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Knowledge gap and conditional receptivity: citizen science uptake among tree and forest professionals in France

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ABSTRACT

Exotic pests and pathogens pose a major threat to forest ecosystems. Early detection of newly introduced organisms is critical for implementing effective eradication measures before they become established. Citizen science platforms have emerged as promising sources of biodiversity data for detecting invasive pests and pathogens, yet their integration into formal biosecurity surveillance remains limited. Using France as a case study, we surveyed 101 professionals involved in forest and urban tree management and pest surveillance to assess their knowledge of regulated tree pests and pathogens and their attitudes towards online citizen science platforms for biosecurity applications. We focused on ten focal species representing different regulatory statuses under EU legislation. We assessed the knowledge professionals have of these species and their regulatory status, and explored sources of variation in their opinions regarding the use of citizen science platforms as a tool for post-border biosecurity. Experts involved in mandatory surveillance of regulated organisms (SORE experts) demonstrated consistent knowledge of quarantine pests, whereas other professionals' knowledge varied by species, with greater familiarity for non-quarantine, widely distributed pests. Half of respondents used citizen science platforms, predominantly to consult species distribution rather than to contribute observations. Professionals' receptivity to citizen science increased significantly when species were perceived as easy to identify, but they expressed more confidence in citizen science for monitoring established pests than for the early detection of quarantine species. The survey reveals that while citizen science platforms are known and valued as information sources, they are not used as mechanisms for sharing field observations, even among surveillance professionals.

Introduction

Forests are at risk. Whereas planted, natural, and urban forests are at the cornerstone of attenuation and adaptation to climate change (Bonan, 2008; Escobedo et al., 2019; Savo et al., 2025; Reek et al., 2026), the sustainability of the functions and services they provide to humanity is increasingly threatened. Climate change fuels the intensity and frequency of major disturbances responsible for forest loss—including drought, fires, and storms—but also chronically increases their vulnerability to pests and diseases (Seidl et al., 2017; Pureswaran et al., 2018; Jactel et al., 2019; Frank, 2021; Hlásny et al., 2025). International trade further amplifies biotic risk by moving potentially harmful species beyond their native range, thus creating opportunities for novel interactions between trees, pests, and pathogens (Liebhold et al., 2023). The biological causes and consequences of the biotic and abiotic risks to which forests are exposed are increasingly well documented (Trumbore et al., 2015 ; Seidl et al., 2017), as are the economic drivers of biological introductions (Liebhold et al., 2012 ; Ramsfield et al., 2016; Meurisse et al., 2019 ; Nahrung et al., 2023). However, the social dimension of forest vulnerability has been largely overlooked to date (Marzano et al., 2016; Raum et al., 2024).

Biosecurity surveillance is an essential activity designed to discover non-native species before their introduction, or at the earliest stage of biological invasion (Nahrung et al., 2023). When the introduction of an

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exotic pest or pathogen is detected soon enough after introduction (i.e. post-border surveillance) or even before its introduction to a new area (i.e. pre-border surveillance), the probability of successfully implementing eradication or containment measures increase (Tobin et al., 2014; Branco et al., 2023), thus calling for the development of effective early warning schemes. The European Commission has established a list of quarantine species whose active surveillance by national authorities is mandatory across the European Union, and whose detection triggers a series of reporting and eradication procedures aimed at eradicating the pest. Despite substantial regulatory, human, and financial resources deployed to this end, a recent study revealed that eradication attempts for invasive pests and pathogens concerned only a minority of biological introductions (Branco et al., 2023). Active surveillance and regulatory tools are therefore insufficient to tackle the risk posed by non-native pests and pathogens (Klapwijk et al., 2016), particularly if the number of observers or their knowledge of the regulations is limited.

There is a continuum of vulnerability of trees across urban, planted, and natural forests (Epanchin-Niell and Pi, 2024; Augustinus et al., 2024). Introductions of pests and pathogens often begin in close proximity to large cities, where their establishment is facilitated by the high diversity of trees, including non-native trees likely to serve as bridgeheads for biological invasions (Dodds and Orwig, 2011; Paap et al., 2017; Branco et al., 2019). Whereas pests and pathogens can move freely across human habitat boundaries, biosecurity is, in practice, often siloed, with agencies in charge of plant health surveillance and protection in cities being different from those in charge of forest health surveillance (Tomlinson et al., 2015; Raum et al., 2025). In France, for instance, the surveillance of regulated and emerging pests (SORE, *Surveillance des Organismes Réglementés et Emergents*) is a centralised, top-down implementation of EU Regulation 2016/2031 built on a multi-level, multi-actor configuration and legally binding, standardised data-collection circuits. The SORE is operated by plant protection officers belonging or closely related to the Ministry of Agriculture. SORE experts are commissioned every year to inspect plants in specific habitats (forests, agricultural lands, urban green spaces, infrastructures and roadsides), searching for the presence of a pre-defined list of pests and pathogens. This list includes Union quarantine pests listed in Implementing Regulation (EU) 2019/2072 (amended Implementing Regulation (EU) 2021/2285), and among them the priority pests designated by Delegated Regulation (EU) 2019/1702. However, agents and agencies operating in forests have little connections with those operating in cities or the agricultural sector. It therefore appears necessary to develop biosecurity approaches that transcend these geographical and administrative boundaries in order to better reflect biological and ecological realities.

Citizen science can reinforce biosecurity surveillance by increasing the number of vigilant eyes in the field (Baker et al., 2019; Gupta et al., 2022; Hulbert et al., 2023; De Groot et al., 2023). Citizen science is an umbrella term describing any form of contribution by people who are not professional scientists to scientific research. It includes the general public as individuals or organized groups as well as professionals from specific sectors who may have an interest in a particular research area (Haklay et al., 2021). In terms of biosecurity, participation in citizen science contributes to raising public awareness of invasive alien species and the threats they pose while advancing scientific knowledge (Pocock et al., 2024). It ranges from structured and standardized surveillance schemes to semi-structured bioblitzes, or incidental contributions through the sharing of pictures of insects on online naturalist platforms (Meentemeyer et al., 2015; Brown et al., 2020; Price-Jones et al., 2022; Meeus et al., 2023; Roe et al., 2024). Although opportunistic and unstructured, these latter forms of public contribution to the surveillance of invasive alien species have proven to be powerful tools for early detection, particularly for large and conspicuous species (Epanchin-Niell et al., 2021 ; Pocock et al., 2024 ; Gonzalez-Moreno et al., 2025), particularly for large and conspicuous species (Caley et al., 2020). In several instances, the presence of an invasive pest in a country was first reported on online naturalist platforms before its presence was known to the national authorities (Epanchin-Niell et al., 2021; Roe et al., 2024; González-Moreno et al., 2025).

Essential to biosecurity are feedback loops and efficient information flows between people making field observations and those in charge of implementing pest and pathogen regulation schemes (Ticehurst and Kruger, 2023; Hutt-Taylor et al., 2025). However, persistent doubts remain about the accuracy and value of data collected by observers whose expertise is unknown (Austen et al., 2016; Collins et al., 2022). Citizen science data indeed suffer from several well-known biases (Pocock et al., 2024): large and conspicuous species are often over-represented compared with smaller or less conspicuous species (Caley et al., 2020), and observations tend to be concentrated where observers are —typically near urban areas— rather than where species occur (de Groot et al., 2022). These well-documented biases may explain experts' reluctance to use data generated by laypeople. On the contrary, it may seem intuitive that any professional with daily and direct contact with plants through their activity (whether, for instance, arborists, forest or greenspace managers) would be the most concerned by tree health issues and the most likely to be the first observer of an introduced pest or pathogen. These professionals may thus constitute a particularly relevant target for biosecurity-oriented citizen science programmes (Thomas et al., 2017).

Despite the potential value of citizen science for forest health surveillance, the extent to which it is actually recognized and used by forest professionals is poorly documented. Using France as a case study, we designed a survey aiming to assess the knowledge and use of citizen science platforms among professionals working with trees (including urban trees) and forests, whether managers or plant protection officers involved in the surveillance of EU regulated pests (henceforth '*SORE experts*', or, in short, *'experts'*). We hypothesized that SORE experts would have a better knowledge of regulated pests than other professionals, regardless of their sector of activity, because the work of SORE experts is to survey for these species, while other professionals focus on species that are harming city trees, regardless of their status. We further documented the level of knowledge they have of citizen science platforms and whether they use them, and if so for which purpose. We anticipated that the extent to which professionals value citizen science as a potential source of relevant information would depend on the conspicuousness of pests or disease symptoms. Specifically, we predicted that professionals would value citizen science data referring to large, easily identifiable species, and be more reluctant to consider citizen science as a valid tool for biosecurity for species whose identification requires greater expertise ; we therefore assumed that citizen science would be more valued when referring to pest insects that disease symptoms. By doing so, our study documents the social component of forest vulnerability to non-native pests and pathogens.

Materials and methods

Study site and model species

The study was conducted in France, Western Europe. The country covers 633 000 km^2 with a population approaching 70 million inhabitants (INSEE, 2026), 80% of which live in cities. Forests cover 25 million hectares, i.e., 33% of the country (excluding ultramarine territories). Three quarters of the forest area is privately owned. Thirty-nine million cubic metres are harvested every year, representing a commercial value of 2800 M€ (Chuine et al., 2023), with 8% of trees being in poor sanitary state (IGN, 2025).

We established a list of 10 focal tree pests and pathogens with different regulation statuses at the EU and national (France) levels (Table 1). The choice was based on the expertise of the authors to cover species listed in Annexes II and III of EU regulation and motivated by the need to keep the survey as short as possible. Specifically, we considered six quarantine species listed in Annex II of EU Regulation 2021/2285, of

Table 1
List of tree pests (i) and pathogens (p) included in the questionnaire. Respondents were presented scientific names and common names in French. Species listed in Annexes IIA and IIB are EU quarantine species, currently absent from the EU territory (IIA), or known to occur within the EU (IIB). Species listed in Annex III are regulated organisms that are not quarantine species at the EU level but are quarantine species in specific areas (though not in France). Note that as this article was being written (July 2026), the presence of the emerald ash borer (so far listed in Annex IIA) was confirmed in Hungary and Slovakia.

French	Scientific	English	EU regulation status	Status in France
Nématode du pin	*Bursaphelenchus xylophilus (Nematoda)*	Pine wood nematode (p)	Annex II B	First detection in November 2025 in SW France
Agrile du frêne	*Agrilus planipennis (Coleoptera)*	Emerald ash borer (i)	Annex II A	Absent
Chancre résineux du pin	*Fusarium circinatum (Ascomycota)*	Pitch canker (p)	Annex II B	Absent, eradicated
Chancre du châtaignier	*Cryphonectria parasitica (Ascomycota)*	Chestnut blight (p)	Annex III	Present, widely distributed
Processionnaire du chêne	*Thaumetopoea processionea (Lepidoptera)*	Oak processionary moth (i)	Annex III	Present, common in NE France
Scolyte de l'épicéa	*Ips typographus (Coleoptera)*	European spruce bark beetle (i)	Annex III	Present, widely distributed
Agrile du bouleau	*Agrilus anxius (Coleoptera)*	Bronze birch borer (i)	Annex II A	Absent
Processionnaire du pin	*Thaumetopoea pityocampa (Lepidoptera)*	Pine processionary moth (i)	Annex III	Present, widely distributed and expanding northward
Chancre coloré du platane	*Ceratocystis platani (Ascomycota)*	Canker stain of plane (p)	Annex II B	Present, restricted distribution
Capricorne asiatique	*Anoplophora glabripennis (Coleoptera)*	Asian longhorn beetle (i)	Annex II B	Present, eradicated

which two were not present in the EU at the time the survey was administered (*i.e.*, Annex IIA), and four were known to occur or have occurred within EU boundaries (*i.e.*, Annex IIB). We also considered four species that are regulated at the EU level but are not classified as quarantine species (*i.e.*, species in Annex III). The three insect species listed in Annex III are widely distributed in France and are frequently spotlighted in the mainstream media (Castagneyrol et al., 2026), either because of the major damage they cause to forests or because they can be harmful to humans. Specifically, the European spruce bark beetle is a major pest responsible for considerable damage to spruce forests. Its impact has intensified over the last decades as a consequence of the combined effects of forest mismanagement and climate change (Hlásny et al., 2021; Hallas et al., 2026). The pine and oak processionary moths are also important defoliators of pines and deciduous oaks, respectively, but are mostly known for their noxious urticating hairs (Battisti et al., 2015). Likewise, the chestnut blight, a major disease responsible for chestnut decay, is widely distributed in France. We regarded processionary moths and chestnut blight as 'control' species that we expected to be well known to respondents. Also listed in Annex III, chestnut blight is a disease causing major damage to chestnut orchards and forests; it is widely distributed across the national territory, where it is not considered a quarantine species. Important to this study is the fact that, in November 2025, the first occurrence of the pine wood nematode was confirmed in southwestern France, attracting significant media attention.

We implemented an online survey between May and July 2026. The survey was inspired by Raum et al. (2024) and was developed with the support of experts in forestry and urban green space management. It was intended to reach plant protection officers whose work involved trees, as well as various groups of professionals working with trees in forest, urban, and peri-urban environments. These categories included arborists and tree care takers, landscape planners and urban planners, park and green space managers and technicians, managers of public and private forests, and forest technicians and consultants. Respondents could identify themselves as belonging to more than one category. The first question asked respondents to confirm that they had or had had a professional activity related to trees.

The survey was administered using Limesurvey version 3. We used a targeted snowball sampling approach (Goodman, 1961) to distribute the survey, sending formal invitations accompanied by brief background information to national contacts within key organisations **(Table S1)**. The invitation to participate in the survey was further disseminated through personal communications by colleagues from our research department who maintain well-established professional relationships with a wide range of stakeholders. This sampling scheme makes it possible to reach hard-to-reach populations, such as, in our context, niche or loosely structured professional groups. However, it is a non-probability method whose response rate cannot be calculated; the composition of the sample depends on the initial seeds, and, because of homophily in referrals, it may overrepresent well-connected individuals and those most interested in the topic.

Questionnaire design

The questionnaire (Appendix A, Supplementary Material) was divided into four sections and 15 questions (Q). The first section assessed respondents' knowledge of the focal tree pests and pathogens (Q1, organized on a four-degree Likert scale), of their regulation status (Q2, yes/no question), and their degree of concern (Q3, four-degree Likert scale). Questions Q1–Q3 referred to "regulated and emerging pests targeted by SORE surveillance". The second section explored the use respondents might have of online citizen science platforms. We first asked whether respondents made any use of a pre-set list of five generalist and professionally oriented citizen science platforms (Q4): the generalist platforms *iNaturalist*, and *Observatoire des Espèces Exotiques Envahissantes* (OEEE), the forest oriented platform *Silvalert*, and *Vigil'Encre* and *VigiCultures*, two platforms designed to survey the presence and spread of plant pests and diseases. *iNaturalist* is an international biodiversity platform on which users post geolocated, time-stamped photographs of plants, animals and fungi. The photographed organism can be identified by the observer, with or without AI assistance, and by other users of the platform. iNaturalist, Silvalert and Vigil'encre are fed by contributions from the general public. VigiCultures targets professionals and OEEE aggregates data from multiple sources. Then, for each citizen science platform, we asked whether it was used in a personal or professional context (Q5) and, for professional use only, we asked why (Q6), how (Q7), what for (Q8) and how much (Q9) it was used.

The third section of the questionnaire aimed at understanding respondents' attitudes regarding the potential use of online citizen science platforms for biosecurity. It only concerned experts involved in the official surveillance of regulated and emerging organisms. We first asked respondents' opinion on the difficulty of identifying the focal tree pests and diseases (Q10), on the probability that users of citizen science platforms would report observations of these species (Q11) and on the probability that they —respondents— would consult citizen science platforms to obtain information regarding the distribution of each pest and pathogen (Q12). Q10-12 were on four-degree Likert scales.

The last section explored two scenarios designed to put respondents in situations in which they would use citizen science platforms in a professional context. The first scenario mentioned the Asian Longhorn

Beetle *Anoplophora glabripennis*, a quarantine species that has occasionally been intercepted in France but has always been successfully eradicated so far, and the oak lace bug *Corythucha arcuata* a non regulated but invasive pest whose range has rapidly expanded seen its first detection in France in 2017. Scenarios read as follows: *"While preparing for an inspection mission, you consult a digital biodiversity oriented citizen science platform out of curiosity to learn about the species already present or reported in your area. While browsing the observations available on the platform, you come across a photograph showing* Anoplophora glabripennis/Corythucha arcuata, *although you have never observed this organism in this area before"*. Questions Q13 (Scenario 1: *A. glabripennis*) and Q14 (Scenario 2 : *C. arcuata*) were on four-degrees Likert scales and asked respondents' opinion on the possibility to obtain reliable abundance, absence, presence and spatial distribution of these two species in France. Eventually, we asked respondents their opinion regarding the potential of citizen science platforms as a relevant tool for tree-related biosecurity in France (Q15).

Statistical analyses

We analysed data in R version 4.4.1 (Team, 2024) using functions provided by the library tidyverse (Wickham et al., 2019) to summarize qualitative variables and visualized the data. The sample size was not sufficient to reliably analyse the detailed answers of respondents regarding their use of each citizen science platform (Q4-Q9). We regrouped their responses and eventually analysed respondents' attitudes regarding citizen science platforms as a whole.

We initially analysed responses to Q1–Q3 with cumulative link mixed models (CLMMs), the ordinal analogues of ANOVA with a random effect. However, assumptions of proportional odds and equal latent variance across groups were not satisfied. We therefore opted for a more flexible Bayesian analog. We modelled respondents' knowledge with a Bayesian adjacent-category logit mixed model, in which predictors were allowed to have category-specific effects (Bürkner & Vuorre, 2019). Unlike proportional odds models, this approach allows coefficients being estimated for each pair of categories (i.e. category-specific) as the log-odds of answering in a category rather than in the category immediately below it (i.e. adjacent category logit mixed model). Specifically, the response variable was the level of knowledge respondents had of each pest and pathogen, treated as an ordinal variable. In the first set of models, the explanatory variables were category-specific species identity and category-specific respondent status with respect to participation in the surveillance of regulated and emerging pests (expert *vs.* non-expert) as well as the two-way interaction. In the second set, we replaced species identity with a coarser functional group description (insect vs. pathogen) and with regulatory status under EU legislation (quarantine vs. non-quarantine). In all models, respondent ID was included as a random effect to account for the possible non-independence of multiple responses from the same respondent. We used the same approach to test whether the characteristics of the pests and pathogens and respondent status influenced the probability of correctly identifying whether each organism is regulated. To this end, we treated each answer as an ordered response (incorrect $<$ "don't know" $<$ correct). We removed the 10 missing answers (out of 1010 respondents $\times$ organisms) In all cases, we fitted models with the brm function from the brms package (Bürkner, 2017). We initiated models with weakly informative priors. We ran four chains of 2,000 iterations each, including 1,000 warm-up iterations, which yielded 4,000 posterior draws. We tested interactions and main effects by comparing models with and without the corresponding terms using approximate leave-one-out cross-validation (LOO; Vehtari et al., 2017). We considered that differences in expected log predictive density (ELPD) such that $|\Delta ELPD| > 2 \times SE_{difference}$ were indicative of meaningful differences between models. We were not particularly interested in predicting respondents' absolute knowledge score. Rather, we aimed at contrasting knowledge across categories of respondents and pests. To do so, we summarised pairwise differences between species, pest status or guilds within each level of respondent status with respect to participation in SORE by computing their posterior median and 95% credible interval. We considered as credibly different pairs whose 95% CrI did not bracket zero.

To correlate respondents' opinion on the difficulty in identifying pests and diseases with their beliefs about the likelihood of using citizen-science platforms to investigate the presence of pests and diseases in France and the likelihood that citizen scientists would report such pests and diseases on a platform (Q10-Q12), we transformed qualitative answers into species-specific weighted quantitative indices I_i (i.e., mean of recoded responses), where i is each of the ten tested species. Specifically, we assumed that the qualitative responses (very unlikely, unlikely, likely, very likely; very difficult, difficult, easy, very easy) reflected underlying continuous latent traits (levels of agreement) partitioned into four classes recoded on a scale from 1 to 4 ($k \in \{1, 2, 3, 4\}$). For each pest or disease i, we multiplied each recoded score by the number of respondents selecting that level, summed the products across all levels, and finally divided the total by the overall number of responses :

$$I_i = \frac{\sum_{k=1}^{4} k \times n_{ik}}{}$$

We finally regressed the scores obtained for the probability of reporting pest and disease observations on citizen-science platforms or the probability of consulting such a platform on the scores reflecting the difficulty of identifying a species, using ordinary-least-squares regression.

We analysed responses to Q13–Q16 within the same Bayesian framework as for Q1-Q3with pest species, scenario of use of citizen science platforms and their interaction as fixed effects, and respondents' ID as random factor.

Results

Respondents' profiles

The survey was opened by 152 persons and completed by 101 respondents. Despite our efforts to balance the number of respondents from the forest and urban sectors, the latter was more represented (Table 2). Responses originated from 48 administrative regions (so called *départements*, **Fig. S1, Supplementary Material**). Slightly more

Table 2
Summary of demographic characteristics of respondents.

Gender		Main declared activity	
Male	62	Management	58
Female	36	Surveillance	43
Other	3	Sector of activity	
No years of professional experience with trees		Agriculture	2
< 5	24	Urban and peri-urban green spaces	68
5-10	30	Forests, urban and peri-urban green species	11
10-20	25	Forests	20
> 20	22	Participation in the Surveillance of Regulated and Emerging Organisms (SORE)	
Highest diploma obtained		No	22
Lower secondary	4	Yes	79
Upper secondary (general)	3		
Upper secondary (vocational)	8		
Short-cycle tertiary	25		
Bachelor	22		
Postgraduate degree («Maîtrise»)	6		
Master	29		
Doctorate	1		
Other	3		

than half of the respondents (57%) had professional activities related to tree, green space or forest management; others declared that their activity involved tree health surveillance. Of those, half were active in the forest sector, and the other half in urban and peri-urban environments **(Fig. S2)**.

Roughly half of respondents (53%) declared being involved in the official national surveillance scheme for regulated and emerging organisms (i.e., *experts*), to which should be added those who declared that their main activity was tree health surveillance, although they were not included in official surveillance schemes at national level (31%). A minority of respondents (22%) declared taking no part in tree health surveillance but only activities related to tree or forest management (Table 2**, Fig. S2)**. Note that a given respondent could report taking part both in an official surveillance scheme and in management activities, or carry out management and surveillance activities without participating in an official surveillance scheme. These multiple activities explain why the percentages do not add up to 100%.

Knowledge of regulated organisms

Respondents' level of knowledge differed strongly among species: removing species identity from the additive model markedly reduced predictive accuracy (LOO test: $|\Delta ELPD| = 91.1 \pm 12.6$, with a cut-off for weak difference being $2 \times 12.6 = 25.2$). Knowledge also differed between respondent groups ($|\Delta ELPD| = 11.6 \pm 5.3$), with experts reporting levels of knowledge than non-experts. Predictive accuracy was not improved by including the interaction between species and respondent status ($|\Delta ELPD| = 10.3 \pm 6.8$). In both groups, respondents reported greater knowledge of the pine and oak processionary moths and of plane canker than of the two *Agrilus* species (Fig. 1). Experts had a better knowledge of pest regulation status than on expert (interaction: $|\Delta ELPD| = 15.0 \pm 5.9$). Respondents not involved in surveillance reported greater knowledge of pests listed in Annex III (posterior median ± 95 % CrI for expected knowledge scores: $2.98 \pm [2.77 - 3.13]$) than of quarantine pests listed in Annex II B ($2.56 \pm [2.29 - 2.84]$) and an even lesser knowledge of species listed in Annex II A ($2.07 \pm [1.79 - 2.41]$), whereas experts reported similar levels of knowledge across regulatory statuses (all expected knowledge scores > 2.91; Fig. S3). Finally, regardless of respondent status (interaction: $|\Delta ELPD| = 0.4 \pm 2.0$) knowledge of pests did not differ between insects and pathogens ($|\Delta ELPD| = 1.8 \pm 2.9$).

The number of respondents who correctly assigned quarantine status to regulated organisms and a non-quarantine status to organisms listed in Annex III differed across species ($|\Delta ELPD| = 112.39 \pm 15.30$), and between experts and other respondents ($|\Delta ELPD| = 21.71 \pm 7.94$) in a similar way (*i.e.*, accounting for the interaction improved predicted accuracy: $|\Delta ELPD| = 5.82 \pm 2.95$). Posterior medians were higher for respondents participating in the surveillance of regulated and emerging pests, which is indicative of a better knowledge of their regulatory status as compared to non experts (Fig. 2). A greater number of respondents participating in the surveillance assigned a correct status to tested pests and pathogens. In both groups, the probability of correctly assigning a species to its regulation status was greater for the plane canker, the pine wood nematode and the Asian longhorn beetle as compared to the two processionary moths, the European spruce bark beetle and the chestnut blight that are all listed in Annex III (Fig. 2). Generally speaking, the number of correct answers was lower for species in Annex III, intermediate for species in Annex II A, and higher for species in Annex II B (Adding EU status improved predictive accuracy: $|\Delta ELPD| = 93.98 \pm 13.92$, **Fig. S4**). There was no evidence that the status of insect pests was better known than that of pathogens ($|\Delta ELPD| = 1.91 \pm 0.84$, Fig. 2).

Attitude towards citizen science

Of the 101 respondents, 47 declared having used citizen science platforms (either those we listed or others) and 49 declared using none; 5 did not answer. Among users, 29 were involved in the surveillance of regulated and emerging organisms. Further descriptive analyses focus only on respondents using citizen science platforms. *iNaturalist* was the most frequently used platform, with respondents involved in SORE using it twice as much as other respondents **(Fig. S5)**.

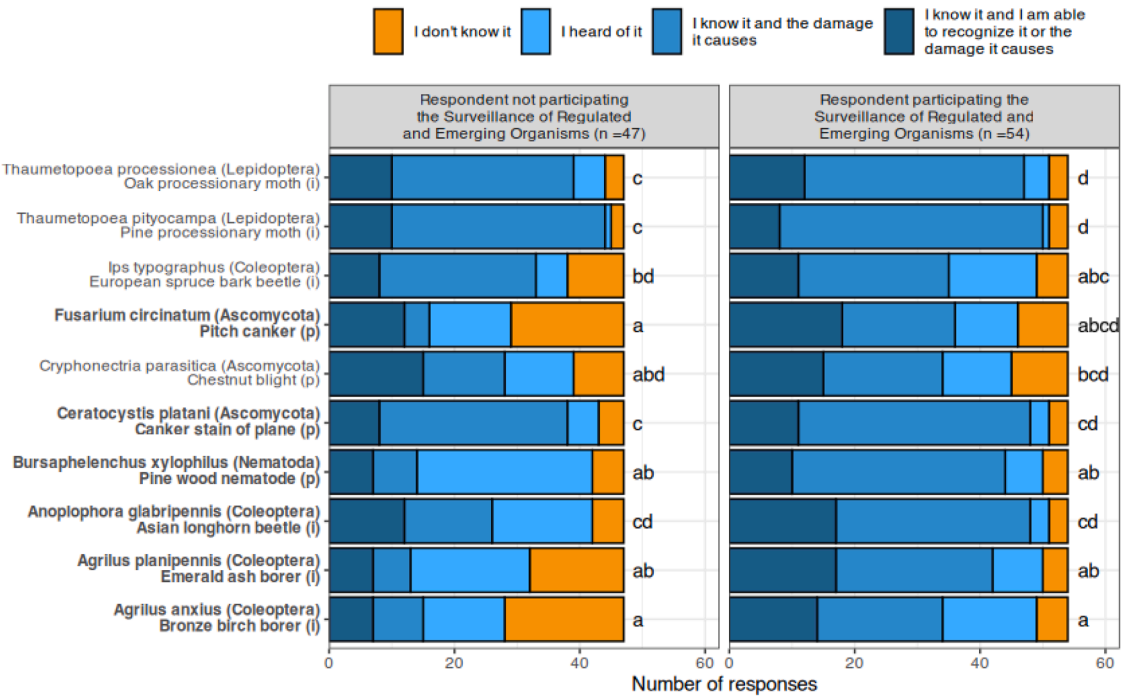

Fig. 1. Level of self-declared knowledge respondents have of focal pests and pathogens depending on the participation in the surveillance of regulated and emerging pests. Names of pests and pathogens in bold correspond to quarantine species in Annex II A and II B of EU Regulation 2021/2285. (i) and (p) refer to insects and pathogens, respectively. Within each panel, species sharing a letter has pairwise differences in predicted probability that do not differ credibly.

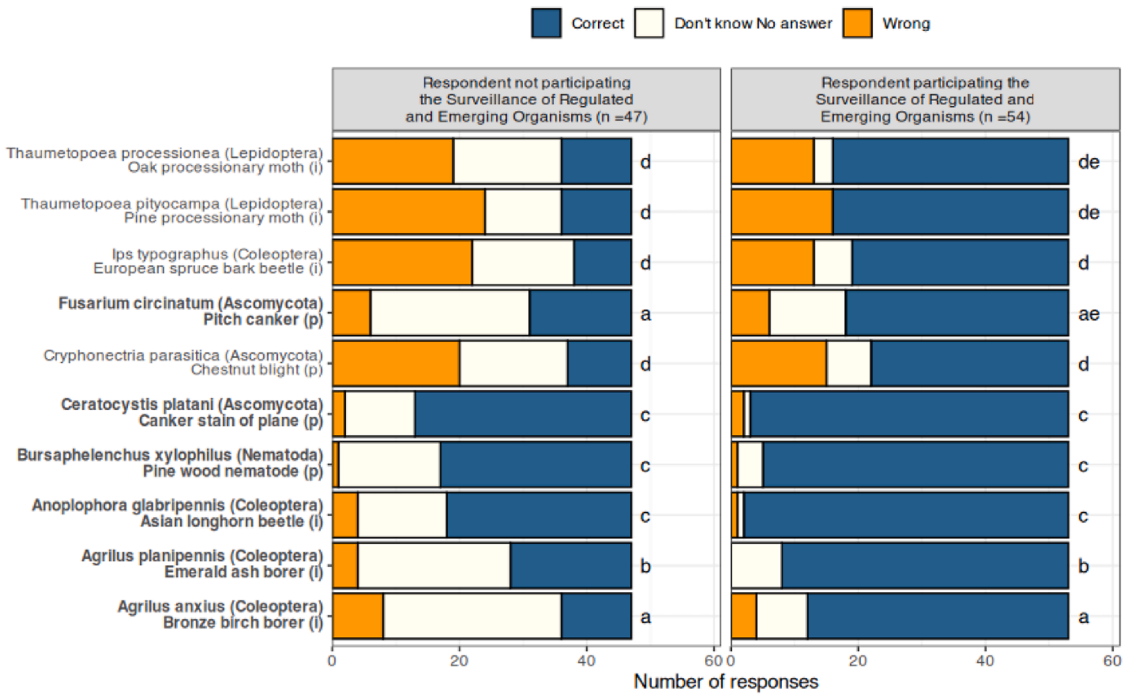

Fig. 2. Number of respondents correctly assigning pest to its regulation status (quarantine vs. non-quarantine) depending on their participation in the surveillance of regulated and emerging pests. Names of pests and pathogens in bold correspond to quarantine species. (i) and (p) refer to insects and pathogens, respectively. Within each panel, species sharing a letter has pairwise differences in predicted probability that do not differ credibly.

Respondents declared using citizen science platforms forpersonal or professional use, the latter being more frequent (Fig. 3A), and a third of declared using these platforms in both contexts. When using citizen science platforms in a professional context, 60% of respondents declared doing so on their own initiative (Fig. 3B). Less than a third of respondents (29%) declared uploading data to citizen science platforms as part of their professional activity (Fig. 3C). Instead, citizen science platforms were used to help with species identification or to visualise the distribution of a particular species (Fig. 3D). More than half of the respondents using citizen science platforms in a professional context did so on a monthly basis or more frequently (Fig. 3E). We refrained from investigating cross-category interactions because of the overall low number of respondents declaring use of citizen science platforms.

Attitudes towards citizen science platforms as a potential tool for the surveillance of regulated species in France

The two processionary moths and, to a lesser extent, the European spruce bark beetle and the Asian longhorn beetle were considered relatively easy to identify by respondents **(Fig. S6)**, and a majority of respondents considered it likely or very likely that they would consult citizen science platforms to obtain information on their presence in a given territory **(Fig. S6B)**. However, a substantially smaller proportion of respondents considered that observations of these species would be reported on citizen science platforms **(Fig. S6C)**. When considering the tested species as a whole, respondents were more likely to consult citizen-science platforms to obtain information about the presence of a pest or disease when they considered that organism easy to identify (slope ± se: 0.93 ± 0.11, $F_{1,8} = 73.83$, P-value < 0.001, $R^2 = 0.89$, Fig. 4). They also regarded occurrences of pests and diseases as being more likely to be reported on citizen-science platforms when the species were easier to identify but the slope between identification and reporting scores was less steep and slightlyreportingweaker (0.22 ± 0.05, $F_{1,8} = 19.52$, P-value $= 0.002$, $R^2 = 0.67$, Fig. 4).

Scenarios of use of citizen science platforms

When asked directly, experts involved in the official surveillance of regulated and emerging organisms were fairly positive about the potential of using citizen science platforms to aid the early detection of the Asian longhorn beetle *Anoplophora glabripennis* and the oak lace bug *Corythucha arcuata*, with more than three quarters of responses being "agree" or "totally agree". However, when asked specific questions regarding the information potentially provided by these platforms, their opinions varied among uses (effect of use: $|\Delta ELPD| = 35.16 \pm 8.02$). Specifically, respondents' opinions were more positive about citizen science platforms as a relevant tool to inform on the presence and distribution of these pests, but not to provide reliable information on absence or abundance (Fig. 5). Respondents also tended to be more positive about the potential use of citizen science for the surveillance of *C. arcuata* than of *A. glabripennis* (Fig. 5). However, including species identity did not improve predictive accuracy ($|\Delta ELPD| = 1.24 \pm 2.73$) thus indicating that species identity, in this case, is not an important driver of respondents opinion on the different uses of citizen science platforms.

Discussion

Our survey of stakeholders involved in the management and surveillance of trees and planted, natural and rural forests in France reveals a variable knowledge of quarantine pests, and mixed attitudes regarding the use and potential of citizen science platforms as relevant sources of information for the early detection and surveillance of regulated tree pests and diseases.

Tree and forest managers have limited knowledge of regulated pests and pathogens and their EU regulatory status

The survey targeted on the one hand experts appointed to the surveillance of regulated and emerging organisms and on the other hand tree and forest professionals having a range of activities including the

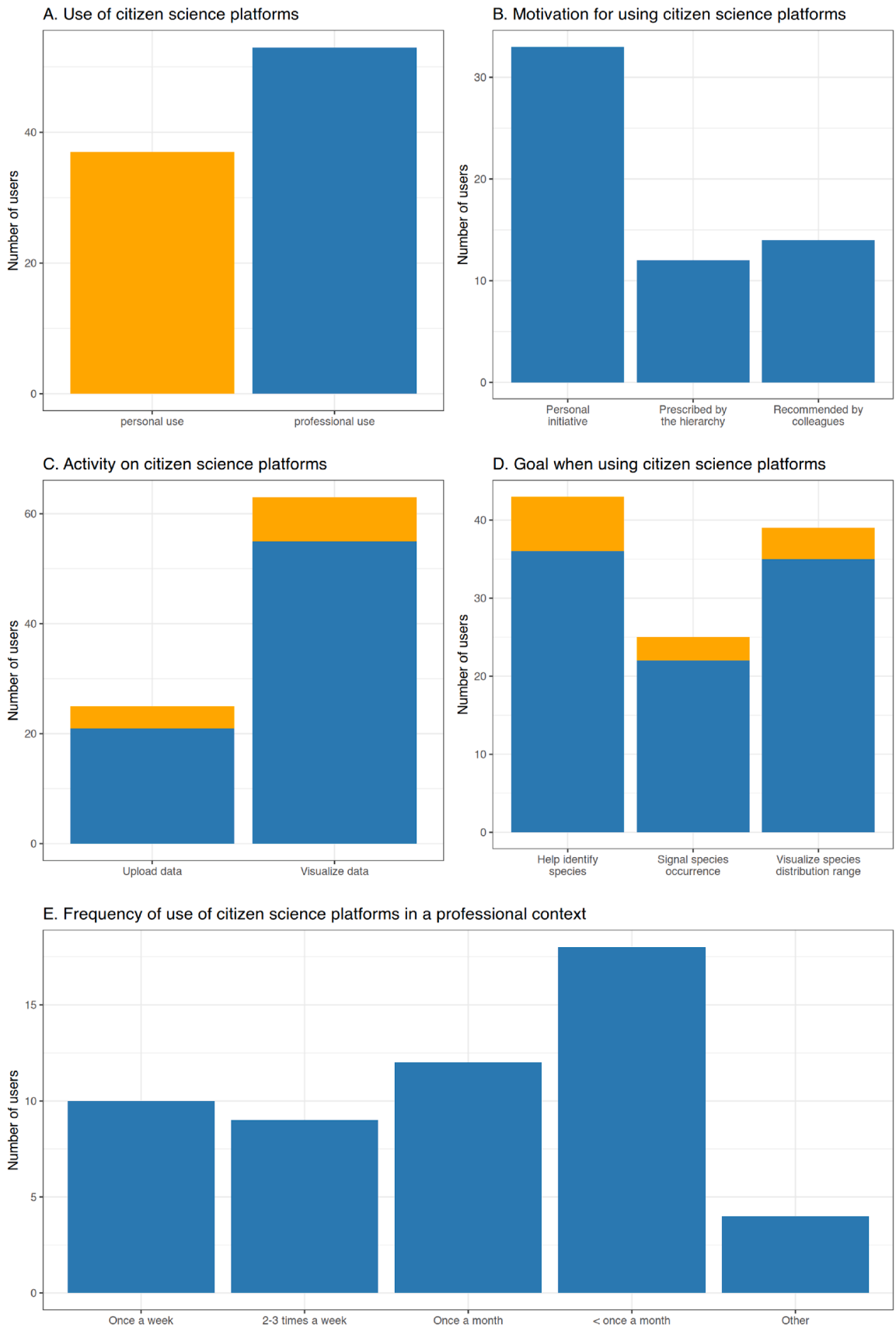

Fig. 3. Summary statistics describing in which context (A), why (B), how (C), what for (D) and how often (E) citizen science platforms are used by respondents. Colours in (A) refer to the use of citizen science platforms in a personal (orange) and professional context (blue). The same colours are used in each panel. The vertical axes show the number of respondents who reported each type of use. The same respondent may use more than one platform for a given use, so the total number of responses can exceed the number of respondents.

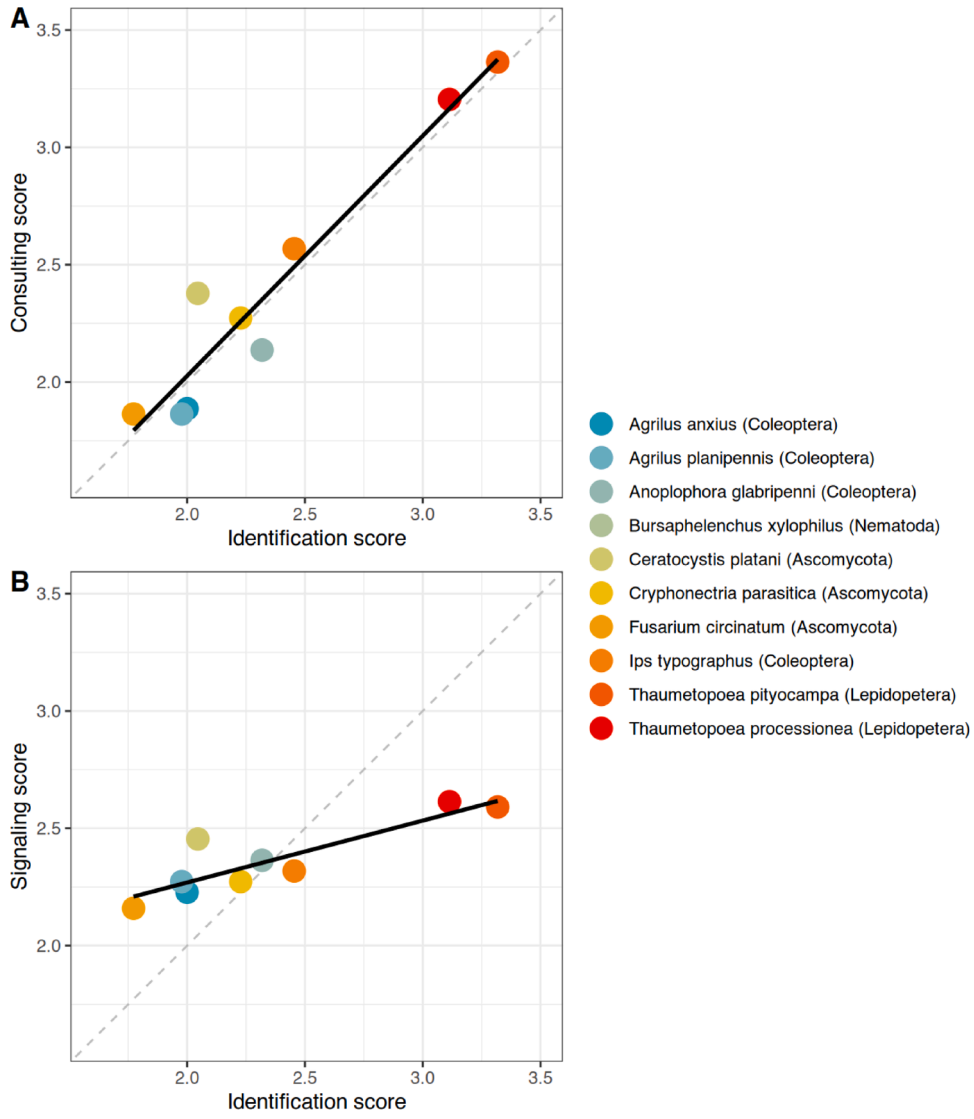

Fig. 4. Relationship between respondents' opinion on the difficulty to identify pests and pathogens and the probability observations are reported on citizen science platforms (signaling) or the probability they would consult these platforms to obtain information regarding the distribution of each pest and pathogen. Dots are averaged scored for each pest or pathogens. The solid line represents the prediction from the ordinary least square regression. The dashed line is the 1:1 relationship.

management and surveillance of trees, with varying degrees of involvement in tree health surveillance. Experts declared having a good knowledge of both regulated pests and species in Annex III, whereas the knowledge of other professionals varied across the tested species.

The surveillance of regulated and emerging pests in France is undertaken by agents employed by different institutions, with sectoral specialisation. For instance, experts in charge of forest health surveillance are not appointed to the surveillance of urban trees or orchards, and *vice versa*. Yet some pests included in our survey are typical forest pests (e.g. pinewood nematode, European spruce bark beetle) whose occurrence in cities is unlikely. Conversely, the canker stain of plane is of greater concern in cities and along roadsides than in forests. Despite this sectoral specialisation, we found no significant difference in the knowledge experts declared having of the different species.

The situation was different for the group of respondents who were not involved in the surveillance of regulated and emerging pests. These respondents declared having a good knowledge of species that are widely distributed in France and that are not quarantine species at the EU level (i.e., species listed in Annex III of EU Regulation 2021/2285). However, their knowledge of quarantine pests was lower, particularly for those species that are not known to occur in the European Union (i.e. species listed in Annex IIA). This result is consistent with previous studies revealing that stakeholders' knowledge of regulated pests is limited, particularly for exotic pests that are not present in the country (Marzano et al., 2016; Raum et al., 2023). Importantly, non-experts had little knowledge of the regulatory status of the set of species we considered in this study; half of them correctly assigned a quarantine status to quarantine species listed in Annex IIB (those known to occur, or to have occurred, in the EU), but had much more limited knowledge of the regulatory status of both species listed in Annex III (wrongly regarded as quarantine pests) and species that are not present in the EU.

We acknowledge that, because the survey assessed self-reported knowledge, respondents' knowledge of species may have been overestimated. If so, these results would further support the view that current post-border biosecurity procedures could be improved by promoting both knowledge of regulated organisms and awareness of biosecurity schemes (Ram et al., 2016; Warman et al., 2025), at least in France, though questions remain about how to effectively engage stakeholders to promote behavioural change (Hall et al., 2020).

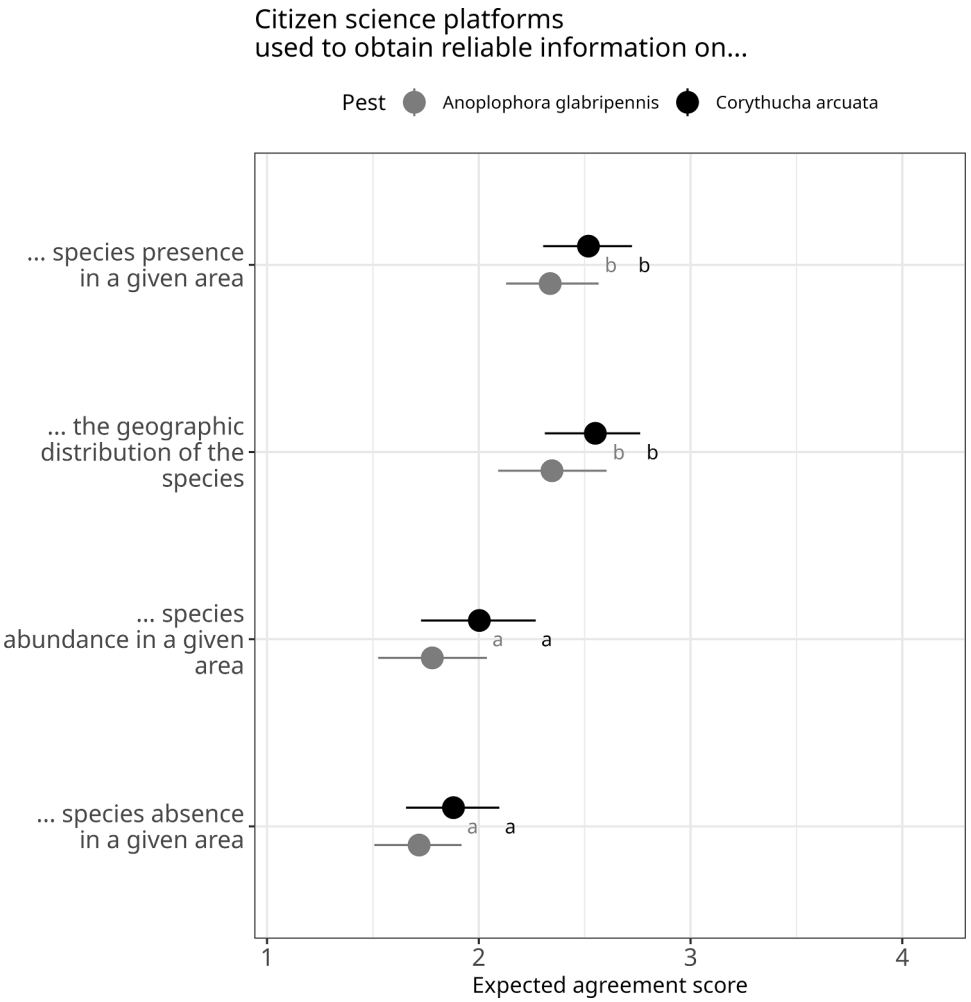

Fig. 5. Expected level of agreement depending on the scenario of use of citizen science platforms. Points are posterior medians and bars are 95% credible intervals of the expected agreement score, ranging from 1 ('Totally disagree') to 4 ('Totally agree'), predicted for a typical respondent by a Bayesian adjacent-category logit mixed model with category-specific effects of pest and use scenario. For each species, scenarios of use sharing a letter do not differ credibly.

Citizen science platforms are known, but only used as punctual sources of information

Early detection of regulated pests and pathogens can benefit from citizen scientists reporting observations of plants and animals on online platforms, thus suggesting that citizen science can be a lever for effective biosecurity (Epanchin-Niell et al., 2021; Roe et al., 2024; González-Moreno et al., 2025). However, this would require that, on the one hand, the people most likely to encounter species of concern report their observations and, on the other hand, that these platforms are known to plant protection officers, trusted as relevant sources of information, and ultimately used by them (de Groot et al., 2023). In these respects, we found mixed evidence.

Half of the respondents declared using citizen science platforms, including a majority of experts involved in the official surveillance of regulated and emerging pests. Most respondents used citizen science platforms in a professional context, mostly on their own initiative. Interestingly, they declared doing so to help identify species or to track the presence or distribution of a particular species, but none of the respondents using these platforms in a professional context declared sharing their own observations. These results indicate that citizen science, as a means of producing and sharing data, has not yet been integrated into the professional routines of tree and forest professionals, even though half of the respondents reported some interest in data generated through these platforms. Still, the fact that tree and forest health professionals do not reject the use of citizen science outright suggests that, under certain circumstances, these platforms could complement the tools they already use.

We can make several assumptions to explain why professionals do not feed citizen science platforms with pest records, even those for whom pest surveillance is a central activity. Professionals involved in the surveillance of regulated pests use internal reporting tools and may therefore not feel the need to use another tool that was not designed for this purpose; they may also lack the time to do so. Finally, these professionals may see no benefit in making occurrence data on regulated species public, or may even have an incentive not to do so. These assumptions, however, remain speculative and would need to be tested more formally to better understand the motivations and incentives for using, or not using, citizen science platforms in the context of pest detection.

The perceived relevance of citizen science for biosecurity varies among pests

Citizen science data are often considered by experts to be unreliable because they suffer from several biases (Caley et al., 2020; de Groot et al., 2022; Pocock et al., 2024), thus limiting their use for post-border biosecurity. Our survey was designed to specifically address the most common beliefs regarding these data, which are frequently regarded as spatially biased (species occurrences indicate where

observers go or do not go rather than where species actually occur) (Baker et al., 2019; de Groot et al., 2022) and taxonomically biased, whereby large, conspicuous species are more likely to be reported than small, inconspicuous ones (Caley et al., 2020). Although we found evidence that respondents share these common beliefs, the detail of the responses they provided draws a more nuanced and encouraging picture. Contrary to what would be expected based on their morphology and dangerousness (Caley et al., 2020), respondents tended to be more positive towards the use of citizen science platforms for the detection of the oak lace bug — a grey bug less than 3 mm long — than for the detection of the large, bright Asian longhorn beetle. This difference might be due to the abundance of the former and the conspicuousness of the damage it causes to deciduous oaks. The oak lace bug is now widespread in south-western France, from where it has spread northward and westward over the last few years. It causes clearly visible discolouration in deciduous oaks as early as mid-summer, so that its presence is easily noticed, even by non-experts. By contrast, the Asian longhorn beetle has not established in the country. Although it can drive trees of several species to death, it does not cause clearly distinctive symptoms and does not reach population levels as high as those attained by the oak lace bug, which might explain the slight difference in respondents' appreciation of the two species. Altogether, these results suggest that stakeholders might consider citizen science platforms more suitable for the monitoring of pests than for the early detection of regulated species (Pocock et al., 2024).

We found that the degree of expertise respondents considered necessary to identify pests and diseases varied among pests, and that it influenced not only their opinion regarding the probability that observations of these pests would be reported on citizen science platforms, but also the probability that they, as stakeholders, would consult these platforms to obtain information on the distribution of pests and diseases. Specifically, we found a strong match between respondents' opinion on the ease of identifying species and the probability that they would consult citizen science platforms. Interestingly, the species regarded as the easiest to identify are also those best known by respondents. There was also a positive correlation between opinion on the ease of identifying species and the belief regarding the propensity of citizen scientists to report their observations on citizen science platforms.

Implications for biosecurity

Although we are well aware that these results are based on only a limited number of responses, we see two main implications for tree and forest biosecurity. First, the fact that citizen science platforms are known and used by stakeholders indicates that there may be a potential for them to be used for the early detection of regulated organisms, as advocated by several authors (Gupta et al., 2022; Hulbert et al., 2023). It also indicates that, despite concerns regarding biases in citizen science data, stakeholders regard these platforms as potentially relevant sources of information. If so, there is a chance that observations of regulated pests shared on citizen science platforms could be noticed by SORE experts and trigger field campaigns aimed at confirming or refuting the observation. Alternatively, citizen science platforms may be used by plant protection officers not to look for the presence of possibly misidentified pests or disease symptoms, but rather to search for their potential hosts and therefore identify vulnerability areas, as exemplified by Potgieter et al. (2024). By targeting areas worthy of investigation (de Groot et al., 2022) — either because the presence of a pest is suspected, either because it concentrates vulnerable host species — the integration of citizen science platforms in the professional routine of plant plant protection officers has the potential to accelerate the early detection of newly introduced regulated pests (González-Moreno et al., 2025) and the implementation of appropriate measures. Second, if the former interpretation is valid, encouraging tree and forest professionals to report observations on these platforms, or facilitating the flow of data between citizen science platforms and the databases managed and maintained by plant protection professionals, has the potential to further increase the value of citizen science platforms. We acknowledge this could imply profound changes in agents' workflows as well as cultural change, which represents a major limiting factor (Magarey et al., 2009; Warman et al., 2025). We can only speculate on the reasons that might explain the observed discrepancy between using citizen science platforms to consult data and using them to contribute data, particularly data derived from the institutional surveillance of regulated pests and pathogens by the competent authorities. SORE experts have to carry out numerous mandatory inspections and probably have a busy schedule, leaving them little time to contribute data to citizen science platforms during working hours. Path dependency is another likely explanation: professionals already use dedicated reporting tools and may not feel the need to use others. Finally, the sensitive nature of quarantine pest occurrences might explain a wish to keep the circulation of information under control.We acknowledge this could imply profound changes in agents' workflows as well as cultural change, which represents a major limiting factor (Magarey et al., 2009; Warman et al., 2025).

Limitations

Respondents self-reported better knowledge of citizen science platforms than we had anticipated. Yet, the survey was designed so that respondents had to give their opinion on each platform they reported knowing. As a direct consequence, the length of the survey increased with the number of platforms known, which might have discouraged some respondents from continuing — hence the 51 respondents who did not complete the survey.

Because pests and pathogens can move freely across administrative borders, we intended to survey stakeholders from both the urban and forest sectors, and disseminated the questionnaire to both professional networks. However, after two weeks, we noticed that the vast majority of respondents had professional activities related to trees in urban environments and trees accompanying infrastructure, but far fewer strictly related to forests. We used various approaches to disseminate the questionnaire to stakeholders in the forest sector, including forest managers, advisors, owners, and the network of so-called *Correspondants-Observateurs* who are forest professionals appointed to the surveillance of regulated and emerging pests in France. Despite these efforts, direct contacts, and contacts with their hierarchy, we obtained a limited number of responses from the forest sector. This limitation constrains the scope of our interpretations and restricts the inferences that can be drawn about the potential of citizen science for the early detection of pests in forest ecosystems. Nonetheless, the low response rate among forest-sector professionals may itself reflect underlying patterns that would be worth investigating.

Finally, we cannot rule out that our having initiated the survey only a few months after the pinewood nematode was discovered in south-western France partly explains the lack of responses from the forest sector. Stakeholders involved in the crisis management may indeed have been overwhelmed by these emergencies. However, we note that this would only have concerned experts in the area under scrutiny, and would therefore not explain the lack of responses from stakeholders in other regions. Another possibility is that this crisis has revealed tensions among stakeholders — including authorities, research institutes, forest owners, and forestry companies — that have hampered their willingness to contribute to this research.

Conclusion

Our survey reveals ambivalent attitudes among tree and forest stakeholders regarding online citizen science platforms and their potential use for the surveillance of tree pests and diseases. First, it highlights that professionals whose activity does not involve the surveillance of regulated and emerging organisms have a limited knowledge of

quarantine pests, which could be partly extended to tree biosecurity more broadly. Yet engaging with citizen science has the potential to raise awareness of the risk and its mitigation (Crall et al., 2013; Pocock et al., 2024). Second, citizen science platforms are known to, and used by, half the responding stakeholders, including a majority of experts involved in the surveillance of regulated and emerging pests. However, they are used exclusively as a source of information rather than as a means of sharing information with others. This one-way usage by those most likely to make relevant observations in the field likely slows the diffusion of knowledge and awareness of the risk within the wider community. Finally, our results allow us to infer that professionals are not reluctant to consider citizen science platforms as a companion tool for tree biosecurity experts, helping to survey the spread of easily identifiable pests. However, we found no indication that citizen science can readily be integrated as a routine tool for the early detection of quarantine pests in France without further methodological and operational developments, the feasibility of which warrants further investigation.

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Consent to participate

Informed consent was obtained from all individual participants included in the study as part of the questionnaire.

Ethics declaration

Informed consent and patient details.

Written informed consent to take part in the study and to publish the article has been obtained from all participants or their legal representatives. The privacy rights of participants have been observed.

Studies in Human

This study was performed in compliance with relevant laws, regulatory frameworks and guidelines where the research took place.

Ethics committee approval was not required under relevant laws and institutional guidelines. Informed consent was obtained from all individual participants included in the study as part of the questionnaire.

CRediT authorship contribution statement

Bastien Castagneyrol: Writing – original draft, Visualization, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Souleymane Bah:** Writing – review & editing, Methodology, Investigation, Data curation. **Baptiste Bedessem:** Writing – review & editing, Methodology, Conceptualization. **Maarten de Groot:** Writing – review & editing, Funding acquisition, Conceptualization. **Amal Ennabih:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tfp.2026.101552.

Data availability

The dataset generated and analysed during the current study is available here:

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