bronze birch borer** | More effective trapping methods | Adoption of Entomoscope for automatic and faster identification of 12 Agrilus species using AI | |

- ❖ **Alignment of provisional Technology readiness level (TRL) of digital tools developed by FORSAID with the stakeholder's expectations**

The provisional outputs of FORSAID are aimed at advancing selected technologies along the Technology Readiness Level (TRL) scale, as defined by Article 19-Commission Decision C(2014)4995. These efforts are intended to support the transition of research-based tools toward practical application and potential market deployment. According to the current planning shown in Table 6, detection tools are expected to reach TRL 5–6, with validation and demonstration in relevant environments beyond laboratory conditions. Identification tools are projected to advance to TRL 6–7, meaning they will move from successful validation in relevant environments to demonstration of system prototypes in operational settings. Monitoring tools are similarly anticipated to achieve TRL 5–6, with field validation and early operational demonstration.

These projections align with the stakeholder needs identified in Table 5, which highlight key areas for improvement, including the enhancement of remote sensing technologies for both detection and monitoring, refinement of insect trap systems, development of robust eDNA protocols for automated detection, and deployment of coordinated trap networks. The project also includes focused studies on near-infrared spectroscopy, aiming to exploit correlations between spectral signatures and the physiological state of tree foliage, as these spectra are strongly associated with chlorophyll changes and water content, which is a significant indicator to the disease development (Cotrozzi, 2022).

In addition, significant emphasis will be placed on the integration of citizen science with artificial intelligence for pest detection. This component is expected to result in the development of comprehensive guidelines that maximize the contribution of citizen scientists to forest pest surveillance.

However, several traditional methods—such as expert-based visual assessments, GIS-based mapping tools, and ground surveys—are not currently targeted for technological advancement within the scope of FORSAID. Nevertheless, these approaches remain essential to integrated monitoring systems and may benefit from future innovation or complementary research initiatives.

**Table 6: Provisional Technology Readiness Level (TRL) of advanced technological innovations developed by FORSAID project (FORSAID submitted version, 2022).**

| Technology/Innovation | Maturity | TRL at start | TRL at the end |
|---|---|---|---|
| AI-based approach to citizen science for pest detection | Idea to application | 1 | 5 |
| Tailor-made citizen science project guideline approaches | Idea to application | 1 | 5 |
| IoT applied to insect trap networks | Idea to application | 2 | 6 |
| AI-based analysis methods of aerial and satellite images | Idea to application | 3 | 5 |
| Near-infrared detection development | Lab to application | 4 | 6 |
| Protocols for eDNA automatic detection | Lab to application | 4 | 6 |
| Robot sorting and image identification of large insect samples | Lab to application | 4 | 6 |
| Automatic image identification of insects | Lab to market | 4 | 7 |
| Trap network for remote transmission of capture data | Lab to market | 4 | 7 |

- **Prioritized environmental settings for the development of novel digital technologies (question 2.2: In which environmental setting would the advancement of novel digital technologies for the identification and monitoring of forest pests and pathogens be most beneficial?)**

The CoS unanimously agrees to position the detection at territory entry points for commodities, like ports or airports, as the most important environmental setting for the improvement of pest detection tools (Fig. 3). Goods entry points are strategic sites for the detection of new species on arrival, due to the large flows of goods and people, carrying possible quarantine organisms from exotic countries. Capturing these organisms before they establish and reproduce in neighbouring natural environments is clearly the most effective strategy.

The second most important environmental settings are the production forests, which can be explained by their significant economic importance and the frequent presence of forest professionals who can easily deploy detection and monitoring technologies on the field. Urban trees and nurseries were both considered relatively important areas for the deployment of new detection methods. They both host a large diversity of tree species, either native or exotic, that can act as sentinel trees for the early detection of new pests. At last, protected forest areas (natural parks, conservation areas, etc.), wood processing sites (sawmill, pulp industry, etc.) and trees in agricultural contexts (agroforestry) received moderate interest.

FORSAID will concentrate its efforts on developing new digital technologies in entry points, production forests, tree nurseries and urban settings which are the first four key environmental settings identified as priorities by stakeholders. Stakeholders can provide valuable insights, enabling FORSAID to conduct targeted trials and refine these technologies within the prioritized settings.

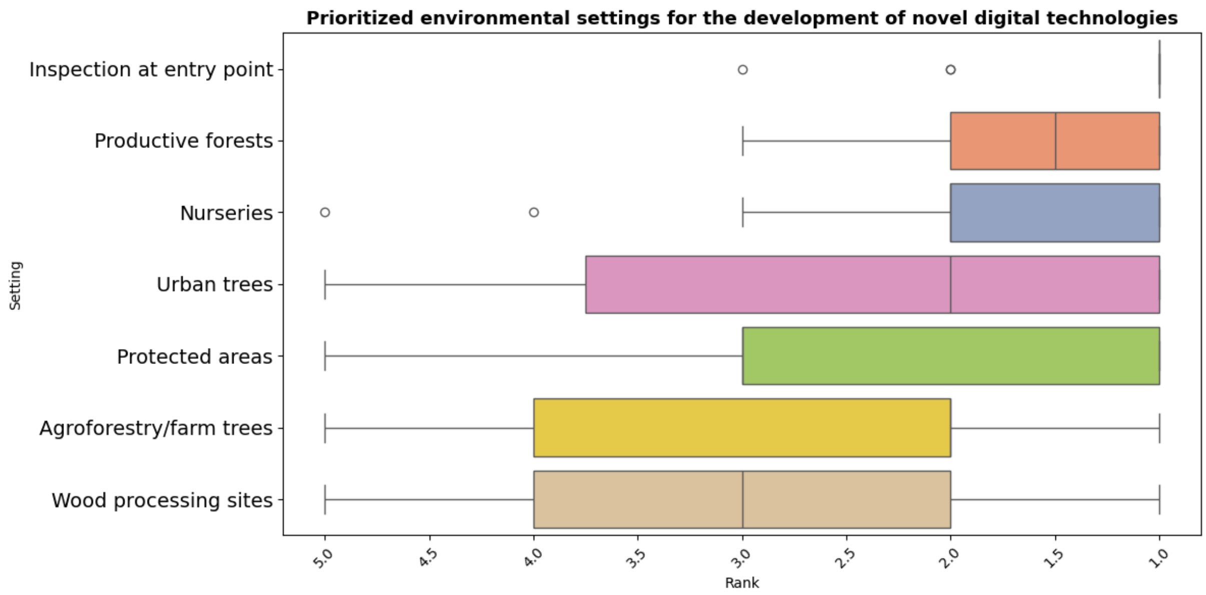


**Figure 3: Prioritized environmental settings for the development of novel digital technologies, scoring from the least important (5.0) to the most important (1.0).**

- **Most promising tools for improving the detection, identification and monitoring of forest pest**

The tools included in the questionnaire present potential applications in forest pest detection, identification, and monitoring across various case studies and spatial scales. While some tools—specifically remote sensing, eDNA techniques, and insect traps—are perceived as particularly critical, others are also very promising from the stakeholders' point of view (Fig. 4). However, a few stakeholders highlighted that satellites and insect traps might not be very effective. 3D machine vision systems elicited a wide range of opinions regarding their perceived importance, possibly due to their narrowed application in tree nurseries rather than at a larger scale and in a heterogeneous environment.

Each tool is designed to fulfil specific tasks, and their suitability depends on the defined objectives of the monitoring program. Since nearly all tools were rated important to various degrees, these findings suggest that the FORSAID project should integrate available tools into a comprehensive and adaptive pest surveillance system. This would require targeted efforts to deploy existing resources, enhance cost-efficiency, and develop robust, generic monitoring models (Poland & Rassati, 2019).

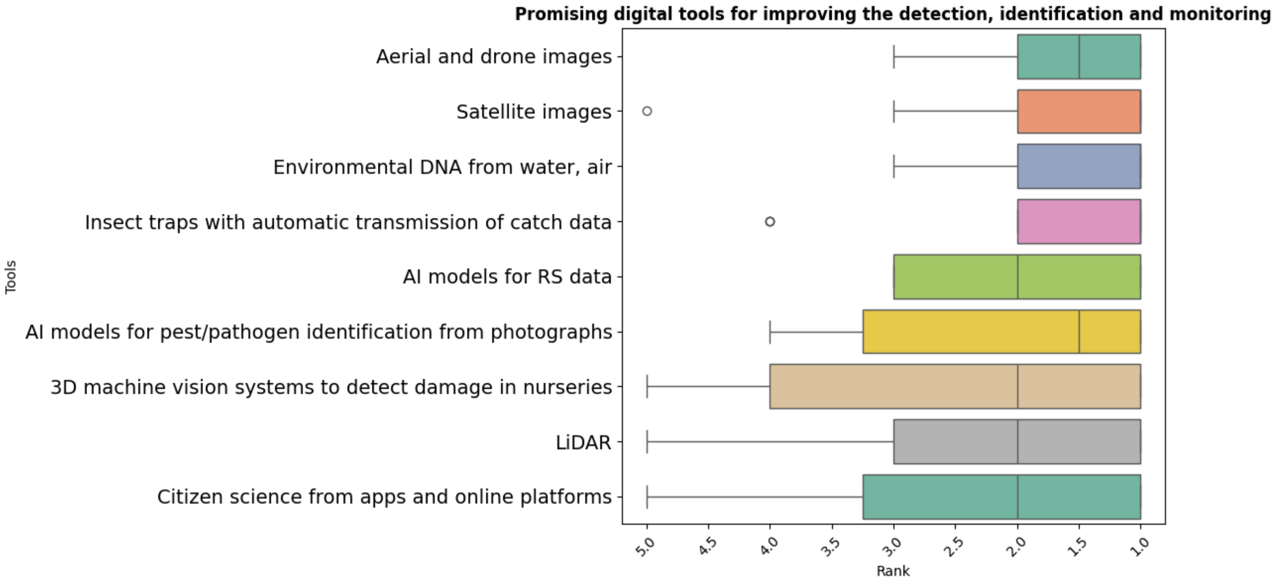


**Figure 4: Promising digital tools for the improvement of forest pest detection, identification and monitoring, scoring from the least important (5.0) to the most important (1.0).**

- **Hindering factors to the use of digital tools**

The adoption of digital technologies in quarantine forest pest monitoring faces multiple technical and operational challenges that limit their accessibility and usability for a broad range of stakeholders. Identifying these hindering factors for each digital tool studied in FORSAID will guide our research work and make it easier to come up with appropriate responses for the more widespread use of digital tools. Based on the answers (Table 7), the application of remote sensing techniques (satellite, plane and drone image) is subject to multiple constraints. From a technological and knowledge-based perspective, limitations often arise from the complex relationship between spectral sensitivity and physiological changes in forest and vegetation covers, as well as the computational complexity of big data analysis involving deep learning and artificial intelligence integrated with environmental and geospatial parameters (Preti et al., 2021). To facilitate the effective use of these tools, comprehensive technical documentation, training resources, and user-friendly guidelines are essential to clarify their functionality and support informed decision-making for real-world applications.

Similarly, the use of aerial imagery, particularly via unmanned aerial vehicles (UAVs), is subject to additional regulatory barriers, as drone operations require specific licenses or permits in several countries or sites like urban areas.

Among the evaluated technologies, eDNA analysis was reported as one of the least accessible, both technically and financially. This may be attributed to the high demand for specialized expertise, including trained entomologists, as well as the time- and labour-intensive nature of sample collection and processing (Chua et al., 2023).

Following technical limitations, a lack of knowledge emerges as the second most hindering factor in accessing digital tools. Stakeholders often express uncertainty about how to access them, under what conditions they can be used, and how they integrate into operational monitoring protocols. Additionally, the rapid pace of technological development can make it difficult for users to stay informed about the latest tools and their capabilities. Addressing this barrier will require user-friendly design but also continuous investment in capacity-building initiatives such as workshops, tutorials, field demonstrations adapted to the environment and needs of the forest health practitioners.

Financial constraints represent a significant barrier to the implementation of high-tech monitoring solutions, such as aerial drones, laser scanning systems, automated detection equipment, and DNA testing machines. In fact, the associated costs extend beyond hardware acquisition and include a wide array of operational expenses—such as field deployment, image acquisition and processing, data analysis, maintenance of supplementary equipment, and access to licensed software—further limiting the scalability and adoption of state-of-the-art remote sensing technologies (Abdullah et al., 2023).

Notably, citizen science using smartphone applications appears to be perceived as less relevant for supporting stakeholders in pest detection and monitoring efforts compared to all other tools. This raises an important question that warrants further discussion in upcoming stakeholder meetings to better understand the underlying causes. Previous responses in the questionnaire indicated that citizen science initiatives are considered promising solutions for improving the detection, identification and monitoring of forest pests. However, it is rarely cited as a method integrated into routine control protocols. The perceived lack of relevance suggests that current applications may not adequately address the challenges faced by stakeholders. Tree health experts may still need to understand how to easily and rapidly retrieve participatory science data, which users to engage with, how to guide user reports toward priority pests, or how to conduct effective awareness campaigns. Citizen scientists can also collaborate with professionals by reporting suspicious damaged trees, which can also compensate for the lack of effectiveness of citizen science and IA in detecting fungi or nematodes. In addition, the financial barrier to deploying citizen science is possibly underestimated by stakeholders. Citizen science initiatives do not stop at the development and maintenance of mobile phone applications but require raising continuous awareness to stimulate participation. Given that citizen science plays a prominent role in the project and is intended to be integrated with other digital technologies to improve the versatility of the tools, this gap highlights the need for further study and strategic alignment.

**Table 7: Heatmap of the main hindering factors for the use of digital tools applied to pests' detection and monitoring.**

| | Technical | Lack of knowledge | Financial | Relevance | Legal | Ethical |
|---|---|---|---|---|---|---|
| Satellite images | 13 | 7 | 6 | 4 | 0 | 0 |
| Aerial and drone images | 9 | 5 | 8 | 3 | 9 | 3 |
| LiDAR | 11 | 6 | 8 | 2 | 0 | 0 |
| AI models for remote sensing data | 10 | 9 | 4 | 0 | 3 | 2 |
| 3D machine vision systems to detect damage in nurseries | 7 | 7 | 8 | 2 | 0 | 0 |
| Insect traps with automatic transmission of catch data | 7 | 3 | 6 | 2 | 0 | 0 |
| AI-integrated models for identification of pests from photographs | 9 | 6 | 5 | 4 | 2 | 1 |
| Environmental DNA from water, air, etc. | 11 | 8 | 8 | 0 | 0 | 0 |
| Citizen science | 5 | 5 | 1 | 10 | 2 | 1 |

# 5 Conclusion

This first consultation with the CoS provided the opportunity to present FORSAID's core topics, in particular the list of targeted quarantine forest pest species and the range of digital technologies that will be developed. Interactions with the CoS aim to foster long-term collaboration in co-defining research activities, monitoring progress, and ensuring the effective upscaling of the project outputs. An initial questionnaire was conducted to better understand stakeholder's knowledge and concerns regarding the target forest pests, as well as their view on existing detection and monitoring tools. Some messages are highly relevant to the rest of the project.

All nine target pest species in FORSAID were cited at least once by the stakeholders as a priority pest for the forest of their country, which shows that the scope of the project is relevant to a great variety of practitioner profiles (nursery, urban tree management, forest owner and manager, customs officer, etc.) and of geographical contexts in the EU. Bark beetles are perceived as the main biotic threat by most respondents from central and northern Europe. Other pests, such as quarantine species like the emerald ash borer or contained pests like the pine wood nematode or the pitch canker of pine, also raise significant concern, despite their limited current spread. These pests affect, or have the potential to affect forests, biodiversity and society in various ways and to different extents. All these impacts must be carefully considered when designing monitoring and control strategies, which should be tailored to the specific environmental context whether urban areas, production forests, biodiversity hotspots, etc.

The survey results provide an overview of the digital methods currently used by practitioners, highlighting areas for improvement and identifying the gaps that have not yet been addressed for improving detection, identification and monitoring practices. FORSAID aims to tackle a large part of these deficiencies, matching the stakeholders' needs, especially in the field of remote sensing and molecular tools for pest identification either in the field or in the lab. FORSAID will also explore some underestimated yet promising areas such as citizen science, AI, ground sensors as well as potential emerging challenges related to the use of digital technologies, including ethical issues related to the use of AI. Responses to the questionnaire, along with discussions from the follow-up online restitution workshop, helped identify stakeholders' individual preferences for specific topics. As a result, stakeholders' expected engagement in monitoring the progress of WP2, 3 and 4 can thus be aligned with each CoS member's personal or professional interests, allowing for a more efficient and targeted contribution from all participants.

Stakeholders' expectations regarding the prioritization of environmental settings for the development of new digital technologies are well aligned with FORSAID's objectives. Indeed, FORSAID will dedicate the majority of its trials and case studies to contexts such as commodities entry points (ports, airports), productive forests, tree nurseries and urban forests. These sites are indeed highly strategic – either because they often are the initial entry points for invasive pests and their early detection can prevent their spreading in natural environments, because cities host a high diversity of tree species that can act as sentinel trees for exotic pests, or because they hold significant economic importance for the forestry sector.

The lack of knowledge remains a key barrier to the adoption of new digital methods. Furthermore, the implementation of these methods is often constrained by the cost of devices, the labour required for operation, and ultimately, the availability of funding within the tree health protection sector. Developing efficient, comprehensive and affordable solutions should be the priority to ensure the broad adoption of newly developed technologies.

Although citizen science is widely regarded as a promising tool for pest monitoring and identification by stakeholders and researchers, it is not yet seen as sufficiently relevant by stakeholders to be adopted into routine monitoring protocols. WP4 therefore holds a special position within the FORSAID project, having to demonstrate the benefits of citizen science for stakeholders and providing new practical solutions for integrating these initiatives into the range of monitoring tools already in use. Nevertheless, with appropriate studies, the establishment of demonstration projects, and tailored support and communication to help stakeholders become familiar with these tools, WP4 has the potential to make a significant impact by bridging this critical gap.

Overall, this questionnaire helped confirm the strategic relevance of FORSAID in both the target quarantine forest pest species and the technologies to be developed. Stakeholders have expressed an interest in transparent communication regarding the level of readiness of these tools, and some are motivated to contribute to the implementation of field trials. Maintaining the momentum of the CoS will require ongoing activities and a progressive rollout of tool trials.

# 6 Acknowledgements

We would like to sincerely thank all the partners who contributed to the design and review of the questionnaire. Our gratitude also goes to the stakeholders who agreed to join the Committee of Stakeholders, took the time to respond to the questionnaire, and enriched their responses during the first online workshop. Their commitment and motivation confirm the importance of WP5 activities. Finally, we acknowledge the partners who were actively involved in finalizing this deliverable.

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# 8 Annex

## 8.1 Annex A: The questionnaire "Stakeholder perspectives on digital tools for detecting, identifying, and monitoring forest pests and pathogens"

Online survey link: https://ec.europa.eu/eusurvey/runner/53e3a93f-3099-ad4a-8348-0e00dd67dacc

# Stakeholder perspectives on digital tools for detecting, identifying, and monitoring forest pests and pathogens.

Fields marked with * are mandatory.

## Survey context and project information

Dear Mr. and Mrs.,

You have agreed to join the Committee of Stakeholders of the FORSAID research project, for which we sincerely thank you. The FORSAID project aims to develop digital technologies for the early detection of forest pests, monitoring their occurrence, and providing data to effectively manage their spread. We are counting on your expertise and knowledge of the monitoring and management of forest pests and pathogens to assess the value and relevance of the new tools and methods that we will be proposing.

Within this questionnaire, we want to understand the biotic threats that concern you as well as the detection, identification, and monitoring tools you usually apply. We would also like to know barriers and attitudes in adoption of advanced digital technologies, in order to better direct our research activities.

***These questions are contextual and depend on your field of activity and research. Please answer the questions by referring to your field of activity.***
This questionnaire should take no more than 20-30 minutes to complete.

By participating in this survey, you agree that your data will be processed in compliance with the General Data Protection Regulation (GDPR). If you have any questions regarding the survey, please contact Benoit de Guerry (b.deguerry@iefc.net) or Tam Do (t.do@iefc.net)

FORSAID is a EU funded project within the Horizon EU programme 2024-2028. It focuses on the application of digital technologies for the detection, identification and monitoring of quarantine pests affecting European forests. To find out more about the project, visit its official website or keep up-to-date by subscribing to our newsletter.

## Part 1: General knowledge of quarantine and regulated forest pests and pathogens

* **Question 1.1: To your knowledge, are the quarantine or regulated forest pests and pathogens listed below present in your country? If none of these species are present, and if there are other species that you are thinking about, please tick "Others" and specify**
Below is the list of quarantine forest pests on which FORSAID is focusing on. It provides Latin name - Main tree genera being attacked - Common name, respectively.

- ☐ *Ceratocystis platani* – Platanus – Canker stain of plane
- ☐ *Cryphonectria parasitica* – Castanea – Chestnut blight
- ☐ *Fusarium circinatum* – Pinus – Pitch canker of pine
- ☐ *Agrilus anxius* – Betula – Bronze birch borer
- ☐ *Agrilus planipennis* – Fraxinus – Emerald ash borer
- ☐ *Ips typographus* – Picea – Spruce bark beetle
- ☐ *Thaumetopoea pityocampa* – Pinus – Pine processionary moth
- ☐ *Thaumetopoea processionea* – Quercus – Oak processionary moth
- ☐ *Bursaphelenchus xylophilus* – Pinus – Pine wood nematode
- ☐ Others (please specify)

* **Question 1.2: From the list of quarantine species that you are aware of, what are the 3 most threatening to the forests in your country?**

*at most 3 answered row(s)*

| | 1st species | 2nd species | 3rd species |
|---|---|---|---|
| *Agrilus anxius* – Betula – Bronze birch borer | ○ | ○ | ○ |
| *Agrilus planipennis* – Fraxinus – Emerald ash borer | ○ | ○ | ○ |
| *Bursaphelenchus xylophilus* – Pinus – Pine wood nematode | ○ | ○ | ○ |
| *Ceratocystis platani* – Platanus – Canker stain of plane | ○ | ○ | ○ |
| *Cryphonectria parasitica* – Castanea – Chestnut blight | ○ | ○ | ○ |

| | | | |
|---|---|---|---|
| *Fusarium circinatum* – Pinus – Pitch canker of pine | ○ | ○ | ○ |
| *Ips typographus* – Picea – Spruce bark beetle | ○ | ○ | ○ |
| *Thaumetopoea pityocampa* – Pinus – Pine processionary moth | ○ | ○ | ○ |
| *Thaumetopoea processionea* – Quercus – Oak processionary moth | ○ | ○ | ○ |
| Others (please specify) | ○ | ○ | ○ |

* **Question 1.3: What are the main impacts of these 3 most important quarantine pests and pathogens on the forests in your country?** (Consider species 1, 2, and 3 according to your selection in question 1.2)

| | 1st species | 2nd species | 3rd species |
|---|---|---|---|
| It kills host trees | ☐ | ☐ | ☐ |
| It affects bioeconomy (timbers, non-wood forest products, ...) | ☐ | ☐ | ☐ |
| It affects biodiversity | ☐ | ☐ | ☐ |
| It affects human well-being (human health, urban landscapes) | ☐ | ☐ | ☐ |
| It increases vulnerability to other biotic and abiotic hazards | ☐ | ☐ | ☐ |
| Others (please specify) | ☐ | ☐ | ☐ |

# Part 2: Forest pest and pathogen detection, identification and monitoring

We distinguish 3 phases in the surveillance activities of pest and pathogen populations: detection, identification and monitoring.
**Detection**: detect the presence of damage or dieback on trees or forest stands, or the presence of the agent.

**Identification**: identify the cause of the damage and the identity of the pest or pathogen. **Monitoring**: monitor the evolution and expansion of pests and pathogens on a regional, national or European scale.

**In the following questions, please give your opinion on the best methods and their areas for improvement for the detection, identification and monitoring of the three pest species selected in question 1.2.**

*** Question 2.1.1: In your opinion, what are the best methods to effectively detect, identify and monitor *Ceratocystis platani*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

| | Best methods | Needs for improvement |
|---|---|---|
| To detect | | |
| To identify | | |
| To monitor | | |

*** Question 2.1.2: In your opinion, what are the best methods to effectively detect, identify and monitor *Cryphonectria parasitica*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

| | Best methods | Needs for improvement |
|---|---|---|
| To detect | | |
| To identify | | |
| To monitor | | |

*** Question 2.1.3: In your opinion, what are the best methods to effectively detect, identify and monitor *Fusarium circinatum*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

| | Best methods | Needs for improvement |
|---|---|---|
| To detect | | |
| To identify | | |
| To monitor | | |

*** Question 2.1.4: In your opinion, what are the best methods to effectively detect, identify and monitor *Agrilus anxius*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

| | Best methods | Needs for improvement |
|---|---|---|
| To detect | | |
| To identify | | |
| To monitor | | |

*** Question 2.1.5: In your opinion, what are the best methods to effectively <u>detect</u>, <u>identify</u> and <u>monitor</u> *Agrilus planipennis*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

| | Best methods | Needs for improvement |
|---|---|---|
| To detect | | |
| To identify | | |
| To monitor | | |

*** Question 2.1.6: In your opinion, what are the best methods to effectively <u>detect</u>, <u>identify</u> and <u>monitor</u> *Ips typographus*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

| | Best methods | Needs for improvement |
|---|---|---|
| To detect | | |
| To identify | | |
| To monitor | | |

*** Question 2.1.7: In your opinion, what are the best methods to effectively <u>detect</u>, <u>identify</u> and <u>monitor</u> *Thaumetopoea pityocampa*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

| | Best methods | Needs for improvement |
|---|---|---|
| To detect | | |
| To identify | | |
| To monitor | | |

*** Question 2.1.8: In your opinion, what are the best methods to effectively <u>detect</u>, <u>identify</u> and <u>monitor</u> *Thaumetopoea processionea*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

| | Best methods | Needs for improvement |
|---|---|---|
| To detect | | |
| To identify | | |
| To monitor | | |

* **Question 2.1.9: In your opinion, what are the best methods to effectively detect, identify and monitor *Bursaphelenchus xylophilus*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

| | Best methods | Needs for improvement |
|---|---|---|
| To detect | | |
| To identify | | |
| To monitor | | |

* **Question 2.1.10: In your opinion, what are the best methods to effectively detect, identify and monitor *the other species you mentioned*? What improvements are needed to enhance these methods and mitigate the pathogen impact?**

| | Best methods | Needs for improvement |
|---|---|---|
| To detect | | |
| To identify | | |
| To monitor | | |

* **Question 2.2: In which environmental setting would the advancement of novel digital technologies for the identification and monitoring of forest pests and pathogens be most beneficial?** Rank the options from 1 (most important) to 5 (least important).

| | 1 | 2 | 3 | 4 | 5 | I don't know |
|---|---|---|---|---|---|---|
| * Inspections at entry points (ports/airports) | ○ | ○ | ○ | ○ | ○ | ○ |
| * Urban trees | ○ | ○ | ○ | ○ | ○ | ○ |
| * Productive forests | ○ | ○ | ○ | ○ | ○ | ○ |
| * Protected areas (Natural parks, conservation areas, nature reserves, etc.) | ○ | ○ | ○ | ○ | ○ | ○ |
| * Agroforestry/ Farm trees | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | |
|---|---|---|---|---|---|---|
| * Nurseries | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| * Wood processing sites (saw mills, pulp industry, etc.) | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| * Other | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |

*** Question 2.3: To what extent are the following digital tools promising for improving the detection, identification and monitoring of quarantine forest pests and pathogens?** (Rank your choice of importance from 1 (most important) to 5 (least important).

| | 1 | 2 | 3 | 4 | 5 | I don't know |
|---|---|---|---|---|---|---|
| Satellite images | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Aerial and drone images | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| LiDAR (Light Detection and Ranging) | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Artificial Intelligence (AI) models for remote sensing data | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| 3D machine vision systems to detect damage in nurseries | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Insect traps with automatic transmission of catch data | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| AI integrated models for identification of pests and pathogens from photographs | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Pest and pathogen identification based on environmental DNA from water, air, etc. | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Citizen science smartphone apps and online platforms | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |
| Others | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ |

*** Question 2.4: What are the difficulties/limitations of each digital tool that may hinder their deployment for the effective monitoring of quarantine forest pests and pathogens?**

- **Legal** (regulations/laws do not allow to use monitoring devices without licenses, *e.g.*, drones)
- **Financial** (cost of devices, cost of data collection, processing and analysis, labour cost for equipment operation)
- **Ethical** (privacy & data protection, transparency and informed consent)

- **Technical** (tools are affordable, but they are not simple and convenient to use, and they require proficient abilities for effective operation)
- **Relevance** (tools do exist but they do not adequately address the challenges faced in the region)
- **Lack of knowledge** (insufficient or missing information for choosing or accessing appropriate tools)

Please indicate your answer

| | Legal | Financial | Ethical | Technical | Relevance | Lack of knowledge | Others | None | I don't know |
|---|---|---|---|---|---|---|---|---|---|
| * Satellite images | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| * Aerial and drone images | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| * LiDAR (Light Detection and Ranging) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| * Artificial Intelligence (AI) integrated models for remote sensing data | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| * 3D machine vision systems to detect damage in nurseries | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| * Insect traps with automatic transmission of catch data | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| * AI integrated models for identification of pests and pathogens from photographs | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| * Pest and pathogen identification based on environmental DNA from water, air, etc. | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| * Citizen science smartphone apps and online platforms | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Comment section**: if you wish to elaborate on any of the issues you have raised above, please comment here.

## Part 3: Personal information

Please indicate your name

Your position

* **Your country**

- Bulgaria
- Denmark
- France
- Germany
- Italy
- Portugal
- Slovenia
- Spain
- Sweden
- Switzerland
- Trans-national

* **Your organization type**

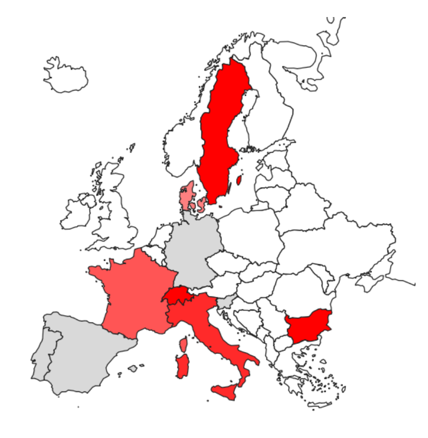
- Forest owner
- Nursery grower
- Forest manager
- Forest industry

- Plant protection organization
- Custom
- Other

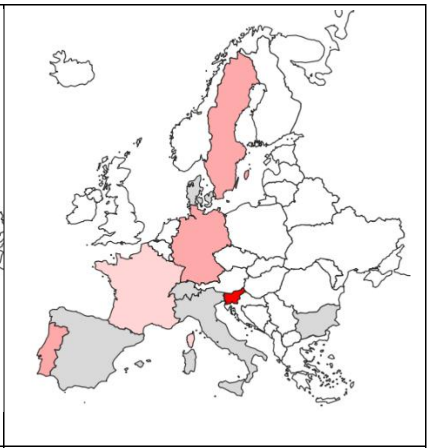
**If you have any questions or comments regarding the objectives of the FORSAID project and your role as a member of the Committee of Stakeholders, please specify them here**

## 8.2 Annex B: geographical distribution of the most threatening species according to the respondents

The red gradient reflects a mean threat index as expressed by respondents in their ranking of their top 3 most threatening pests
In grey, countries where the respondents did not select the pest in their top 3 priority species


Spruce bark beetle


Pine wood nematode


Pitch canker of pine

| Pine processionary moth | Oak processionary moth | Chestnut blight |
|---|---|---|

| | | |
|---|---|---|
|  |  |  |
| Canker stain of plane | Bronze birch borer | Emerald ash borer |