

An impact-based prioritization of the European Union's List of Quarantine Pests

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ABSTRACT

Here, we propose organisms from the European Union's (EU) List of Quarantine Pests for regulation as priority pests based on their potential economic, social and environmental impacts in the EU territory. First, a shortlisting methodology was developed to recommend, from the total organisms in the Union Quarantine Pest list, a subset of pests for detailed assessment. Second, expert knowledge was elicited for 46 pests selected by EU risk managers from the shortlisted pests. Third, expert-based estimates of biological parameters were used to inform a multi-criteria analysis. Our methodology combines impacts on economic, social, and environmental domains into a composite indicator, which is used to rank the pests by their expected impacts. The robustness of our recommendation with respect to the uncertainty in biological parameters and the potential diversity of importance given by risk managers to different domains was evaluated. The contributions of the economic, social, and environmental impact-domains to the composite indicator reveal that high potential impact can be driven by diverse profiles. The regulation on priority pests mandates control and monitoring efforts in all EU Member States, which require considerable resources. Our study provides evidence-based decision support to risk managers, to inform decisions on where to allocate the limited resources for plant health surveillance and monitoring. If the list of priority pests is to remain unchanged in size, our results suggest that if based only on impacts, 9 of the 20 currently listed pests should be substituted.

1. Introduction

The spread of invasive species is one of the main drivers of global biodiversity loss (Clarke and McGeoch, 2023; Doherty et al., 2016; Gallardo et al., 2024). Estimates from FAO consider that up to 40% of crops can be lost because of pests and diseases in pre- or post-harvest stages (FAO, 2022), similar figures are reported by Savary et al. (2019) who signal that the impact is very heterogeneous by crop and region. This risk underscores the need to safeguard against invasions of new crop pests (Savary et al., 2019). Much research has been devoted to controlling such invasions (Baker, 2017; Epanchin-Niell, 2017; Kim et al., 2006; Mehta et al., 2007), with the general consensus being that prevention efforts are better than managing introduced species. However, prevention efforts can also require significant resources, both financial and human (Hauser and McCarthy, 2009). The long list of potentially harmful invaders in turn challenges risk managers in their

allocation of scarce resources. Arguably, resources should be allocated to mitigate pest risk up to the point where the marginal cost of mitigation is equal to the expected marginal damage of the pest (i.e. the damage avoided).

A significant body of literature deals with the usually negative consequences of invasive species (Dobrzycka-Kraheil and Román-Hidalgo, 2025; Doherty et al., 2016; Paini et al., 2016). Impacts of invasions may be direct losses to yields (Savary et al., 2019), or by exacerbating existing problems such as mycotoxin contamination. (Giacopelli et al., 2025; Kolawole et al., 2025). Nevertheless, assessments of potential future impacts of possible invasion scenarios are most often performed on individual species and single impact metrics such as production losses (Kartakis et al., 2025; Schneider et al., 2020). The agricultural system is inherently complex with potentially multifaceted consequences in economic, social, and environmental domains (Karri et al., 2026). While joint impact assessments across these three pillars are becoming more

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frequent (Ferreira et al., 2022), a quantitative multi-criteria indicator on the potential impacts of invasive species is currently lacking.

The European Union (EU) adopted Regulation 2016/2031, which establishes measures to protect the EU's territory and plants, addressing the risk of biological invasion for the Union (Baquero et al., 2023; Seebens et al., 2021). As part of this regulation, a list of quarantine pests has been compiled for pests capable of entering and establishing. The list is subject to regular amendment based on information on pests' emergence and impact in non-EU countries and their distribution in the EU. At present, the list contains 395 pests.

For species expected to cause the most severe economic, environmental, and/or social impact, the European Commission (EC) adopted the Commission Delegated Regulation (EU) 2019/1702, which establishes a List of Union Quarantine Pests (UQPs) that qualify as 'priority pests', as outlined in Article 6(2) of Regulation (EU) 2016/2031 on protective measures against pests of plants. To inform that decision, an estimation of potential impact of a selection of pests using the Impact Indicator for Priority Pests (I2P2) had been conducted (Sánchez et al., 2019). I2P2 is a composite indicator intended to reflect the potential economic, social, and environmental impacts if a pest were to occupy its full potential distribution in the Union's territory assuming farmers and foresters maintain their current practices.

Here, we extend the previous assessment to the full list of Union Quarantine Pests. To achieve this, we begin with a shortlisting process from which 46 pests were selected combining information of production and area at risk, invasiveness and priorities of EU risk managers for an in-depth evaluation conducted by the European Food Safety Authority (EFSA) with over 100 experts. The expert-elicited parameters inform a multi-criteria assessment that derives pest-specific impact scores. The composite impact scores are then ranked, supporting a more informed discussion between EU Member States' risk managers and the EC when deciding which pests to include on the list of priority pests. Our results provide evidence-based decision support to risk managers, to inform decisions on where to allocate the limited resources for plant health surveillance and monitoring. In doing so, our article makes a significant contribution to science-based regulation, showing how plant health law requirements can be implemented following a science-based approach.

2. Materials and methods

In what follows, first we describe the methodology used to shortlist the full set of Union Quarantine Pests (UQPs). Second, we provide a summary of the expert knowledge elicitation. Third, we describe the I2P2 model (Sánchez et al., 2019). Lastly, we sketch all robustness checks performed.

2.1. Shortlisting step

An application of the developed multi-criteria model on the entire UQP list was judged to be infeasible in terms of the resources that would be needed to conduct EKEs for nearly 400 pests. In turn, a shortlisting methodology was developed to guide risk managers in selecting a subset of pests for detailed analysis by I2P2.

A less data intensive shortlisting methodology was developed to assist risk managers in selecting the subset of pests for which such a detailed analysis should be conducted (European Food Safety Authority (EFSA), 2023). By combining an evidence-based invasiveness score with publicly available host-data from Eurostat, FAOSTAT, and country-level forestry inventories, the shortlisting focused on quantifying the potential speed of an invasion with the relative impact based on host production value (Euro) and area under cultivation (ha). The analysis involved constructing a comprehensive host-species list for each pest, drawing from multiple sources. By reviewing values available from literature concerning spread capacity in combination with crop production and forestry data, the shortlisting focused on obtaining an initial ranking based on their capacity of spreading and likelihood of finding

suitable hosts of economic relevance to the EU. Sub-sections from 2.1.1 to 2.1.4 describe in detail the methods used for the shortlisting step. This shortlisting approach clearly employs a set of simplified worst-case assumptions regarding host availability and potential impacts. Specifically, we assume that each pest could spread to the full extent of its host's distribution within the EU, and that the impact would equate to the total value of the host's production or area. This pragmatic approach aims to minimize an inefficient allocation of public resources by swiftly excluding pests that would very likely remain a low priority relative to other pests in the assessed sample.

2.1.1. Host list

We first compiled a list of hosts for all pests. Three databases were used to compile this information. Namely, the EPPO Global Database, relevant EFSA outputs (Pest Categorisations, Pest Risk Assessments, Pest Survey Cards, and Priority Pest Reports), the CABI Compendium¹, and other authoritative options (e.g. national pest risk analysis). The systematic literature search yielded 91 pests for which host impacts were expected to be minor. These pests were excluded from subsequent analysis as the ranking exercise is driven by impact and pests with minor impacts would obtain low values in the indicator used for ranking. Host-data extraction was also not conducted for pests regulated only because of their vectoring capacity without direct impacts on host plants. Last, macro groups (i.e. taxa regulated at family or genus level), were also excluded as the number of plant species that can potentially host at least one species belonging to the macro group can be very high.

2.1.2. Invasiveness score

For the shortlisting process, the importance of the spread of each pest with reported impact(s) was quantified using an invasiveness score, calculated for each of the 395 UQPs (European Food Safety Authority (EFSA), 2023). The invasiveness score for each pest was determined by summing the values assigned to key spread mechanisms relevant to that pest. The natural and human-assisted spread mechanisms of each UQP were extracted from EFSA's pest categorisations. Each spread mechanism was assigned a value, ranging from 1 for very low to 5 for very high, by expert consultation reflecting its relative contribution to the pest's potential spread capacity. Invasiveness scores ranged from 4 to 20 and were normalized by the maximum to derive scores between [0,1].

2.1.3. Production data

The pest-specific host list was subsequently matched to all available Eurostat and FAOSTAT data on production, area under cultivation, and prices. For forestry hosts, no data is available in Eurostat or FAOSTAT. Consequently, previously conducted Member State surveys were used to obtain data on the national area, growing stock, and prices for different forestry hosts. Data were collected at species level, when possible, otherwise at genus or family level as a backup.

For crop-hosts, the annual production and area under cultivation was represented by computing median values. The year range was dynamically adapted to the data availability at country- and host-level to include at least three years going backwards from 2021. Similarly to the year-range prioritization, the database used for production values and prices were dynamically adapted to the data availability at country- and host-level. Priority to select the databases was given to Eurostat as a source and production as a concept.² EU-wide area or value of target hosts was computed by aggregating country- and host-specific impacts for production value and area under cultivation, respectively. Crop and

¹ <https://www.cabidigitallibrary.org/journal/cabicompendium>.

² This means the following hierarchy in data source use: 1) production and prices from Eurostat; 2) production from Eurostat and prices from FAOSTAT; 3) production from FAOSTAT and prices from Eurostat; and 4) production and prices from FAOSTAT.

forestry estimates were standardized by the maximum values across pests to derive the measurement in relative terms. This does not estimate actual impact, which would require pest-specific yield loss estimates, but rather identifies pests threatening larger production values under a worst-case assumption.

Of the 219 pests with at least one host record, 9 could not be matched to any economic host data and were excluded, leaving 210 pests. For each remaining pest, EU-level host value and host area were computed and standardized by their respective maxima across pests to derive relative scores in $[0,1]$. These were combined with the normalized invasiveness score as an unweighted sum, giving a theoretical maximum of 2. Pests were ranked directly by this composite score, separately for the value-based and area-based variants.

2.1.4. The standing committee on plants, animals, food and feed (PAFF)

The union of the top 50 ranked pests under the value-based and area-based composite scores comprised 66 pests; of these, 22 had already been evaluated under the prior 2019 assessment, leaving 44 new candidate pests. We proposed these 44 candidate pests for detailed analysis to the PAFF Committee, in addition to the 20 pest species already regulated as priority pests and 3 further pests evaluated under the 2019 assessment but not currently regulated. The PAFF Committee comprises national experts representing the National Plant Protection Organizations of the EU Member States and informs the implementation of legislation that is already adopted. All selected candidate pests would be subject to the same comparative I2P2 analysis taking into account the most recent available knowledge to allow for the relative ranking.

The Committee's role was to confirm the selection of pests for in-depth analysis, drawing on their regulatory- and domain-expertise. In selecting the pests for further analysis, in addition to their relative ranking using the shortlisting approach described above (for new pests) and the I2P2 score obtained in 2019 (for pests already analyzed), the PAFF considered the additional factors described in Section 3.2.

2.2. Expert knowledge elicitation (EKE)

EFSA compiled pest-specific evidence dossiers, identified world-leading experts for each pest, and conducted EKEs for the selected pests. In what follows, we describe the results of this in-depth analysis. For more detailed results on the shortlisting step, readers are referred to the Supplementary Material and Schneider et al. (2025). This process aimed to assess the available evidence and estimate a set of parameters as inputs for the I2P2, as detailed in (European Food Safety Authority (EFSA), 2025c). The main estimated parameters were the lag period (expressed in months or years), rate of expansion (expressed in meters or kilometers per year), and impacts on crop production (yield and quality losses expressed in percentage of yield reduction and/or quality losses), as well as the environment (see environmental impact indicators below).

After reviewing the compiled evidence and uncertainty related to all parameters, experts first selected the hosts for the impact assessment on agricultural and forestry production. These hosts were chosen based on pest preference, plant susceptibility, and economic and ecological importance in the EU. Next, the EU area of potential distribution of the pest was determined, encompassing both the area of potential establishment and regions where the pest may occur seasonally (transient populations), together with the area of distribution of potential hosts. The EU area of potential distribution is defined by the presence of suitable hosts and favorable climatic conditions for pest development, with protected crops also considered when relevant.

Under a set of standardized general and specific scenario assumptions the experts were guided through a group exercise by an elicitor, answering questions related to the parameters to be estimated. The EKE process, including scenario assumptions, and specific questions posed to experts during the EKE meetings are detailed in (European Food Safety Authority (EFSA), 2025c). One of the key parameters from the EKE process is the estimate of yield and quality losses once the pest's

maximum spread has occurred. This parameter is provided as pest-host specific probability distribution with the parameters being the values estimated to reproduce the quantiles elicited by experts. We implemented these distributions using Python statistical libraries ensuring compatibility with the @RISK parameterisations used by EFSA. The yield loss estimates are then adjusted by the relevant Member State using country-specific 'proportion' factors provided by EFSA, resulting in pest-host-country-specific yield loss estimates. For each pest, we computed the non-normalized indicator values for 99 percentiles spanning the 1st through to the 99th yield loss quantile. Subsequently, we used Latin Hypercube Sampling to generate 100,000 simulations that systematically mixed and compared all possible yield loss quantiles across pests. Each sample represents one complete I2P2 scenario where every pest takes a specific percentile value from its yield loss distribution, independently from the values taken by other pests.

2.3. Impact Indicator for Priority Pests (I2P2)

The Impact Indicator for Priority Pests (I2P2) is a composite indicator to rank plant pests based on their potential economic, social, and environmental impacts in the European Union (Sánchez et al., 2019). The structure tries to capture all the impacts that according to the Plant Health Regulation (EU 2016/2031) would lead a pest to be considered a 'priority pest'. The I2P2 model is a hierarchical indicator with four tiers: the I2P2 score ($N = 1$), the domain specific values ($N = 3$), the sub-domain specific values ($N = 10$), and the indicator specific values ($N = 24$). A full overview of the model is provided in Table 1. All calculations are carried out considering that the pest has already entered the EU irrespective of the probability of this entry happening. Moreover, yield impacts are assumed under a scenario of maximum spread assuming that farmers and foresters maintain current management practice. Therefore, the time needed to reach the maximum impact is not taken into account when measuring impacts. When pests can affect multiple hosts (polyphagous pests), indicators are aggregated for all pest-host pairing when the data are cardinal and in absolute values. When that is not the case (i.e. shares or ratios), the maximum value of the indicator from the different pest-host values will be taken.

For the economic domain, we consider three sub-domains and eleven indicators that cover the impacts on production, disturbances to international trade, disturbances to the internal market and impact beyond agricultural markets. For production, the sub-domain includes three indicators that consider the value of expected losses, the share that those losses represent in total production and the production that would be at risk before the pest was detected. For trade, the sub-domain includes four indicators that consider the number of trade partners that would ban imports from the EU if the pest was present, the value of the exports to those countries, how much that value relates to total production in the EU and a measure of dispersion of exports. For internal market impacts, the sub-domain includes two indicators that measure the potential impact on prices, and the relative size of the production loss in relationship to imports. Lastly, for the impact beyond agricultural markets, the subdomain includes two indicators capturing potential impacts on input providers (upstream) and sectors using the affected commodities (downstream). Systematic differences in terms of economic stocks (forestry hosts) versus economic flows (crop hosts) are accounted for through pest-group-specific normalizations of indicators. In particular, for forestry, the impacts on production represent a reduction in the value of standing stock, while for crops, impacts on production represent a reduction in the annual flow values. Both are comparatively static, with the underlying assumption that the pest has reached its maximum distribution and is causing the elicited, host-specific, yield impact.

For example, the first indicator (maximum value of production losses), refers to the market value of the production reduction, plus the loss in market value of the production affected by quality loss due to damages caused by the pest during the outbreak in the potential area affected in a scenario of maximum spread. The indicator is calculated as follows,

Table 1

Overview of the I2P2 model illustrating the domain specific values ($N = 3$), the sub-domain specific values ($N = 10$), and the indicator specific values ($N = 24$).

Domain	Sub-domain	Indicator		
Economic Impacts	1.1 Production impacts	I.1 Maximum value of production losses		
		I.2 Share of EU production value affected		
		I.3 Difficulty of eradication		
	1.2 Trade impacts	I.4 Number of importing countries expected to impose restrictions on trade		
		I.5 Value of export losses		
		I.6 Share of export losses over total production		
		I.7 Trade dispersion		
	1.3 Price and market impacts	I.8 Change in domestic price		
		I.9 Change in domestic production over imports		
	1.4 Impacts on other agents	I.10 Upstream effects		
		I.11 Downstream effects		
Social Impacts	2.1 Impact on employment	I.12 Job losses		
	Crops		Trees	
	2.2c Impact on food security or food safety	I.13c Share of caloric supply	2.2f Impact on social forestry aspects	I.13f Quantity losses of wild forest products collected by households
		I.14c Share of protein supply		I.14f Reduction in quantity sold by Households with wild forest products income exceeding 10%
		I.15c Share of fat supply		I.15f Losses in PM2.5 accumulation capacity affecting forests
		I.16c Ability to produce fungal toxins		I.16f Losses in PM2.5 accumulation capacity affecting street trees and parks
	2.3 Impact on recreation, landscape or cultural heritage	I.17 Share of holdings with other gainful activities		
		I.18 Products covered by EU quality labels		
		I.19 Presence of affected hosts on cultural heritage landmarks		
Environmental Impact	3.1 Impact on ecosystem services	I.20 Loss in EU ecosystem service flow		
	3.2 Impact on biodiversity	I.21 Loss in EU community biodiversity		
		I.22 EU protected areas with host plants		
		I.23 Weighted count of IUCN host species		
	3.3 Increase of the use of plant protection products	I.24 Increase in pesticide use		

adding across the different MS (i) and the different hosts affected by the pest (j):

where PL is the maximum value of production losses in euros, A is the host planted area in hectares, Y is the yield of the host in tonnes per hectare, P is the average price of the crop in euros per tonne, P' is the

$$PL = \sum_{j=1}^{j=n} \sum_{i=1}^{i=28} \left[\left(A_{j,i} \times Y_{j,i} \times P_{j,i} \times r_{loss\ i,j} \right) + \left(A_{j,i} \times Y_{j,i} \times (1 - r_{loss\ i,j}) \times Q_{loss\ i,j} \times (P_{j,i} - P'_{j,i}) \right) \right]$$

average price of the second quality crop in euros per tonne, r_{loss} represents the EFSA provided potential proportion of loss in yield, and Q_{loss} the EFSA provided potential proportion of remaining production after yield loss that would result in lower quality product.

For the social domain, we consider three sub-domains and seven indicators which cover impacts on employment, food security and safety, and recreation, landscape and cultural heritage. For employment, the sub-domain includes an indicator that considers the number of jobs that would be lost due to reduced production. For food security and safety, the sub-domain includes four indicators. The indicators used in this sub-domain varies depending on whether the pest affects crops or trees. For pests affecting crop production, three indicators focus on food security capturing the impacts on food availability in terms of calories, proteins and fats. The food safety indicator focuses on whether the pest has the ability to produce toxins that in turn would pose a risk to human health. For pests affecting trees, two indicators focus on food security capturing the production of wild forest products associated with the affected trees. The food safety aspect is replaced by the potential health impacts of reduced forests in particulate matter accumulation both in urban and rural areas.

For example, when calculating indicator number 12 (job losses) this is estimated in terms of reduced labour use per activity, for each individual host affected by a pest, which is linked to the extent of the impact of the pest on production. We only consider employment losses and not potential additional labour needs related to control and eradication measures. The indicator is calculated as follows, adding across the different MS (i) and the different hosts affected by the pest (j):

$$JL = \sum_{j=1}^n \sum_{i=1}^{i=28} \left(A_{ji} \times \frac{PL_{ji}}{TP_{ji}} \times L_{ji} \right)$$

where JL is the effect on employment loss in number of annual working units, A is the host planted area in hectares, PL is the production loss in quantity due to the pest outbreak, TP is the total production and L is the labour requirement per hectare in AWU for production of the host.

For the environmental domain, we consider three sub-domains and five indicators which cover the impacts on ecosystem services, biodiversity and undesired effects of control measures (detailed in (European Food Safety Authority (EFSA), 2025c)). For ecosystem services, the sub-domain includes an indicator that evaluates the reduction in ecosystem services flow as a consequence to the pest presence (for detailed results see EFSA, 2025f). For biodiversity, the sub-domain includes three indicators that measure species biodiversity at community level, the relative importance of pests' hosts on protected areas of the Natura 2000 network and the number of species with conservation concern considers all host species falling in IUCN classes weighted by the level of extinction risk and the estimated pest symptom severity. For undesired effects of control measures, the sub-domain includes an indicator focusing on the expected increase in the use of plant protection.

For example, when calculating indicator number 22 (EU protected areas with host plants) this is estimated as the level of exposure of the different Natura 2000 sites to the risk of the pest's presence. For this we consider the importance of the host plants in the plant communities of the area at risk defined as potential area of establishment. The importance of the hosts is calculated as the area covered by host plants of the pest in the Natura 2000 area as follows:

$$PA = \sum_{i=1}^{i=n} \frac{NH_i}{NS_i} \left/ \frac{AE_i}{AT_i} \right.$$

where i represents each of the protected areas where the host plant(s) is (are) part of the plant communities present, NH is the number of host species, NS is the total number of plant species, AE is the area of establishment for the pest in the specific protected areas and AT is the total area of the protected area.

An overview table holding the formulas used in the construction of

the 24 indicators can be found in the supplementary materials. For further details on the construction of the other individual indicators, readers can refer to Sánchez et al. (2019) for the model, Schneider et al. (2025) for the updates, and European Food Safety Authority (EFSA) et al. (2025) for the environmental domain.

When constructing the composite indicator, we incorporate the difference in measuring units and unbalanced distribution of sub-domains and indicators. To tackle the former we normalize values at indicator level before the aggregation. The different indicators have different units (e.g. euros, number of countries, share of production) and scales (e.g. from 0 to infinity, from 0 to 218, from 0 to 1). In order to avoid this affecting the importance an indicator has in the overall index, before aggregating the specific indicators (see below) each one is normalized following this expression:

$$I_n = \frac{X - X_{min}}{X_{max} - X_{min}}$$

where I_n is the normalized value of an indicator, X the original value of the indicator, X_{max} the maximum value the indicator takes for the pests assessed, and X_{min} the minimum value. This normalization implies that the maximum value of the indicator will be 1 and the minimum 0, with all the rest distributed in the $[0,1]$ space. Due to the difference in indicators used for the food security and safety sub-domain for pests affecting crops and trees as well as for the difference in production data for crops and trees normalization and ranking is done separately for these two types of pests.

For the latter, the composite indicator is constructed using a hierarchical weighting structure that split importance equally across sub-domains and indicators within them.

Due to the unbalanced number of indicators under each of the three main domains and ten sub-domains a hierarchical weighting approach is proposed to avoid that more importance is given to any given (sub) domain due to the existence of more data. Under this approach, the weight (100%) at each level is split among the three main domains, the different sub-domains, and the individual indicators. In this manner, and under an equal weights scheme domains, the fact that there are four sub-domains for economic impact domain and three for social impact one has no impact on the overall importance of the domain. The same applies across sub-domains, where one sub-domain has several indicators and another just one. The final indicator specific weight ($\bar{W}_{ix}$) is the result of the multiplication of the domain weight, the sub-domain weight and the indicator weight as follows:

$$\bar{W}_{ix} = W_{Di} \times W_{SDj} \times W_{lix}$$

s.t.

$$\sum_{i=1}^{i=3} W_{Di} = 1$$

$$\sum_{j=1}^{j=n} W_{SDj} = 1 \quad \forall i(1,3)$$

$$\sum_{x=1}^{x=n} W_{lix} = 1 \quad \forall i(1,3) \& \forall j(1,n)$$

where W_{Di} is the weight of the domain i in the I2P2 for each of the three domains, W_{SDj} is the weight of sub-domain j in its respective domain (with j taking the value 3 or 4 depending on the domain); and W_{lix} is the weight of the indicator in its respective sub-domain (with x ranging from 1 to 4 depending on the sub-domain). For example, the normalized weight of indicator I.2 ($\bar{W}_{i2}$) will be the result of multiplying the weight of the economic impact domain (W_{D1}) by the weight of the production sub-domain (W_{SD11}) by the weight of indicator I.2 (W_{i111}).

This aggregation rule considers that each of the domains, sub-

domains and indicators are perfectly substitutable, with a very high impact in one domain / sub-domain / indicators can be offset by lower impacts in others.

When a pest affects both kind of hosts, we use both sets of indicators for the food security and safety sub-domain and rank them separately. We provide additional results in the Supplementary Material showing correlations between indicators. While some indicators were found to be correlated, the construction of the I2P2 model, and thus the inclusion of the various indicators, was not based on the expected statistical properties of the final design, but rather on the model reflecting the legal text of the underlying regulation. Because correlated indicators are grouped within the same sub-domains, their joint influence is mediated through that aggregation. The equal weighting across sub-domains ensures that these correlations do not disproportionately affect the overall index.

Compared to the previous version of I2P2 (Sánchez et al., 2019), we updated all underlying data where available and the expert-based estimates of biological parameters, the geographic scope reflects the EU after Brexit, and added four social indicators for forestry hosts that deal with non-wood forest products and the loss in the absorption of particular matter.

2.4. Robustness checks

The model has several sources of parameter-specific uncertainty. First, the elicited biological parameters are uncertainty distributions. Second, the aggregation from indicators to sub-domains, from sub-domains to domains, and from domains to the final I2P2 score follows a subjective weighting scheme that might influence the results. We address both these sources of uncertainty through simulation-based analyses.

The EKE provides pest-host-specific yield loss point estimates derived from probability distributions based on estimates elicited from experts. These distributions may reflect the substantial uncertainty inherent in pest impact assessments, for example, that arising from limited empirical data on Union Quarantine Pests (UQP), expert confidence and context-dependent biological processes. However, the ranking results assume deterministic yield impacts taken at median values for all pest-hosts. Concerning the biological parameters, for each pest we report the maximum rank it can attain in the 100,000 simulations of percentile specific yield loss for each pest as well as the percentage of cases in which the pest falls into the top 10 (for pests affecting crops) or top 6 (for pests affecting trees).

In each of the 100,000 simulations, a yield loss percentile between the 1st and 99th was drawn to obtain a full alternative set of pest-host yield-loss values; draws were independent across pest but common across their hosts to reduce the overall parameter dimensionality. Indicator normalization was recalculated within each simulation using the

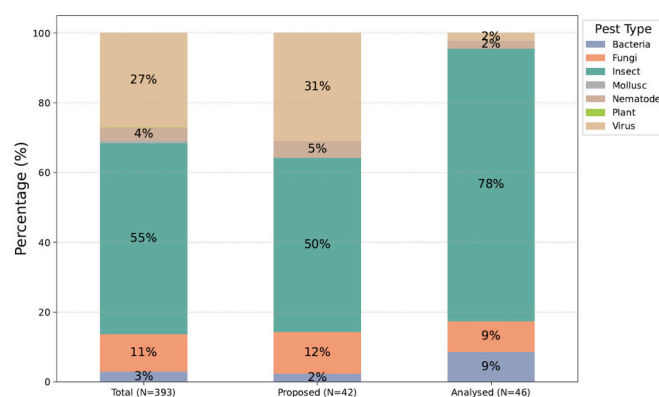


Fig. 2. Proportion of pest types in the List of Union Quarantine Pests, short-listed and proposed to The Standing Committee on Plants, Animals, Food and Feed (PAFF), and the by risk managers selected pests for an in-depth analysis.

drawn values, and the I2P2 score and ranking were recomputed for every simulation under the same equal-weight aggregation as used in the main analysis. This robustness check assesses uncertainty in the elicited proportion of yield loss only with the other parameters held fixed. The choice of a yield-specific uncertainty assessment was made due to the parameter being used in a wide range of indicators.

With regards to the subjective weighting scheme, the main results presented correspond to an equal weighting scheme across sub-domains and domains. Nevertheless, we perform a sampling approach to simulate combinations of different weights used in the aggregation step. Subsequently, we assess the lowest rank a pest could achieve under any weighting scheme.

In addition, the additive aggregation rule used to obtain the I2P2 score is itself a modelling choice, as it allows a high score in one domain, sub-domain, or indicator to offset a low score elsewhere (compensability). To assess the impact of this choice on the ranking, we recomputed pest rankings using three alternative aggregation rules that span a range of established multi-criteria approaches. The hierarchical model structure (domain, sub-domain, indicator) was held fixed, while the aggregation operator was varied: (i) a weighted geometric mean, which partially penalises imbalanced profiles; (ii) a weighted Chebyshev (minimax) compromise, which is the fully non-compensatory extreme in which a pest's score is driven by its worst-performing weighted indicator, following the logic of (Xavier et al., 2025); and (iii) a Borda rank-based aggregation, which replaces normalized indicator values with within-group percentile ranks before applying the same weights, making the result robust to skewness in the underlying indicator distributions.

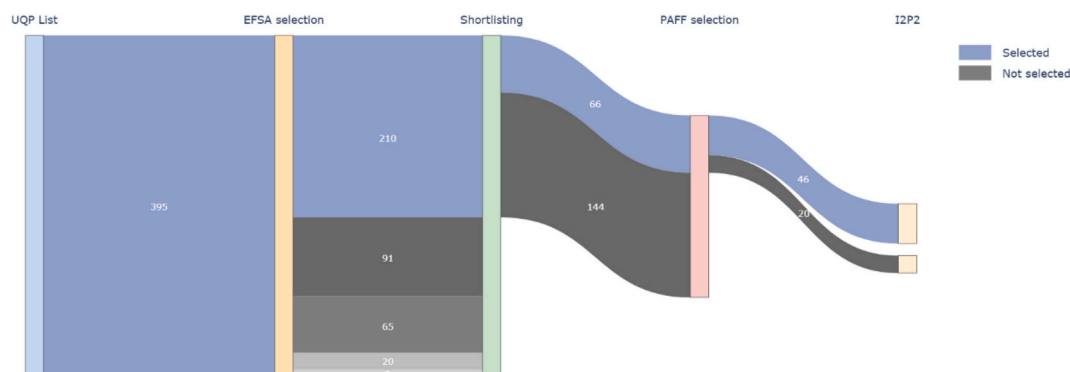


Fig. 1. Flow chart of the pest selection. Different shades of grey in the EFSA selection refer to pests without reported impacts ($N = 91$), vectors ($N = 65$), macrogrogroups ($N = 20$), and pests for which no economic host data was identified ($N = 9$).

3. Results

3.1. Short-listing step

Of the 395 UQPs, 20 pests were excluded in agreement with the legislators due to being macrogroups, 65 pests were excluded in agreement with the legislators due to being disease vectors with no direct impact on plants, and 91 pests were excluded due to the absence of reported impacts on host plants according to our systematic review of the literature (see unique subset following Criterion 2 to 4 in (European Food Safety Authority (EFSA), 2023)). On average across the remaining pests, 83% of the hosts were successfully matched to data for the shortlisting step. For nine pests, none of the hosts could be matched to data (Fig. 1). The matching resulted in an assessment of 65 unique crop-host and 86 unique forestry-host.

Under the assumption of full yield losses, this shortlisting step resulted in a preliminary ranking of 210 pests. The union of the top 50 ranked pests under the value-based and area-based composite scores comprised 66 pests, of which 44 were new candidates not previously assessed (Section 2.1.4). Following review by the PAFF Committee, 23 of these 44 were selected for in-depth analysis; together with the 20 currently regulated priority pests and 3 pests evaluated under the 2019 assessment but not currently regulated, this yielded the 46 pests assessed with the I2P2 approach in detail (Section 3.2), incorporating the additional factors discussed below.

3.2. Selected pests for the I2P2 analysis

The list of UQPs comprises 395 pests, of which around 55% are insects, 27% viruses, 11% fungi, 4% nematodes and 3% bacteria (Fig. 2). The subset of pests proposed to PAFF by our shortlisting methodology largely reflected the same proportions of pest types, implying that our methodology was unlikely to be biased toward any lifeforms. From the 66 shortlisted pests, 46 were subject to in-depth analysis. The reasons for excluding the 22 pests included: i) a low risk of introduction, e.g. due to existing import bans on host plants such as vines, conifers, and potatoes. ii) the difficulties in diagnostic differentiation, e.g. for the diverse strains related to *Candidatus Phytoplasma pruni* and *Phytophthora ramorum* (non-EU isolates). iii) whether pests already were subject to effective control measures and whose priority status would not improve the current phytosanitary regime, e.g. for *Candidatus Phytoplasma pruni* and *Phytophthora ramorum*. iv) whether pests are expected to become non-quarantine pests in the near future according to EU legislators, e.g. *Torradovirus lycopersici* and *Nepovirus nicotianae*. v) whether pests currently have a very restricted geographical distribution and are therefore posing a limited risk of introduction, e.g. *Oeonia hirta*. Finally, iv) whether pests already are widespread in the EU, e.g. the tomato leaf curl New Delhi virus. The subset of pests requested for in-depth analysis had a different composition, with a noticeable increase in the proportion of insects and bacteria and a decrease in the proportion of fungi and viruses (Fig. 2). The assessed pests reflect the selection made by EU risk managers under consideration of these additional aspects. Notably, the prevalence of polyphagous arthropods among pest introductions in the EU over the last two decades may explain the particular concern risk managers seem to have for this pest type (Rosace et al., 2023).

The 46 shortlisted pests include 36 insects, 4 fungi, 4 bacteria, 1 virus, and 1 nematode. They can be classified by their primary mode of interaction with their host plants and the resulting physiological or structural impact, albeit that some pests act through multiple modes.

A key group of shortlisted insects includes wood and stem borers, whose larvae or adults tunnel into plant tissues (Sreedevi et al., 2022). This activity disrupts vascular transport, weakens structural integrity and often facilitates secondary colonization by other pests. Notable examples include the bronze birch borer (*Agilus anxius*), the emerald ash borer (*Agilus planipennis*), and the oak timberworm (*Arrhenodes*

Table 2

Pest ranking and composite score under the median values for the elicited biological parameters and an equal weighting scheme for all sub-domains and domains. Score shows the relative composite impact of pests normalized within their group (crop, forestry, agroforestry). Prop. shows the cumulative proportion of the total composite impact for all pests represented by the pest considered. Econ., Soc., and Env. values refer to percentage contributions of economic, social, and environmental impact to the composite score.

Pest	Rank	Score	Prop.	Econ.	Soc.	Env.
Pest with crops as main hosts						
<i>Xylella fastidiosa</i>	1	0.66	10	35	37	28
<i>Listronotus bonariensis</i>	2	0.60	20	31	24	45
<i>Popillia japonica</i>	3	0.42	26	27	22	52
<i>Spodoptera litura</i>	4	0.35	31	47	30	23
<i>Thaumetobia leucotreta</i>	5	0.31	36	32	30	39
<i>Candidatus liberibacter</i>	6	0.29	41	41	20	38
<i>Porphyrophora tritici</i>	7	0.26	45	37	20	43
<i>Ralstonia pseudosolanacearum</i>	8	0.25	49	42	36	22
<i>Helicoverpa zea</i>	9	0.25	53	56	17	27
<i>Conotrachelus nenuphar</i>	10	0.24	56	32	45	23
<i>Diabrotica undecimpunctata howardi</i>	11	0.23	60	49	23	28
<i>Spodoptera frugiperda</i>	12	0.22	63	39	26	35
<i>Phylloticta citricarpa</i>	13	0.20	66	46	27	28
<i>Anthonomus eugenii</i>	14	0.20	69	24	20	56
<i>Bactrocera zonata</i>	15	0.19	72	26	46	29
<i>Bactericera cockerelli</i>	16	0.18	75	35	34	31
<i>Bactrocera dorsalis</i>	17	0.18	78	25	44	31
<i>Prodiptosis longifolia</i>	18	0.18	81	22	16	63
<i>Rhagoletis pomonella</i>	19	0.17	83	41	28	32
<i>Phymatotrichopsis omnivora</i>	20	0.17	86	71	25	4
<i>Thrips palmi</i>	21	0.15	88	15	13	72
<i>Xanthomonas citri</i>	22	0.15	91	34	30	37
<i>Anastrepha ludens</i>	23	0.14	93	28	33	39
<i>Acleris minuta</i>	24	0.13	95	27	31	42
<i>Choristoneura parallela</i>	25	0.10	96	18	26	55
<i>Keiferia lycopersicella</i>	26	0.09	98	34	7	59
<i>Diabrotica virgifera zea</i>	27	0.09	99	70	30	0
<i>Nepovirus myrtilli</i>	28	0.05	100	56	44	0
Average				37	28	35
Pests with trees as main hosts						
<i>Dendrolimus sibiricus</i>	1	0.55	19	27	36	37
<i>Agilus anxius</i>	2	0.40	33	39	56	6
<i>Choristoneura fumiferana</i>	3	0.27	43	48	36	15
<i>Polygraphus proximus</i>	4	0.25	51	31	41	28
<i>Anoplophora glabripennis</i>	5	0.25	60	13	32	54
<i>Pissodes strobi</i>	6	0.23	68	39	45	16
<i>Agilus planipennis</i>	7	0.22	76	72	22	5
<i>Pissodes nemorensis</i>	8	0.19	82	39	42	19
<i>Bursaphelenchus xylophilus</i>	9	0.12	86	37	27	36
<i>Bretziella fagacearum</i>	10	0.10	90	39	36	25
<i>Pseudocercospora pini-densiflorae</i>	11	0.07	92	50	29	21
<i>Pissodes nitidus</i>	12	0.07	95	64	36	0
<i>Arrhenodes minutus</i>	13	0.06	97	45	55	0
<i>Acleris semipurpurana</i>	14	0.06	99	71	5	24
<i>Pissodes terminalis</i>	15	0.03	100	100	0	0
<i>Pissodes yunnanensis</i>	16	0.00	100	100	0	0
Average				51	31	18
Pests with crops and trees as main hosts						
<i>Anoplophora chinensis</i>	1	0.51	57	35	50	14
<i>Aromia bungii</i>	2	0.38	100	24	7	69
Average				30	29	42

minutus). Coniferous trees are particularly susceptible to weevils such as *Pissodes* spp. and bark beetles (e.g., *Polygraphus proximus*), which attack shoots, terminals, and stems. Herbaceous plants are affected by pests such as the Argentine stem weevil (*Listronotus bonariensis*), whose larvae bore into stems while the adults feed on leaves. Defoliating pests, including both larvae and adults that feed on plant foliage (Schabel, 2006), represent another major group of shortlisted insects. Their

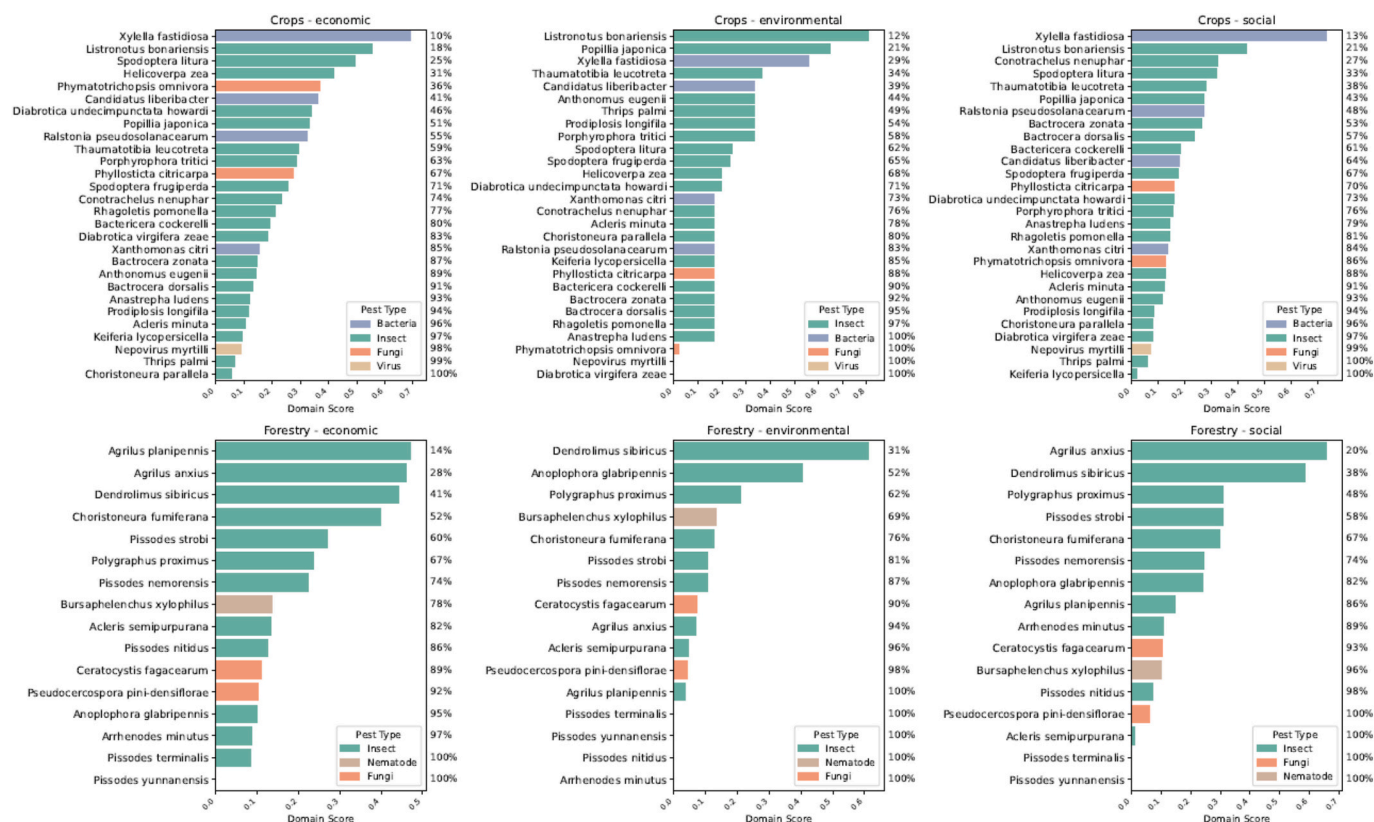


Fig. 3. Domain scores for crop and forestry pests under the median values for the elicited biological parameters and an equal weighting scheme for all sub-domains. The percentages on the right-hand sides show the cumulative proportions on the total domain impacts across pests.

feeding reduces photosynthetic capacity, increases plant stress, and decreases yield. Various leafrollers and budworms (*Acleris* spp. and *Choristoneura* spp.) damage a wide range of plants by feeding on and webbing leaves and buds. The Siberian silk moth (*Dendrolimus sibiricus*) threatens coniferous forests. Some shortlisted pests mainly target reproductive structures such as fruits, flowers and seeds, resulting in direct yield losses (Papadopoulos et al., 2024). The larvae of the corn earworm (*Helicoverpa zea*), for example, bore into corn ears, cotton bolls, and tomato fruits. Various fruit flies, including the Mexican fruit fly (*Anastrepha ludens*), oriental fruit fly (*Bactrocera dorsalis*), peach fruit fly (*Bactrocera zonata*), and the apple fruit fly (*Rhagoletis pomonella*), cause damage as their larvae develop within the pulp of fruits. Root-feeding pests among the shortlisted species impair plant health by attacking the root system (Johnson et al., 2016). This disrupts water and nutrient uptake, reduces overall vigour, and increases vulnerability to soil-borne diseases. Examples include the larvae of corn rootworms (*Diabrotica undecimpunctata howardi* and *Diabrotica virgifera zea*), Japanese beetle (*Popillia japonica*), and wheat ground pearl (*Porphyrophora tritici*). Their adult stages are also known defoliators.

Sucking pests extract sap from plant tissues using piercing-sucking mouthparts (Zhang et al., 2023). This leads to direct damage, such as stippling, distortion, and wilting. Some also act as vectors for plant pathogens or induce abnormal growths, such as galls, albeit that here only direct impact was accounted for. Examples include the melon thrips (*Thrips palmi*) which damages foliage and transmits viruses, the citrus gall midge (*Prodiptosis longifolia*), and potato psyllid (*Bactericera cockerelli*) which causes feeding damage and vectors the bacterium ‘*Candidatus Liberibacter solanacearum*’.

3.3. I2P2 analysis

Results for the multi-criteria analysis are presented in Table 2. I2P2 is

computed separately for crop, forestry, and agroforestry pests to account for systematic differences in data and some indicators. For example, value for crop hosts represent economic flows, whereas value for forestry hosts reflect economic stocks. Group-specific normalization of impacts adjust for such systematic differences and resulted in a dimensionless score that allows for relative comparisons across pests. For crop pests, *Xylella fastidiosa* remains the most significant threat, maintaining the highest position as in the previous assessment (c.f. (European Food Safety Authority (EFSA), 2025f; Sánchez et al., 2019)). *Listronotus bonariensis* follows, emerging as a pest with potentially high impact on permanent grasslands and cereals (European Food Safety Authority (EFSA), 2025d). Following these two pests, there is a considerable drop-off in the I2P2 scores for the remaining pests, with the third pest's impact score (*Popillia japonica* (European Food Safety Authority (EFSA), 2025e)) showing a substantially lower score. Overall, the top nine pests concentrate much of the assessed potential impact. For forestry pests, *Dendrolimus sibiricus* (European Food Safety Authority (EFSA), 2025b) was found to rank first, followed by *Agilus anxius* (European Food Safety Authority (EFSA), 2025a). Once again, a small group of four top-ranking pests captures a large share of the relative variation in potential impacts within the group.

Table 2 shows the domain-contributions to the overall impact score (see Supplementary Material for the sub-domain contributions). On average across crop pests, impacts in the economic, social, and environmental domains contributed 37, 28, and 35% to the overall impact, respectively. On average across forestry pests, the domains contributed 51, 31, and 18% to the overall impact, respectively. While the average contributions reflect broad impacts across all domains, pest-specific results reveal diverse impact profiles. Higher ranks were associated with more diversified impact profiles, suggesting that our methodology derives a prioritization that captures pests of concern across domains.

Fig. 3 decomposes the scores presented above into the three main

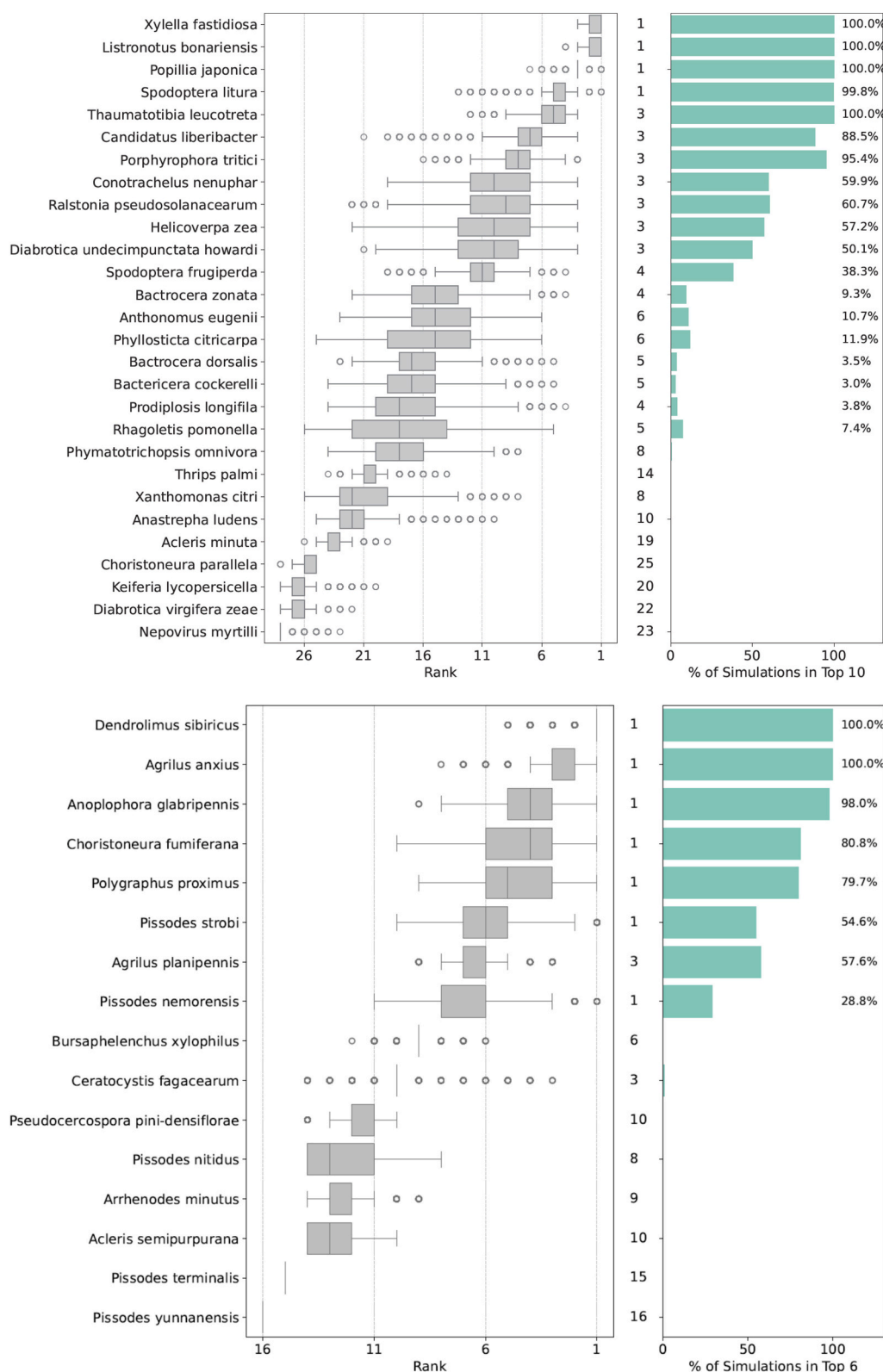


Fig. 4. Distribution of pest rankings across 100,000 stochastic yield loss scenarios for crop pests (top) and forestry pests (bottom). Rank distributions result from Latin Hypercube Sampling of pest-specific yield loss quantiles (1st-99th percentile), with each of the 100,000 scenarios representing one complete I2P2 ranking where every pest assumes a specific percentile from its elicited distribution. Left panels: Boxplots show the distribution of ranks obtained across all simulations, with boxes representing the interquartile range (25th to 75th percentile of ranks), horizontal lines indicating median ranks, whiskers extending to the 5th and 95th percentiles, and circles showing outlier scenarios. Narrow boxes indicate stable rankings with low sensitivity to yield loss uncertainty, while wide boxes indicate high rank volatility depending on the assumed yield loss. The maximum rank is displayed numerically to the right of each boxplot. Right panels: Green bars show the percentage of simulations in which each pest appeared in the top 10 (crops) or top 6 (forestry), providing a probabilistic measure of prioritization confidence. Pests are ordered by median rank within each host type category. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

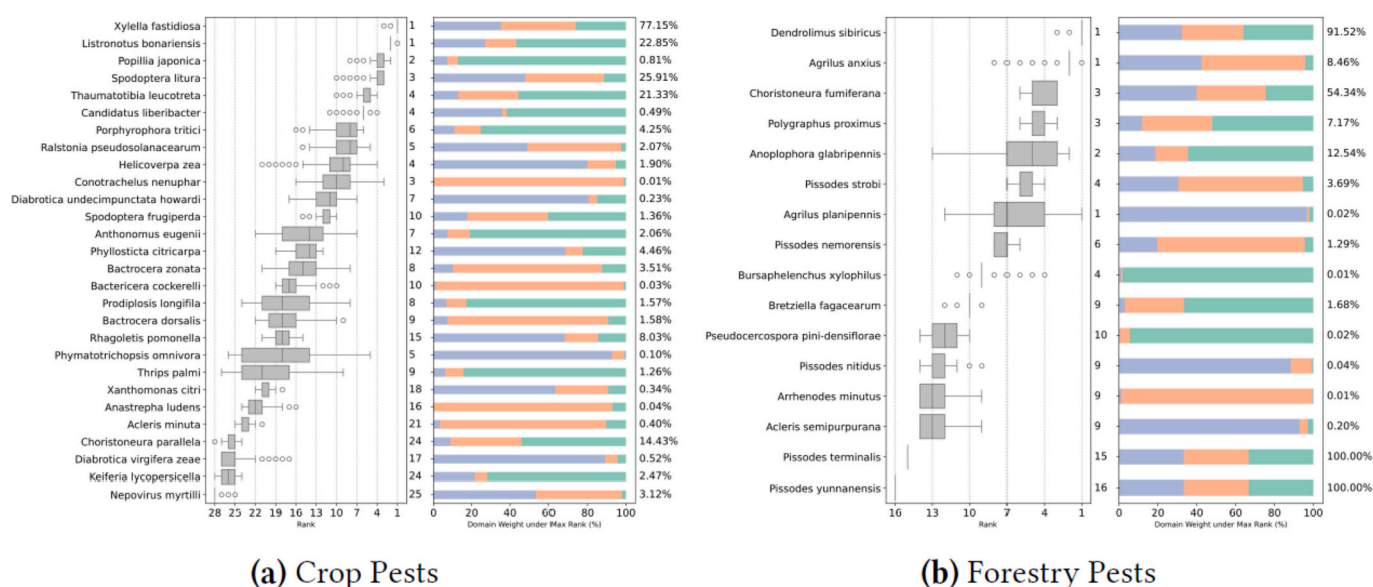


Fig. 5. Distribution of pest ranks for the stochastic simulation of domain weights. The maximum rank achieved is shown on the right-hand side of the rank distribution panels. The right-hand panels show the average domain weight (economic = blue, social = orange, environmental = green) for the subset of simulations that led to the maximum rank. The share of simulations (%) that led to the maximum rank is shown on the right-hand side ($N = 50,000$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

impact domains. This allows insights on pest rankings with regards to their economic, social, and environmental impacts only. For example, for crop pests *Listronotus bonariensis* and *Popillia japonica* are expected to outrank *Xylella fastidiosa* in terms of environmental impact, but not with regards to economic and social impacts. Across all impact domains, the top eight ranked pests caused over half of the domain impacts (Fig. 3). For forestry pests, *Dendrolimus sibiricus* is expected to cause considerable environmental and the highest social impact. However, in terms of economic impact *Dendrolimus sibiricus* drops to position three following *Agrilus planipennis* and *Agrilus anxius*. While for economic and social impacts, the top four ranked pests caused over half of the domain impacts, for environmental impacts *Dendrolimus sibiricus* and *Anoplophora glabripennis* alone caused over half of the domain impacts (Fig. 3).

Systematically incorporating uncertainty into the analysis (Fig. 4), we identify substantial heterogeneity in ranking confidence across pests, which can provide additional insights to inform prioritization decisions. From this perspective, we can classify pests into one of three categories. The first of them comprises organisms with exceptionally stable, high-priority rankings irrespective of the underlying uncertainty regarding yield impacts. In the case of pests affecting crops, we find four pests in this category which all achieve a maximum rank of 1 and appear in the top in over 99% of simulations. Their narrow rank distributions (interquartile ranges spanning from zero to two positions) indicate that prioritizing these pests is robust in the face of the elicited yield loss uncertainty. In the case of pests affecting trees, stable high-priority rankings are observed for two pests. A second group also consistently ranks in the top 10 in 88–100% of scenarios but with a higher rank volatility (interquartile ranges spanning from two to 5 positions) reflecting its wider yield loss uncertainty range. Their larger rank distributions indicate that prioritizing these pests is less robust in the face of yield loss uncertainty.

The third group contains pests which rankings are always low even in cases where their impacts would be at the highest end of their distribution and the rest of the pests at their lowers. For crops, this group contains seven pests and for pest affecting trees this group contains six. Based on their potential impacts, these pests should not be considered for prioritization.

An inherent property of multi-criteria analysis is an aggregation step to derive a composite indicator, such as the I2P2 score. This aggregation

is most frequently done in a weighted fashion, whereby the weights are intended to capture the subjective preferences of the risk managers (Razmak and Aouni, 2015). Our results for the I2P2 composite score were obtained using an equal weighting scheme, which was deemed to most accurately reflect the impartial preferences of EU legislators. However, since the weighting of different impacts is subjective and significantly influences the final pest ranking, we conducted a stochastic analysis to explore the robustness of results under different weighting configurations. Using a Latin hypercube sampling simulation, we generated 50,000 different weighting schemes to calculate corresponding I2P2 scores, allowing us to evaluate how pest rankings change when the relative importance of economic, social, and environmental impacts is varied by computing the highest rank each pest was able to achieve across all simulated weighting schemes (Fig. 5).

Evidently, there is a considerable overlap in the rank distributions, particularly in the center positions. Consequently, under preferences of risk managers who prioritize economic and social impacts over environmental ones the ranking could be affected. The rank distributions implicitly reveal the degree of multidimensionality in the anticipated impacts of the pests. For instance, the rank distribution across all possible weighting schemes for *Xylella fastidiosa* is narrow. This is attributable to the fact that *Xylella fastidiosa* scored highly in all domains (cf. Fig. 3), and variation in the weighting did not have a significant effect on the final rank. By contrast, the distribution for *Popillia japonica* is wider, because *Popillia japonica* scored highly only in the environmental domain, while placing in center positions for economic and social impacts (cf. Fig. 3). Hence, the final rank for *Popillia japonica* is more contingent on the weighting scheme.

Fig. 5 effectively takes a worst-case approach to each individual pest and suggests the maximum rank achievable if more importance were to be given to its main impact domain(s). In so doing, we provide preference-free results on the potential impact for each pest. The average domain weights and the share of simulations that led to the maximum rank inform on the generalization of the achievable maximum rank. For example, *Xylella fastidiosa* reached its highest rank in 77% of weighting schemes, whereas *Popillia japonica* reached its highest rank in only 0.80% of schemes that gave high weight to environmental impacts.

Reranking pests under the three alternative aggregation rules shows that the ranking in the main analysis is overall robust, but not uniformly

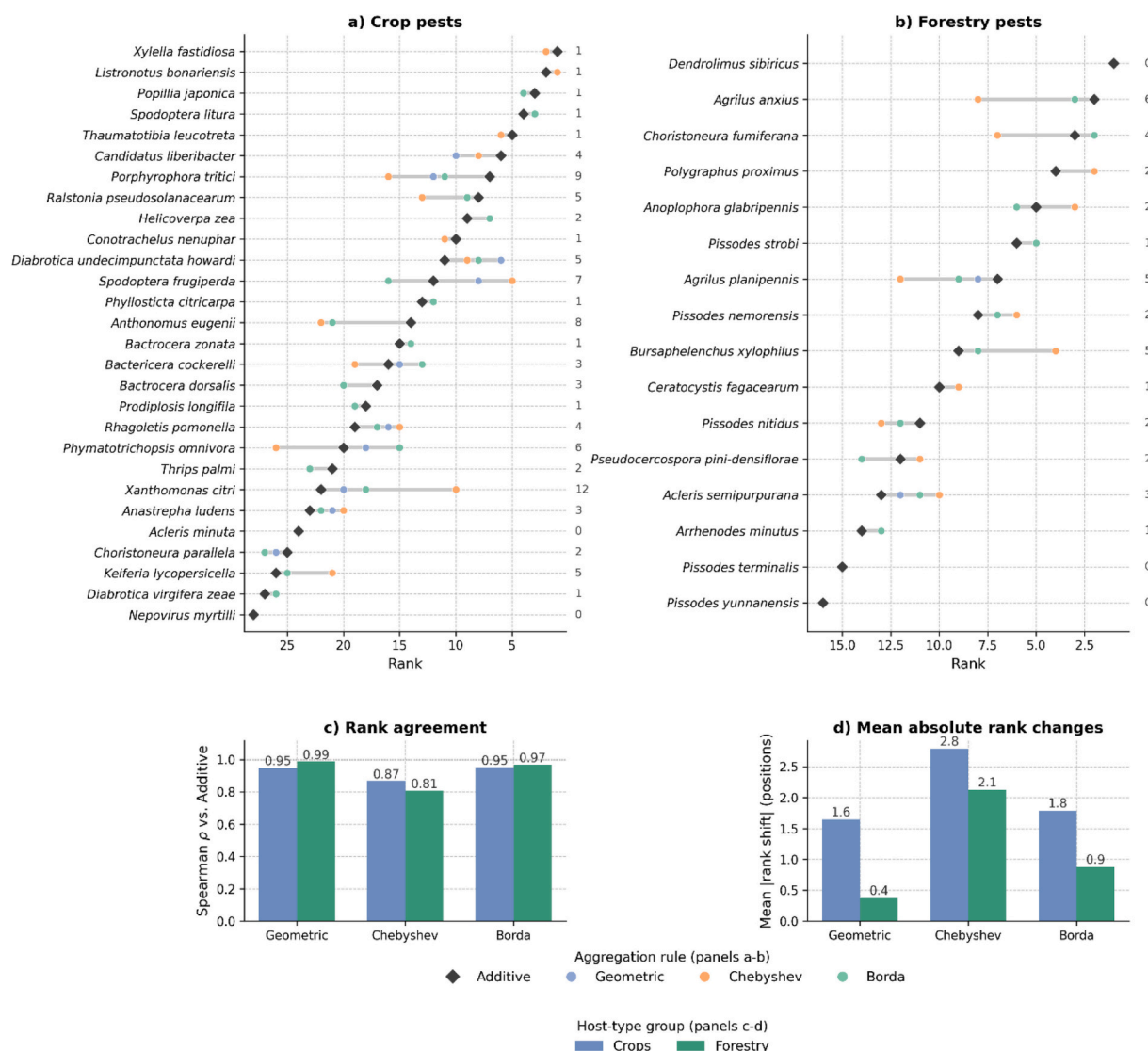


Fig. 6. Robustness of the I2P2 ranking to the choice of aggregation rule. (a-b) Rank of each crop (a) and forestry (b) pest under the main-text additive rule (diamond) and three alternative aggregation rules (circles); grey bars span each pest's full rank range across the four rules, and the number to the right of each row gives the largest rank shift (in positions) relative to the additive ranking. (c) Spearman rank correlation between each alternative rule and the additive ranking by host-type group. (d) Mean absolute rank shift relative to the additive ranking by host-type group.

so (see Fig. 6). The geometric and Borda rules remain close to the additive ranking (Spearman's $\rho = 0.95\text{--}0.99$ for both crop and forestry pests; mean rank shift of less than two positions), suggesting that the degree of compensability and the use of cardinal versus ordinal indicator information have little impact on their own. The Chebyshev rule, being the only fully non-compensatory alternative tested, diverges more ($\rho = 0.81\text{--}0.87$; mean shift of up to three positions), confirming that compensability is a meaningful choice for the ranking, particularly when it is entirely excluded rather than merely reduced. Robustness is highest at the (politically relevant) top of each list, with sensitivity to the aggregation rule occurring mostly in the middle of each ranking. This is consistent with the fact that, by construction, pests with a uniformly high or low profile across domains are aggregation-rule-invariant whereas those with an uneven profile are not.

4. Discussion

The regulation of emerging plant pests is challenging for risk managers due to the general absence of data on possible consequences and the increasing number of species of concern. In turn, data-driven

decision support tools such as I2P2 aim to inform expert discussions by providing guidance on which organisms to focus on, and by shedding light on potential impacts that may be expected upon invasion (Epanchin-Niell, 2017; Maguire, 2004). The EU is among the few regulatory jurisdiction that legally requires a scientific method to estimate and rank the risks of quarantine pests, to mandate investments for their control. The legal text specifies all elements to be considered, including social, economic, environmental, and cultural risks. Our article translates these regulatory needs into a novel scientific framework that assures equal treatment to all species, avoiding that more importance is given to pests for which more data is available and has been accepted by decision makers at the EU and Member States.

Commission Delegated Regulation (EU) 2019/1702 imposes considerable control and surveillance measures for the priority pests in all Member States. Consequently, an increase in the number of priority pests would result in additional resource needs. It may therefore be expected that a consensus decision between national risk managers and

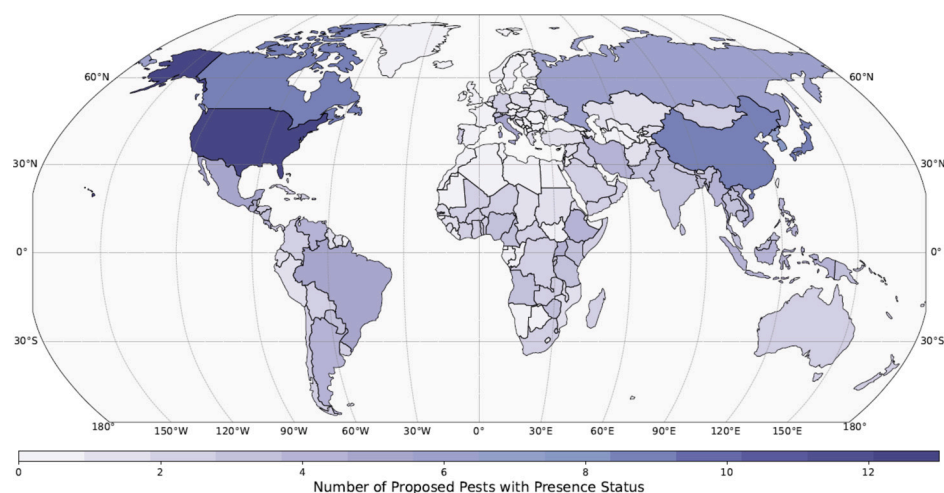


Fig. 7. A count of the number of pests present/reported in each country of current distribution, with no distinction between native or invasive pest as per EPPO methodology (EPPO, online). Data: EPPO (European and Mediterranean Plant Protection Organization), multiple accesses over 2024, EPPO Global Database. Available online: <https://gd.eppo.int>.

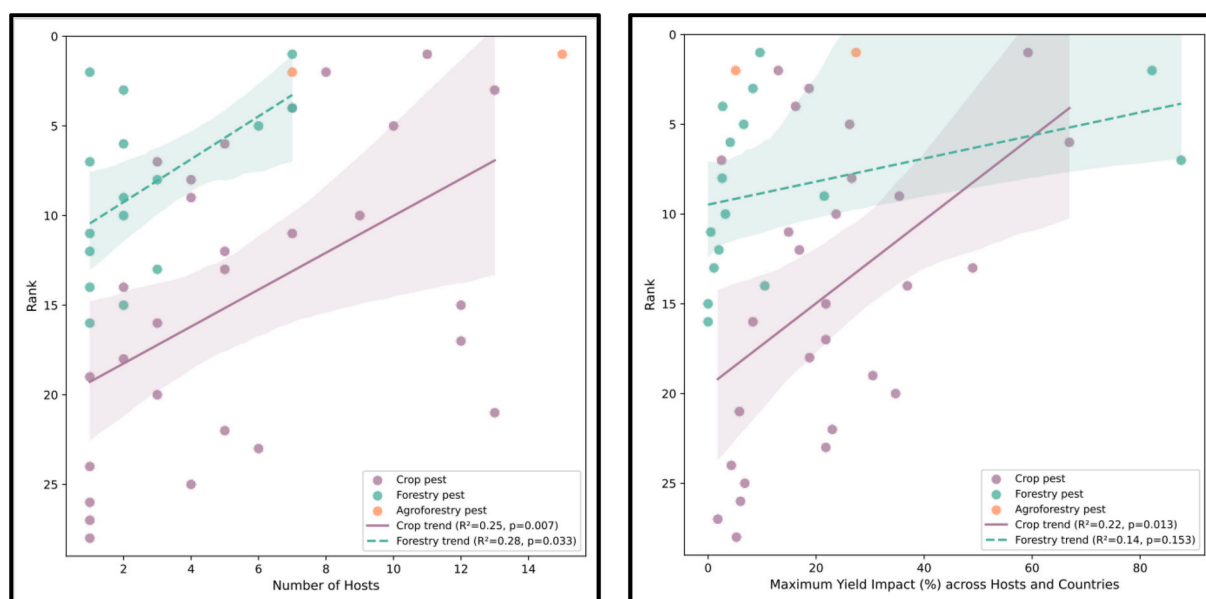


Fig. 8. Association between pest characteristics (left – number of hosts; right – maximum yield impact) and I2P2 rank under median values for elicited biological parameters and equal weighting across sub-domains. Points represent individual pests coloured by host type: purple = crop pests, green = forestry pests, orange = agroforestry pests. Trend lines show ordinary least squares regression with 95% confidence intervals (shaded bands) for crop (solid) and forestry (dashed) pests separately. Agroforestry pests ($n = 2$) were not included in trend line calculations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the EC could keep the current size of the priority pest list unchanged. The list currently holds 20 pests,³ following an I2P2 assessment (Sánchez et al., 2019), covering 13 that have crops as main hosts, 5 with trees as main hosts forestry, and 2 with both crops and trees as main hosts.

Assuming that a possible revision of the priority pest list must result in the regulation of a maximum of 20 UQPs due to resource constraints, our results would propose 12 crop-, 6 forestry-, and 2 agroforestry-pests, representing about 63% and 68% of the cumulative normalized I2P2 scores among crop and forestry pests, respectively. Because the I2P2 score is a dimensionless composite of normalized indicators, this

proportion reflects how concentrated the assessed relative potential impact is across pests within the index, rather than a share of avoidable economic, social, or environmental damage in absolute terms. Successfully controlling these pests would therefore address the largest share of assessed potential impact as captured by the index (Table 2). Notably, such a revision would effectively entail the substitution of nine pests from the current priority pests list. Crucially, the present work constitutes an evidence-based proposal derived from a systematic assessment of impacts only. In turn, the derived proposal needs to be complemented by EU risk managers' expertise on other relevant factors before deciding on a possible revision of the current list of priority pests.

Control and surveillance measures for the priority pests include efforts to intercept potential introductions through import inspections (Chen et al., 2018; Hulme, 2009). The 20 proposed pests have different countries with reported presences around the world. Fig. 7 displays the

³ <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1702>.

number of presences of the 20 proposed pests in each country. Evidently, the USA, Canada, Mexico, China, Russia and Brazil are among the hot-spots for presence countries and are also important trading partners for the EU. The flow of products and people is known to contribute to biological invasions (Hulme, 2009, 2021, 2025), underscoring the expected risks given the potential impacts calculated here and the higher likelihood of introduction from close trading partners. Measures that may introduce trade barriers must be supported by scientific evidence on potential risks, further underscoring the importance of science-based regulatory support.

Elicited pest characteristics were partially associated with their final ranking (Fig. 8). We examined associations between elicited pest characteristics and final I2P2 rankings using ordinary least squares regression separately for crop and forestry pests.⁴ The two agroforestry pests were excluded from regression analyses due to small sample size but are shown in plots for completeness. The number of hosts considered in the EKE explained around 25 and 28% of variance in the crop and forestry rankings, respectively. The maximum yield impact across all hosts and regions considered in the EKE was moderately associated with the final ranking. Consequently, while general tendencies emerged with the number of hosts and the expected yield impacts, high rankings were achieved both by single-host high-impact pests as well as polyphagous pests.

Several methodological choices warrant explicit discussion. First, the equal weighting of economic, environmental, and social domains in our baseline analysis follows the regulatory mandate that all three dimensions must be considered equally important for priority pest designation. We clearly acknowledge that this may not reflect all possible societal preference structures. For instance, pests ranking higher in economic impact alone may rank lower overall due to more limited expected impacts in other domains. The focus on pests causing impacts across all domains is an intended characteristic of the multi-criteria framework, not a methodological shortcoming. Critically, we address this by providing domain-specific rankings (Fig. 3) and a stochastic analysis of alternative weighting schemes (Fig. 5) allowing stakeholders to evaluate priorities under different preference structures.

Second, our reliance on expert-judgement based estimates necessitates careful interpretation. Expert Knowledge Elicitation (EKE) was necessary given data scarcity for many of the 46 pests assessed in depth. While EKE is an established methodology in regulatory risk assessment with well-documented protocols, it has recognized limitations including potential for overconfidence, anchoring bias, and framing effects (Morgan, 2014). Our approach attempts to mitigate these concerns through: (i) structured elicitation protocols with trained facilitators, (ii) pest-specific expert selection based on demonstrated knowledge of the organisms, (iii) documentation of evidence bases, and (iv) propagation of uncertainty through the analysis. Nevertheless, the resulting parameter estimates, which are inputs for the I2P2 model, should be interpreted as informed expert judgments under uncertainty and not as measured empirical data.

Finally, our rankings have not been compared against other pest prioritization frameworks, expert consensus from other jurisdictions, or retrospective analysis of observed invasion impacts. While our sensitivity analyses demonstrate internal consistency and robustness to parameter uncertainty, validation against real-world outcomes would strengthen confidence in the approach. Such validation is challenging given that many pests have not yet invaded the EU given our forward-looking risk assessment. However, a comparison with countries where invasions have occurred could be a valuable direction for future research. In the EU context, such validation efforts would also be valuable future work as more empirical data on invasive pest impacts (may unfortunately) become available in the future.

5. Conclusions

Assessing potential impacts of invasive species is notoriously difficult due to the absence of systematic data across the wide range of potentially hazardous invaders. Here, we aimed to assess potential impacts of the full list of the European Quarantine Pests ($N = 395$) using a diverse set of indicators across economic, social, and environmental domains. The generation of systematic data necessitates a time- and resource-demanding process of eliciting parameters from experts. In turn, a simplified but scalable shortlisting step was required to reduce the number of candidate pests. Risk managers were consulted to conclude on the final set of 46 pests that were assessed in-depth. For crop pests, *Xylella fastidiosa*, *Listronotus bonariensis*, and *Popillia japonica* are expected to have the highest impacts. For forest pests, *Dendrolimus sibiricus*, *Agrilus anxius*, and *Choristoneura fumiferana* are expected to have the highest impact. The contributions of the economic, social, and environmental impact-domains to the composite indicator reveal that high potential impact can be driven by diverse profiles. If the list of priority pests is to remain unchanged in size, our results suggest that 9 of the 20 currently listed pests should be substituted.

There are some areas that require future work. First, in agreement with the legislator and due to different conceptual or implementation limitations number of pests were omitted from the shortlisting process. This subset should be evaluated in more detail to assess whether an in-depth I2P2 analysis might be warranted, and to judge their current listing as a quarantine pest. Second, the analysis is based on potential impact and not pest risk. This is driven by two aspects of pest risk that are left out of the analysis when evaluating impacts. First, entry and establishment probabilities are not taken into account, considering that all evaluated pests have the same probabilities, when multiple factors affect these processes both when considering geography and climate (e.g., Rosace et al., 2023) but probably also when considering also pest type. On top of this, the I2P2 model is inherently static and does not capture the dynamics of pest spread over time. This assumption is necessary because the development of robust spread models for each pest would have been time-consuming and would have required more granular host distribution data (see e.g. (Robinet et al., 2012; Schneider et al., 2020)). Thirdly, the composite indicator is built using a fully compensatory approach such as the additive aggregation, while other options based on alternative aggregation of multi-criteria analysis exist (Xavier et al., 2025). As shown in Fig. 6, the choice of aggregation method also affects the ranking. However, findings are robust for the most policy-relevant, top-ranked pests, with rankings shifting only for pests further down the list. Fourth, for a small number of hosts, such as ornamentals and grassland, systematic economic data with the necessary granularity are lacking. In turn, such hosts were not fully captured in the I2P2 model; especially within the economic domain. Additional robustness checks suggest that, for example, the inclusion of grassland for *Listronotus bonariensis* could lead to a change in rank with *Xylella fastidiosa*. Finally, climate change is known to exacerbate the risk posed by plant pests worldwide (IPPC Secretariat, 2021) potentially leading to shifts in the rankings under future scenarios (Dobrzycka-Kraheil, 2023; Dobrzycka-Kraheil and Medina-Villar, 2020). Future work is needed to address the methodological limitations identified here, to expand the set of pests evaluated in depth, and anticipate potential pest impacts under a changing climate.

Declaration of use of generative AI and AI-assisted technologies

During the preparation of this work, the author(s) used ChatGPT in order to edit language and improve writing. After using ChatGPT, the authors reviewed and edited the content. We take full responsibility for the content.

⁴ Using <https://seaborn.pydata.org/generated/seaborn.regplot.html>.

CRediT authorship contribution statement

Kevin Schneider: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jesus Barreiro-Hurle:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Estefania Vazquez-Torres:** Writing – review & editing, Visualization, Software, Methodology, Investigation, Data curation. **Sara Tramontini:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Data curation, Conceptualization. **Alexandre Nougadère:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization. **Viola Di Cori:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Emilio Rodriguez-Cerezo:** Writing – review & editing, Validation, Supervision, Project administration, Conceptualization.

Disclaimer

The views expressed are purely those of the authors and may not under any circumstances be regarded as stating an official position of the European Commission and the European Food Safety Authority.

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecolind.2026.115423>.

Data availability

All data used in the analysis is available on the interactive dashboard available at https://datam.jrc.ec.europa.eu/datam/mashup/I2P2_INDI_CATORS_2024/index.html and the EFSA pest technical reports available at <https://www.efsa.europa.eu/en/topics/priority-pests#efsa-pest-reports>.

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