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Screening potential pests of Nordic coniferous forests associated with trade in ornamental plants

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Plant pests moved along with the trade in ornamental plants could pose a threat to forests. In this study plant pests potentially associated with this pathway were screened to identify pests that could pose a high risk to the coniferous forests of Finland, Sweden and Norway. Specifically, the aim was to find pests that potentially could fulfil the criteria to become regulated as quarantine pests. EPPO's commodity study approach, which includes several screening steps, was used to identify the pests that are most likely to become significant pests of *Picea abies* or *Pinus sylvestris*. From an initial list of 1062 pests, 65 pests were identified and ranked using the FinnPRIO model, resulting in a top list of 14 pests, namely *Chionaspis pinifoliae*, *Coleosporium asterum* s.l., *Cytospora kunzei*, *Dactylonectria macrodidyma*, *Gnathotrichus retusus*, *Heterobasidion irregulare*, *Lambdina fiscellaria*, *Orgyia leucostigma*, *Orthotomicus erosus*, *Pseudocoremia suavis*, *Tetropium gracilicorne*, *Toumeyella parvicornis*, *Truncatella hartigii* and *Xylosandrus germanus*. The rankings of the pests, together with the collected information, can be used to prioritize pests and pathways for further assessment.

Introduction

There is a general increasing global trade in products, and ornamental plants are no exception. Large amounts of plants and plant parts, such as cut trees and branches, are brought into the Nordic countries for ornamental purposes each year (Customs Finland, 2019; Statistics Sweden, 2019; Statistics Norway, 2019). For example, almost all coniferous ornamentals used in Finland today originate outside the country (Hannunen *et al*., 2014). During the last 10 years ornamental plants have been traded into Finland, Sweden or Norway from more than 70 different countries (Customs Finland, 2019; Statistics Sweden, 2019; Statistics Norway, 2019). These commodities may provide a pathway for non-native pests with a potential to cause damage to the coniferous forests of the region to which they are imported. Pests of coniferous forests may be brought in with ornamental plants not only with trade but also, for example, when private individuals bring home plants from international travel or when plants are brought in for research purposes.

Invasive pests have caused extensive ecological and economic impacts worldwide (Meyerson & Reaser, 2003; Hulme *et al*., 2008; Pejchar & Mooney, 2009) and they are introduced into new areas especially via the trade in living plants. For example, Kenis *et al*. (2007) and Santini *et al*. (2013) have shown that the majority of introductions of non-native insects and plant pathogens to Europe have been associated with the international trade in living plants. Similarly, almost 70% of the insects and pathogens that established in the United States between 1860 and 2006 most likely entered on imported living plants (Liebhold *et al*., 2012). The likelihood of establishment of new non-native pests may also increase in the future in the Nordic countries as a result of climate change.

The introduction of non-native plant pests through trade is mitigated with plant health regulations, including lists of quarantine pests and phytosanitary requirements for the international trade. New pests may be added to the lists if they are assessed to fulfil the criteria of a quarantine pest according to the relevant International Standards for Phytosanitary Measures (ISPMs) (FAO, 2007, 2013).

The aim of this study was to identify plant pests associated with the trade in ornamental plants and plant parts that could pose a high risk to the coniferous forests of Finland, Sweden and Norway. Since the Nordic coniferous forests are dominated by two species, Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*), the focus was placed on these. Specifically, the objective was to identify pests that potentially could fulfil the criteria to become regulated as quarantine pests following the criteria set out in the Norwegian (Norwegian Ministry of Agriculture & Food, 2017) and EU plant health regulations (EU, 2016). Another aim was to produce a database of all recorded pest species associated with *Picea* spp. and *Pinus* spp., and compile the information relevant for assessing whether the pests pose a high risk to the coniferous forests in Finland, Sweden and Norway. The database can be used also in future assessments of pest risks to the Nordic coniferous forests.

Methodology

The methodology used for screening the pests associated with ornamental plants was based on the EPPO Secretariat's approach for commodity studies (EPPO, 2016). The methodology was adapted to meet the aims of the present study and performed as outlined below. The pests that were retained after the screening were ranked based on the probabilities of entry, establishment and spread, and the likely impact, using the FinnPRIO model and the hypervolume approach (Heikkilä *et al*., 2016; Yemshanov *et al*., 2017).

Scope

Area at risk
The area at risk was Finland, Sweden and Norway.

Focal plant species
The study focused on the identification of pest risks to the two major native conifer forestry species in the area at risk, namely Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*).

Commodities of interest
Commodities of interest included any species of ornamental plants for planting, cut trees and branches intended to be used outdoors or indoors, regardless of whether they currently are traded to the area at risk. For plants for planting (i.e. plants intended to remain planted, to be planted or replanted) all parts of the plant (e.g. leaves, branches, stem, bark and roots) and the growing medium used were considered as part of the commodity. For simplicity, the phrase 'the pathway ornamental plants' is used in the rest of this document.

Type of pests considered
The plant pests considered in this study included insects, arachnids, nematodes, fungi, chromists, bacteria, viruses and viroids.

Origins considered
The origin considered was the entire world.

Output
(1) A list of pests that may have the potential to fulfil the criteria to become regulated as quarantine pests according to the Norwegian (Norwegian Ministry of Agriculture & Food, 2017) and EU plant health regulations (EU, 2016).
(2) A database of pests associated with *Picea* spp. and *Pinus* spp. including information relevant for assessing the risk that they constitute.

Screening and ranking process

A stepwise approach as suggested by EPPO (2016) was used to identify the plant pests that constitute the highest risk for the Nordic coniferous forests and that may have the potential to become regulated as quarantine pests according to the Norwegian (Norwegian Ministry of Agriculture & Food, 2017) and EU plant health regulations (EU, 2016). The screening was divided into four steps and an additional fifth step was used to rank the pests that received high ratings in the screening (Table 1).

*Step 1: Establishing a list of all pests of spruce (*Picea *spp.) and pine (*Pinus *spp.)*
A list of all recorded pests of Picea spp. and Pinus spp. was established using three major pest databases, i.e. the EPPO Global Database (EPPO, 2018), the CABI Crop Protection Compendium (2018) and Pest Information Wiki (2017).

Pest species for which *Picea* spp. or *Pinus* spp., as well as *Pinus sylvestris* or *Picea abies* specifically, were listed as hosts in the EPPO Global Database (EPPO, 2018) and the CABI Crop Protection Compendium (2018) were extracted using the following key words: '*Picea*', '*Picea abies*', '*Pinus*', '*Pinus sylvestris*'. The pest lists were retrieved from these databases in April 2018. The list of pests associated with *Pinus* and *Picea* in Pest Information Wiki (2017) was kindly provided by Bernhard Zelazny from the International Society for Pest Information in December 2017.

For each pest, information about the taxonomy and, when available, synonyms and EPPO Codes was obtained from the three databases. Since the information was collected from three sources, the initial pest list contained some species more than once, with the same or different name. Such duplicates were identified and the information merged by searching for records with the same scientific name, comparing the scientific name to the synonymous names of other records and comparing the EPPO Codes (when available) of the different pest records.

Step 2: Screening the pest list to identify potentially relevant species
The pest list was screened to only retain the pests that could potentially pose a high risk and become regulated in the area at risk, i.e. Finland, Sweden and Norway. This was done by applying the following exclusion criteria:

- First, since the focus of this study was on pests classified as insects, arachnids, nematodes, fungi, chromists,

Table 1. An overview of the steps and outputs of the study

Step	Aim	Output
1	Establish a list of all pests of *Picea* spp. and *Pinus* spp.	A list of pests, with scientific names, taxonomy and, when available, EPPO Codes
2	Screen the pest list to identify potentially relevant species	(1) A list of pests that need further consideration, with information on distribution, host plant species, location of life stages on plant parts and the type of damage caused, and (2) a list of pests not considered further
3	Rate the pests against a number of criteria	A list of pests with ratings for each criterion, with justifications
4	Select pests based on their ratings	A list of selected pests that potentially can pose a significant risk to the Nordic coniferous forests
5	Rank the selected pests using the FinnPRIO model and the hypervolume approach	A list of pests ranked according to the risk they pose to the Nordic coniferous forests and a short description of the top ranked pests

bacteria, viruses or viroids, other organism groups were excluded.

- Second, the pests that already were regulated (when the study was conducted) were excluded, i.e. pests listed in Annex I or II of Council Directive 2000/29/EC of the European Union (European Council, 2000) and in the Norwegian Regulations of 1 December 2000 no. 1333 (Norwegian Ministry of Agriculture & Food, 2017).
- Third, pest species known to be established in the area at risk were excluded. This was done based on the records in the Finnish, Swedish and Norwegian biodiversity information species national databases (i.e. Laji.fi, Artportalen.se, Dyntaxa.se, Artsdatabanken.no), information in the scientific literature and by consulting national experts.

Finally, the retained pest species were divided into two groups: (1) pests that are present in Europe, but not present in the area at risk, and (2) pests that are not present in Europe. In the latter group pests were excluded if they were restricted to certain host plant genera (e.g. *Abies*, *Cedrus*, *Chamaecyparis*, *Juniperus*, *Larix*, *Picea*, *Pinus*, *Pseudotsuga* and *Tsuga*) whose import into EU or Norway is banned (European Council, 2000; Norwegian Ministry of Agriculture & Food, 2017). This is because the pathway ornamental plants was considered to be closed for these pest species.

The exclusion criteria were used one at a time. Once a pest was excluded, further information was not collected. For the remaining pests, further information about their distribution, host plants and pest characteristics (e.g. the location of different life stages on the plant parts and the type of damage they cause) was collected when readily available.

There were some differences between the databases used regarding which countries/regions were considered as a part of Europe. A precautionary approach was used where a pest species was considered as present in Europe if it was reported to be present in Europe in any of the databases. For pest species reported to be present in Russia, additional information about their distribution in the country was searched to determine whether the species were present in the European part of Russia or not.

Step 3: Rating the pests against a number of criteria

To identify the pests that constitute the highest risk of those that were retained after Step 2, several rating criteria were used. The criteria, ratings and subratings used were based on the EPPO Secretariat's approach for commodity studies (EPPO, 2016) but adapted to the current study. In total six criteria were used:

(A) Association with the pathway ornamental plants
(B) Host range
(C) Climatic similarity
(D) Recorded impact
(E) Recorded interceptions
(F) Known emerging pest

A detailed description of each criterion and their ratings are given in File S1 (see Supporting Information). In short, criterion A was used to assess whether the pest could be carried on the pathway ornamental plants, considering the plant parts that the pest's different life stages are associated with. Criterion B was used to rate the pests based on their host range. This criterion also included a subrating that specified whether the pest species is known to be associated with the focal plant species in the area at risk, i.e. *Picea abies* and *Pinus sylvestris*. Criterion C was used to assess if the pest is present in areas with climate similar to that in the area at risk. This was done with the CLIMEX software and its 'match regional climate' algorithm (Kriticos *et al.*, 2015). The analysis was carried out both in the present climate and using future climate scenarios for the time period around 2050 (see File S1 for details of the analysis). Criterion D was used to rate the pests based on their recorded direct impact on coniferous species. Criteria E and F were used to identify pests that are known to move with trade and pests that have extended their distribution or are becoming more damaging.

When the rating was highly uncertain, the precautionary principle was used, i.e. the highest potential rating was given.

Step 4: Selecting pests based on their rating

In this step, the pests constituting the highest risk were selected based on the ratings given in the previous step.

First, pests that have been recorded to cause mortality or significant damages to coniferous plants, and that may be carried with plants for planting, cut trees or branches were selected. These were pests rated as high or medium for their impact and assessed to be associated with the main elements of the commodity.

Then, from the list of pests *present* in Europe, only the pests that are known to have *Picea abies* and/or *Pinus sylvestris* as hosts were retained. It was assumed that pests that are present in Europe and are a risk to *Picea abies* and/or *Pinus sylvestris* are likely to have been already recorded on these tree species considering their wide distribution in Europe.

From the list of pests *not present* in Europe, the selection was done based on the climatic similarity between the current distribution area of the pest and the area at risk. Only the pests that occur in areas which were rated to have a medium to very high climatic similarity with the area at risk were retained. If the rating was medium, the presence of the pest in climatically similar areas was verified by overlying the Köppen climate classification (Peel *et al*., 2007) with presence observation points gathered from multiple databases (gbif.org, bison.usgs.gov, idigbio.org, inaturalist.org, holos.berkeley.edu and ala.org.au). The ratings of criteria E (Recorded interceptions) and F (Known emerging pests) were not used in the selection process, but the information was used in the FinnPRIO assessments in Step 5.

Step 5: Ranking the selected pests using the FinnPRIO model and the hypervolume approach

The pests selected in the previous step were ranked using the FinnPRIO model (Heikkilä *et al*., 2016) and the hypervolume approach (Yemshanov *et al*., 2017). FinnPRIO is a pest ranking model that can be used to assess and compare the risk that non-native plant pests pose to plant health. The model consists of multiple-choice questions with different answer options yielding a different number of points. For each question the most likely answer option and the plausible minimum and maximum options are chosen based on a quick assessment of the available scientific evidence. The given answer options are used to define a PERT probability distribution that describes the uncertainty in the answer. The probability distributions of the final scores of the likelihood of invasion, impact and risk are derived from the question-specific PERT distributions using a Monte Carlo simulation. The FinnPRIO model is described in detail in Heikkilä *et al*. (2016).

In the current study FinnPRIO was used to separately assess the pest's likelihood of entry considering current official risk management measures, the likelihood of establishment (including spread), the likelihood of invasion (entry × establishment), the magnitude of economic, environmental and social impacts, and the risk (likelihood of invasion × magnitude of impacts). The FinnPRIO model provides semiquantitative scores for the relative probabilities of entry, establishment and invasion, the magnitude of impact, and risk. Hence, the scores are comparable with each other, but high scores do not necessarily mean that the pest constitutes a high risk.

To provide an indication of whether some of the assessed pests may fulfil the 'unacceptable impact' criteria of quarantine pests, four reference quarantine pests were also assessed with FinnPRIO. The four reference pests were *Acleris variana*, *Cronartium harknessii*, *Lecanosticta acicola* and *Pissodes strobi*, which were all regulated as quarantine pests in the EU and Norway. It should, however, be noted that *Lecanosticta acicula* has recently been re-evaluated and it is currently listed as a Union regulated non-quarantine pest (European Commission, 2019), i.e. a non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact (FAO, 2019). Because the risk of the reference pests is already mitigated with the plant health legislation, their entry and establishment scores are not comparable with the scores of non-regulated pests. Therefore, only the magnitude of impact score was used to compare the ranked pests with the reference pests.

The FinnPRIO assessments were done using the FinnPRIO graphical user interface (Marinova-Todorova *et al*., 2019) with some modifications to the original assessment instructions by Heikkilä *et al*. (2016). A detailed description of these modifications is presented in File S2 (see Supporting Information). The probability distribution of the scores for the likelihoods of entry, establishment and invasion, and the magnitude of impacts (all ranging from 0 to 1) were simulated using R version 3.2.3 (R Core Team, 2015) and R package 'mc2d: Tools for Two-Dimensional Monte Carlo Simulations' (Pouillot & Delignette-Muller, 2010) with 1000 iterations. The lambda parameter of the PERT distribution was set to 1, implying a low confidence of the most likely estimate. Equal weight was given to economic (50%) and environmental and social impacts (50%).

FinnPRIO expresses the assessment results as probability distributions that indicate the uncertainty of the assessments. The functional form of the distributions is not consistent between the assessments and hence the distributions cannot be reliably described or ranked based on summary metrics, e.g. mean or median. To facilitate comparison of the distributions, the hypervolume (HV) approach was used to aggregate the distributions into a simple single-dimensional form that reveals the preference order relationship of the distributions (see Yemshanov *et al*. (2012, 2017) and Tuomola *et al*. (2018) for details). In short, the hyperovolume approach establishes the relative order of the score distributions using a pairwise stochastic dominance rule and a hypervolume indicator. It first converts the probability distributions into cumulative distribution functions, which are then ordered using the pairwise stochastic dominance rule. This function establishes the ordinal rank order of the subsets of the score distributions. Within a subset, none of the score distributions stochastically dominate other distributions and hence the subset is treated as a single priority rank. The quantitative positions of the ranks, i.e. subsets of score distributions, are estimated using the HV indicator with a continuous measure from 0 to 1.

The rankings with the pairwise stochastic dominance rule and the HV indicator calculations were performed using a stand-alone program written in C++ that applies the hypervolume calculation algorithm from While *et al*. (2012). The program was kindly provided by Denys Yemshanov from Natural Resources Canada. The cumulative distribution functions were calculated from the score distributions at 60 equal intervals and ordered using the first-order stochastic dominance rule to calculate the HV indicators.

Additional analyses

The impact of climate change on the likelihood of establishment of the rated pests in the area at risk was examined using the CLIMEX analysis done in Step 3 (File S1). The influence of using different pest species databases on the pests retained in each step was also analysed.

Results

Outcome of the screening

In total 1087 pest species records with unique scientific names were included in the initial list of pests of spruce (*Picea* spp.) and pine (*Pinus* spp.). After removing duplicates (pests recorded in the databases with different synonyms), 1062 unique pest species records remained (Fig. 1). Of these, 851 pests were not considered further since they fulfilled at least one of the exclusion criteria (File S3) (see Supporting Information). Out of the excluded pests 70 did not belong to the taxonomic groups considered in this study, 111 pests are already regulated as quarantine pests in Finland, Sweden and Norway, and 405 pests are already established there. From the remaining pests not present in Europe, 216 were excluded because they only have host plant species that cannot be imported into EU or Norway according to the plant health regulations. Finally, 49 pests were excluded because they were found not to be pests of *Picea* spp. or *Pinus* spp.

For the remaining 211 pests, information on their potential association with the pathway, host range, distribution, impact and spread history was collected in a database and the pests were rated using the criteria in File S1. The ratings are presented in File S3. From these pests, according to the currently available information, 146 are present in Europe while 65 are not. About 80% of the pests considered at this stage were insects or fungi (Table 2).

From the 211 rated pests, 65 were selected, based on their ratings, for the FinnPRIO assessments and the hypervolume ranking (Step 4, Fig. 1 and Table 3). These were pests that can potentially be associated with the main elements of the commodity and have either high or medium recorded impact on conifers. In addition, the selected pests *present* in Europe are known to have *Picea abies* and/or *Pinus sylvestris* as hosts, while from the pests *not present* in Europe, only species that are present in areas with at least medium climatic similarity to the area at risk were selected.

From the 65 ranked pest species, 38 were present in Europe while 27 were not (Table 3). The European countries that had the highest number of the selected pests present within their territories were Italy, France, Germany, the United Kingdom and Spain, with 22, 17, 17, 17 and 16 of the selected pests present, respectively (Fig. 2). The non-European countries that had the highest number of the selected pests present within their territories were the USA, Canada, China, Japan and Mexico with 38, 28, 21, 8 and 8 pests, respectively.

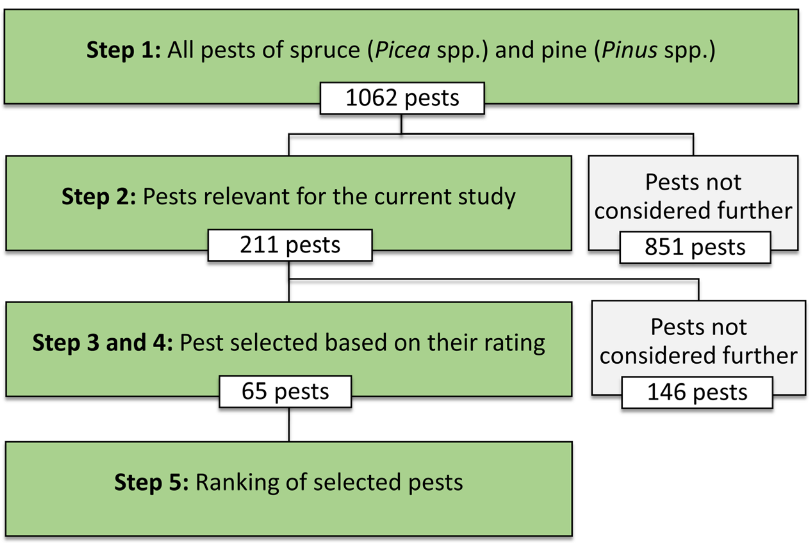

Fig. 1 The outcome of the different steps of the screening. [Colour figure can be viewed at wileyonlinelibrary.com]

Table 2. The number of rated pests by pest type (Step 2)

Type of pest	Number of species
Arachnida	1
Bacteria	6
Chromista	9
Fungi	48
Insecta	119
Nematoda	27
Viruses and viroids	1
All	211

Table 3. The number of the 65 ranked pests that potentially can pose a significant risk to the Nordic coniferous forests by pest type and presence in Europe (Step 3 and 4)

Type of pest	Present in Europe	Not present in Europe	All
Arachnida	1	0	1
Bacteria	2	0	2
Chromista	2	0	2
Fungi	15	6	21
Insecta	17	21	38
Nematoda	1	0	1
Viruses and viroids	0	0	0
All	38	27	65

Ninety per cent of the selected pests were insects or fungi (Table 3). For each of the 65 selected pests, information about their known distribution, host plants and a description of the impacts on conifers is given in File S3.

The screening process showed that there were in general more known pests that constitute a risk to *Pinus* species than *Picea* species, and more known pests that constitute a risk to *Pinus sylvestris* than *Picea abies* (Table 4). For example, 84% of the 1062 pests on the initial list were known to be pests on *Pinus* spp., while only 39% were known to be pests on *Picea* spp. This was the trend in each step of the screening.

Results of the risk ranking

The hypervolume approach stratified the 65 ranked pests into ordinal rank groups for each section separately assessed with FinnPRIO. It created 14 ordinal rank groups for the likelihood of entry, 18 groups for the likelihood of establishment and spread, 19 groups for the likelihood of invasion, 20 groups for the magnitude of impacts and 19 groups for the risk (Table 5).

In terms of risk, the group with the highest rank consisted of the fungal pathogens *Cytospora kunzei* and *Dactylonectria macrodidyma* (Table 5). The group with the second highest rank consisted of three pests, the white-marked tussock moth *Orgyia leucostigma*, the alnus ambrosia beetle *Xylosandrus germanus* and the fungal pathogen *Truncatella hartigii*. The group with the third highest ordinal rank also consisted of three pests, the pine needle scale *Chionaspis pinifoliae*, the pine tortoise scale *Toumeyella parvicornis* and the fungal pathogen *Coleosporium asterum* s.l.

Based on the likelihood of invasion, the fungal pathogen *Dactylonectria macrodidyma* received the highest rank followed by the fungal pathogen *Truncatella hartigii*. The third highest rank was much lower than the first two ranks and consisted of two pests, the fungal pathogen *Cytospora kunzei* and the yellows disease phytoplasma '*Candidatus* Phytoplasma asteris'. These pests were also in the highest rank for likelihood of entry. It should be noted, however, that some studies indicate that *Truncatella hartigii* and *Cytospora kunzei* may already be present in Sweden and *Truncatella hartigii* in Norway (Lagerberg, 1912; Jørstad, 1936; Strid *et al*., 2014) but whether they are established needs to be verified.

Based on the magnitude of impacts, the group with the highest rank consisted of the fungal pathogen *Heterobasidion irregulare*, the hemlock looper *Lambdina fiscellaria* and the Mediterranean pine beetle *Orthotomicus erosus*. Because of a low likelihood of invasion these three pests obtained a relatively low rank for risk (Table 5). The group with the second highest rank consisted of two insects, the finehorned spruce borer *Tetropium gracilicorne* and the western pinewood stainer *Gnathotrichus retusus*. The pine needle scale *Chionaspis pinifoliae* obtained the third highest rank while the fourth rank contained a group of four insect pests, namely the common forest looper *Pseudocoremia suavis*, the white-marked tussock moth *Orgyia leucostigma*, the alnus ambrosia beetle *Xylosandrus germanus* and the pine tortoise scale *Toumeyella parvicornis*.

The mean impact scores of the FinnPRIO assessments were highest for the two reference pests *Cronartium harknessii* and *Pissodes strobi* (Figs 3 and 4). These pests also received the highest minimum and maximum scores. The scores of the other two reference pests *Acleris variana* and *Lecanosticta acicola* were lower than those of several of the ranked pests (Fig. 3). The following 16 pests, ordered from highest to lowest rating, had higher mean impact scores than the reference pest with the lowest mean impact score (i.e. *Lecanosticta acicola*): *Lambdina fiscellaria*, *Orthotomicus erosus*, *Heterobasidion irregulare*, *Gnathotrichus retusus*, *Tetropium gracilicorne*, *Xylosandrus germanus*, *Orgyia leucostigma*, *Chionaspis pinifoliae*, *Toumeyella parvicornis*, *Pseudocoremia suavis*, *Armillaria novae-zelandiae*, *Lygus lineolaris*, *Lygus Hesperus*, *Armillaria sinapina*, *Pityokteines curvidens* and *Cytospora kunzei* (Fig. 3). It should be noted, however, that the impact assessments were limited to the potential damage of the pests on *Picea abies* and *Pinus sylvestris* in Finland, Sweden and Norway. The overall impact of the pests for the area at risk as well as for the EU may be different should, for example, impacts on other hosts be included in the assessments.

The ranked pests that were present in Europe generally had higher likelihood of invasion scores than the pests not present in Europe, while the magnitude of impact scores of these groups were not clearly different (Fig. 4B).

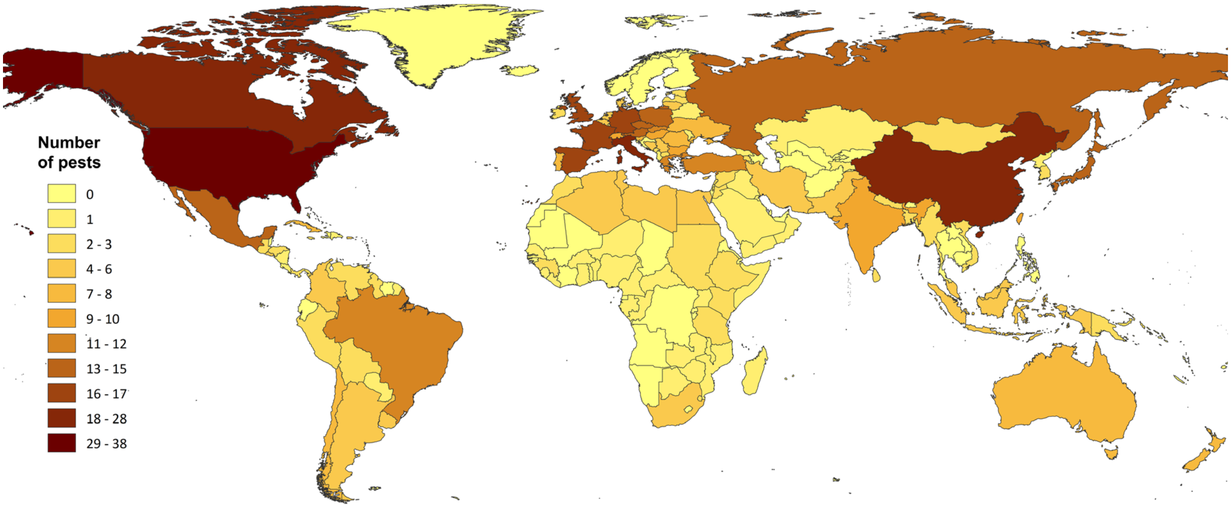

Fig. 2 The number of pests, out of the 65 ranked pests present in different countries. [Colour figure can be viewed at wileyonlinelibrary.com]

Table 4. The number of known pests of species in the *Pinus* and/or *Picea* genera, and the number of pests that are known pests particularly on *Pinus sylvestris* and/or *Picea abies*

Step	All	*Pinus* spp.	*Picea* spp.	*Pinus* spp. and *Picea* spp.	*Pinus sylvestris*	*Picea abies*	*Pinus sylvestris* and *Picea abies*
1	1062	887 (84%)	418 (39%)	244 (23%)			
2	211	193 (91%)	77 (36%)	59 (28%)	60 (28%)	30 (14%)	14 (7%)
3 and 4	65	56 (86%)	41 (63%)	32 (49%)	32 (49%)	19 (29%)	11 (17%)

The proportion of the number of pests from all pests is in brackets.

Description of top ranked pests

Short descriptions of the 14 pests that were top ranked for risk and impact are given below (cf. Table 5). The main uncertainties that could be addressed in pest risk assessments and some other information that may be relevant for risk management decisions are also provided (see File S3 for more information about the 65 pests that were ranked).

The pest species ranked highest for risk

Dactylonectria macrodidyma *(risk rank 1, HV risk indicator 0.63). Dactylonectria macrodidyma* is a fungal pathogen reported from North and South America, Australia, New Zealand and South Africa and from several countries in Europe (Farr & Rossman, 2019). The fungus causes diseases in different hosts, e.g. black foot disease of *Vitis* spp. (Halleen *et al*., 2004). In Lithuania, the fungus has been found in seedlings of both *Picea abies* and *Pinus sylvestris* in forest nurseries, clear cuts and farmlands (Menkis *et al*., 2006). The fungus has been isolated from both healthy-looking roots and roots with disease symptoms and is suggested to be an opportunistic pathogen causing disease in stressed seedlings (Menkis & Vasaitis, 2011; Menkis & Burokienė, 2012). Considering its wide global distribution, the association with seedlings in nurseries and its opportunistic behaviour, the pathogen may already be established in the area at risk, but not reported.

Conclusion: The expected impact of this pathogen was ranked relatively low, but it received the highest risk rank of all assessed pests due to its very high likelihood of invasion. Further investigation is needed to confirm whether the pathogen is already established in the area at risk.

Cytospora kunzei *(risk rank 1, HV risk indicator 0.63). Cytospora kunzei* is a fungal pathogen reported from North America, Asia, South Africa and Europe (Farr & Rossman, 2019). The fungus may already be established in Sweden as it was found in decaying logs of *Picea abies* and associated with bark beetles in two locations in Uppland (Strid *et al*., 2014). The pathogen is reported from different conifer host species causing canker disease and dieback of trees (Sinclair & Lyon, 2005). *Picea abies* is reported to be susceptible in the USA (Clement *et al*., 2006). *Pinus sylvestris* is also reported as a host (Farr & Rossman, 2019), but the susceptibility is unclear. The pathogen causes disease in trees stressed by, for example, drought, but mortality of the affected trees is rare (Sinclair & Lyon, 2005). Damage is mainly reported from ornamental trees (e.g. Christmas trees) and trees in windbreaks but also from plantations (USDA, 1998, 2011a; Kavak, 2005; Natural Resources Canada, 2019a).

Table 5. The HV indicators of the pests assessed with FinnPRIO [Colour table can be viewed at wileyonlinelibrary.com]

Pest	Type of pest	Present in Europe	Entry HV indicator	Establishment and spread HV indicator	Invasion HV indicator	Impact HV indicator	Risk HV indicator
Dactylonectria macrodidyma	F	Yes	0.99	0.79	0.95	0.18	0.63
Cytospora kunzei	F	Yes	0.66	0.67	0.55	0.45	0.63
Orgyia leucostigma	I	No	0.08	0.67	0.13	0.66	0.35
Truncatella hartigii	F	Yes	0.85	0.90	0.86	0.06	0.35
Xylosandrus germanus	I	Yes	0.21	0.90	0.24	0.66	0.35
Chionaspis pinifoliae	I	No	0.21	0.68	0.17	0.67	0.31
***Coleosporium asterum* s.l**	F	Yes	0.66	0.68	0.47	0.29	0.31
Toumeyella parvicornis	I	Yes	0.10	0.79	0.13	0.66	0.31
Armillaria novae-zelandiae	F	No	0.10	0.68	0.17	0.45	0.26
Coleotechnites piceaella	I	Yes	0.38	0.68	0.37	0.22	0.26
Haematoloma dorsatum	I	Yes	0.38	0.78	0.37	0.22	0.26
Orthotomicus erosus	I	Yes	0.10	0.81	0.10	0.96	0.26
Phytophthora citrophthora	C	Yes	0.47	0.71	0.37	0.29	0.26
Tetropium gracilicorne	I	Yes	0.21	0.81	0.17	0.76	0.26
Heterobasidion irregulare	F	Yes	0.07	0.90	0.10	0.96	0.20
Lygus lineolaris	I	No	0.10	0.68	0.17	0.33	0.20
Macrophomina phaseolina	F	Yes	0.47	0.68	0.47	0.11	0.20
Candidatus Phytoplasma asteris	B	Yes	0.66	0.68	0.55	0.03	0.20
Candidatus Phytoplasma pini	B	Yes	0.47	0.71	0.37	0.06	0.20
Armillaria sinapina	F	No	0.10	0.71	0.17	0.33	0.18
Barbitistes constrictus	I	Yes	0.38	0.78	0.31	0.18	0.18
Calonectria kyotensis	F	Yes	0.47	0.70	0.37	0.11	0.18
Lambdina fiscellaria	I	No	0.03	0.68	0.05	0.96	0.18
Lygus hesperus	I	No	0.10	0.71	0.13	0.29	0.18
Calonectria cylindrospora	F	Yes	0.38	0.70	0.31	0.11	0.16
Malacosoma disstria	I	No	0.18	0.70	0.13	0.29	0.16
Rosellinia desmazieresii	F	Yes	0.18	0.68	0.17	0.22	0.16
Biston regalis	I	No	0.10	0.45	0.10	0.18	0.11
Calonectria canadiana	F	No	0.38	0.68	0.31	0.06	0.11
Gnathotrichus retusus	I	No	0.02	0.81	0.05	0.76	0.11
Heterobasidion abietinum	F	Yes	0.07	0.79	0.10	0.22	0.09
Meloderma desmazieri	F	Yes	0.18	0.68	0.24	0.03	0.09
Pseudocoremia suavis	I	Yes	0.07	0.64	0.08	0.66	0.09
Thyridopteryx ephemeraeformis	I	No	0.18	0.45	0.08	0.22	0.09
Chrysomyxa ledicola	F	No	0.07	0.68	0.10	0.09	0.07
Ctenopseustis obliquana	I	No	0.03	0.64	0.06	0.22	0.07
Phytopythium vexans	C	Yes	0.38	0.37	0.17	0.03	0.07
Pineus similis	I	Yes	0.10	0.78	0.13	0.12	0.07
Setomelanomma holmii	F	Yes	0.10	0.64	0.10	0.09	0.07
Calonectria brassicae	F	No	0.38	0.25	0.10	0.06	0.06
Hylastes tenuis	I	No	0.07	0.55	0.05	0.33	0.06
Ips subelongatus	I	Yes	0.07	0.78	0.10	0.33	0.06
Leptographium guttulatum	F	Yes	0.18	0.71	0.13	0.09	0.06
Nepytia phantasmaria	I	No	0.03	0.71	0.05	0.22	0.06
Bursaphelenchus fungivorus	N	Yes	0.08	0.68	0.10	0.12	0.05
Dioryctria amatella	I	No	0.03	0.71	0.07	0.29	0.05
Pityokteines spinidens	I	Yes	0.08	0.68	0.08	0.29	0.05
Rhizoctonia butinii	F	Yes	0.07	0.67	0.10	0.09	0.05
Aphrophora saratogensis	I	No	0.07	0.55	0.07	0.11	0.03
Ceroplastes rubens	I	No	0.47	0.21	0.10	0.03	0.03
Elasmopalpus lignosellus	I	No	0.21	0.45	0.17	0.00	0.03
Korscheltellus gracilis	I	No	0.03	0.81	0.05	0.09	0.03
Lepidosaphes pini	I	No	0.10	0.55	0.13	0.03	0.03
Orgyia pseudotsugata	I	No	0.07	0.68	0.10	0.03	0.03
Pityokteines curvidens	I	Yes	0.00	0.81	0.03	0.45	0.03
Grosmannia serpens	F	Yes	0.07	0.67	0.08	0.06	0.03
Pronocera angusta	I	Yes	0.07	0.64	0.05	0.03	0.03
Cinara pinimaritimae	I	Yes	0.10	0.37	0.08	0.06	0.03
Marchalina hellenica	I	Yes	0.07	0.37	0.05	0.06	0.03
Philus antennatus	I	No	0.08	0.37	0.05	0.03	0.02
Trisetacus ehmanni	A	Yes	0.07	0.37	0.05	0.05	0.02
Chrysomyxa himalensis	F	No	0.03	0.42	0.05	0.03	0.01
Teia anartoides	I	No	0.02	0.68	0.05	0.06	0.01
Thaumetopoea pityocampa	I	Yes	0.38	0.00	0.05	0.00	0.01
Tomicus destruens	I	Yes	0.03	0.00	0.00	0.06	0.00

Type of pest: A, arachnida; B, bacteria; C, chromista; F, fungi; I, insecta; N, nematoda.
Top ranked pests are written in bold.

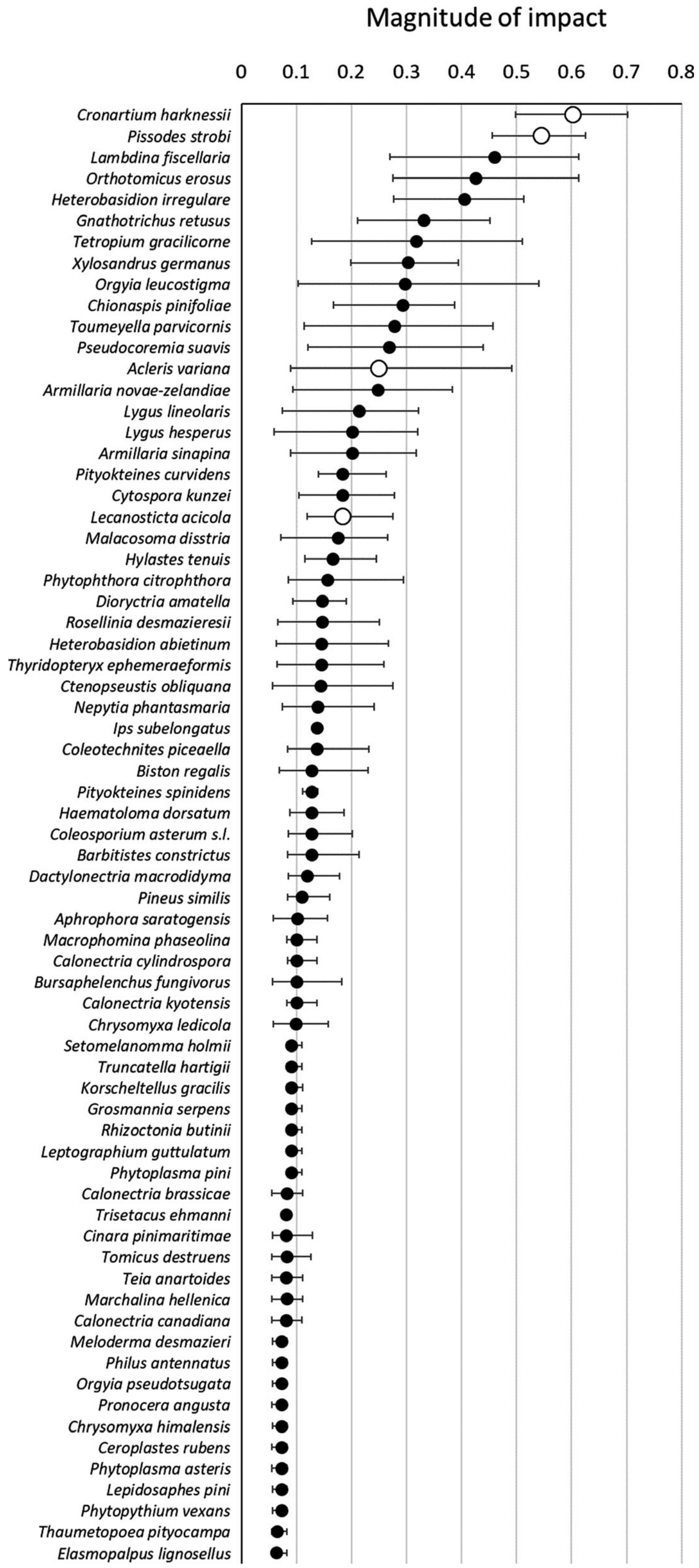

Fig. 3 The FinnPRIO scores for the magnitude of impact of the 65 ranked pests (filled circles) and the four reference pests (open circles). The dots and circles represent the means and the whiskers the minimums and maximums of the simulated probability distributions and hence indicate the uncertainty of the assessment. The pests are ordered from high to low impacts based on the means.

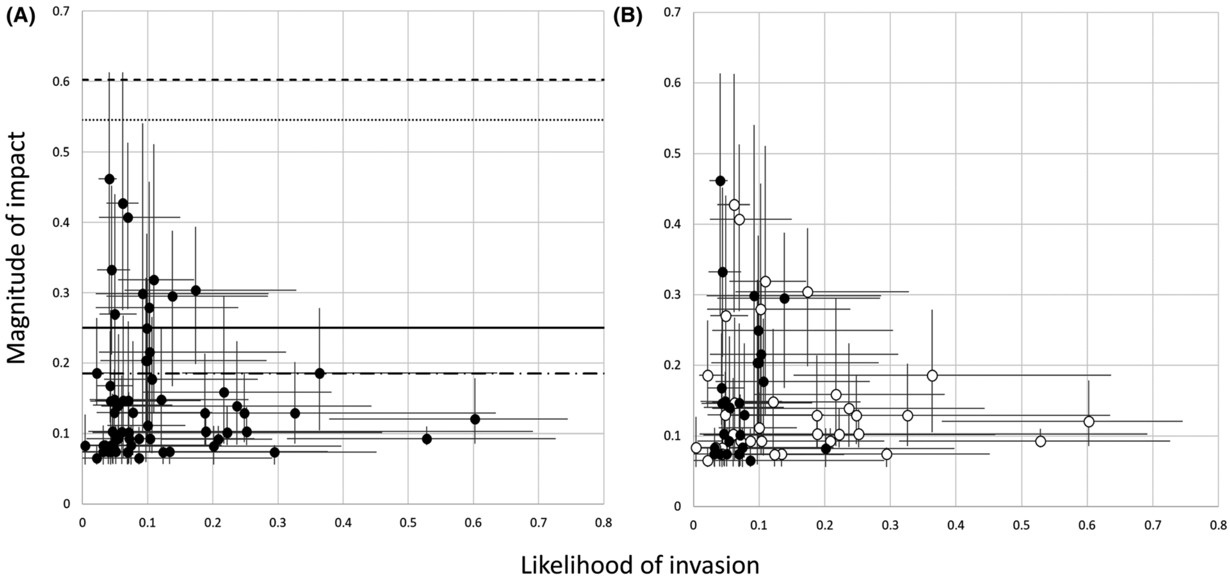

Fig. 4 FinnPRIO likelihood of invasion scores plotted against the magnitude of impact scores of the 65 ranked pests. The circles show the means and the whiskers show the minimums and the maximums of the probability distributions and hence indicate the uncertainty of the assessments. (A) The four thick horizontal lines represent the means for the four regulated reference pests (---, *Cronartium harknessii*; ···, *Pissodes strobe*; —, *Acleris variana*; —·—, *Lecanosticta acicola*). (B) The filled circles represent the pests that are not present in Europe and the open circles represent the pests that are present in Europe.

Conclusion: This pathogen ended up in the highest risk rank based on a relatively high score for both invasion and impact. Further investigation is needed to confirm whether the pathogen is already established in the area at risk.

Orgyia leucostigma *(risk rank 2, HV risk indicator 0.35). Orgyia leucostigma*, white-marked tussock moth, has a distribution limited to North America, where it is native (CABI, 2019a). There are, however, unconfirmed records of the pest from England (Wilstermann & Schrader, 2018). The pest is very polyphagous, and the list of its known hosts includes both trees and herbaceous plants (CABI Plantwise Knowledge Bank, 2019a). *Pinus strobus* is one of its main hosts, but it is primarily considered to be a pest of broadleaved trees (CABI Plantwise Knowledge Bank, 2019a; Natural Resources Canada, 2019d). It may attack conifers when the population is high and may cause severe damage in Christmas trees (Natural Resources Canada, 2019d). The pest has been a quarantine pest in Mexico since 2018 (EPPO, 2019). According to an express Pest Risk Analysis (PRA) the phytosanitary risk of *Orgyia leucostigma* for EU member states is high with high certainty (Wilstermann & Schrader, 2018).

Conclusion: *Orgyia leucostigma* received a relatively low rank for likelihood of invasion while the potential impact was ranked high. The assessment of the potential impact on *Pinus sylvestris* was, however, highly uncertain. According to an express PRA done in 2018, the risk is high with high certainty (other hosts than ornamental plants were also considered in that assessment).

Truncatella hartigii *(risk rank 2, HV risk indicator 0.35).* Truncatella hartigii is a fungal pathogen reported from North America, Asia, South Africa and numerous countries in Europe (Farr & Rossmann, 2019). The fungus has a very broad host range, including both conifers and broadleaved tree species as well as cereals (Farr & Rossman, 2019). Both *Picea abies* and *Pinus sylvestris* have been recorded as hosts. The fungus has been isolated from pine seeds and cones (Vujanovic *et al*., 2000), and is associated with stem girdling of seedlings in nurseries (Spaulding, 1961). There are reports of the pathogen from nurseries in Norway and Sweden (Lagerblad, 1912; Jørstad, 1936). There are also records from Finland, Norway and Sweden in Farr & Rossman (2019) citing sources not readily available. Thus, the pathogen could already be established in the area at risk but that needs to be confirmed.

Conclusion: *Truncatella hartigii* was ranked high due to the likelihood of invasion although its expected impact was ranked relatively low. Further investigation is needed to confirm whether the pathogen is established in the area at risk.

Xylosandrus germanus *(risk rank 2, HV risk indicator 0.35). Xylosandrus germanus*, black timber bark beetle, is an ambrosia beetle native to Asia (CABI, 2019b). The beetle has been introduced into North America and many countries in Europe (Björklund & Boberg, 2017; EPPO, 2019; CABI, 2019b). In Sweden, the pest has been trapped twice but it is not considered as established (Björklund & Boberg, 2017). The beetle colonizes both broadleaved and conifer tree species, including *Picea abies* and *Pinus sylvestris* (CABI, 2019b). A rapid PRA was performed for Sweden in 2017 where it was concluded that *Xylosandrus germanus* does not fulfil the criteria to become a protected zone quarantine pest in Sweden, perhaps due to limited possibilities to prevent natural spread from Denmark (Björklund & Boberg, 2017).

Conclusion: A recent rapid PRA for Sweden concluded that *Xylosandrus germanus* does not fulfil the criteria to become a protected zone quarantine pest in Sweden.

Chionaspis pinifoliae *(risk rank 3, HV risk indicator 0.31; impact rank 3, HV impact indicator 0.67).* Chionaspis pinifoliae, pine leaf scale, is an armoured scale probably native to North America, and also found in a few countries in South America and Africa (CABI, 2019e). It is a pest of conifers with known hosts in the genera *Pinus* (main), *Abies*, *Cedrus*, *Cupressus*, *Juniperus*, *Picea*, *Pseudotsuga*, *Taxus*, *Torreya* and *Tsuga* (CABI, 2019e). *Pinus sylvestris* appears to be susceptible (Eliason & McCullough, 1997). Damage seems to usually be limited to nurseries, Christmas tree plantation and ornamental trees (Eliason & McCullough, 1997; Tooker & Hanks, 2000 (and references therein); Quesada & Sadof, 2017). The pest could be associated with ornamental plants (see, e.g. Green, 1930) and it has previously been introduced to new continents (CABI, 2019e), but the import of plants for planting in the EU of most of the known host genera of the pest is banned from outside of Europe.

Conclusion: The potential impact of *Chionaspis pinifoliae* appears to be limited to nurseries and ornamental trees. The likelihood of invasion was assessed to be relatively low but there is no import ban for two host genera of the pest, i.e. *Cupressus* and *Torreya* (European Commission, 2019).

Coleosporium asterum *s.l. (risk rank 3, HV risk indicator 0.31).* Coleosporium asterum, pine-aster rust, alternates between hosts from *Pinus* and *Asteraceae*. The taxonomy and nomenclature of this species have recently been revised (Beenken *et al*., 2017; McTaggart & Aime, 2018). *Coleosporium solidaginis* has formerly been considered a synonym, but recent studies show that they are not conspecific (Beenken *et al*., 2017; McTaggart & Aime, 2018). *Coleosporium solidaginis* is found on *Pinus* spp. and *Solidago* spp., assumed to be native to North America, but has spread to Asia and Europe (Beenken *et al*., 2017; McTaggart & Aime, 2018). *Coleosporium asterum* is instead found on *Pinus* spp. and *Aster* spp. (Beenken *et al*., 2017), is assumed to be native in Japan, but has also been reported from other countries in Asia (McTaggart & Aime, 2018). Due to the recent taxonomic separation of the two species both their distribution and host range are uncertain and here the species were treated together as *Coleosporium asterum* s.l.. Both species have been found infecting *Pinus sylvestris* (Farr & Rossman, 2019). On *Pinus* spp. the fungi infect the needles and infection levels can be heavy. Damage, however, is usually limited to mainly defoliation and stunted growth of small trees and Christmas trees (Sansford, 2015 and references therein). Several interceptions on cut flowers of *Solidago* sp. and *Solidaster* sp. have been reported from the UK (Sansford, 2015). *Coleosporium asterum* has been a quarantine pest in Mexico since 2018 (EPPO, 2019). A PRA was performed for *Coleosporium asterum* in the UK in 2015 where statutory actions were not considered appropriate/justified (Sansford, 2015).

Conclusion: The species delimitation is currently not clear. Based on the spread history, the likelihood of invasion was assessed as rather high but the impact on *Pinus sylvestris* in the area at risk was assessed to be lower than that of many other ranked pests. In a PRA from 2015 for the UK, statutory actions against the pest were not considered necessary.

Toumeyella parvicornis *(risk rank 3, HV risk indicator 0.31; impact rank 4, HV impact indicator 0.66). Toumeyella parvicornis*, pine tortoise scale, is native in North America and has been introduced to several Caribbean islands and Italy (Garonna *et al*., 2015; Malumphy & Anderson, 2016). Its host range is limited to *Pinus* spp., and *Pinus sylvestris* is reported as one of the primary hosts (Clarke, 2013). The pest is reported to cause mortality of seedlings, saplings and dieback of branches of Christmas trees in North America, and in the Caribbean high mortality has been observed (Malumphy *et al*., 2012; Clarke, 2013; Natural Resource Canada, 2019c). Due to, for example, a less favourable climate, similar high levels of damage are not expected in the area at risk (Malumphy & Anderson, 2016). The pest is associated with seedlings and could thereby be associated with traded plants for planting but import of *Pinus* spp. plants for planting from outside of Europe is banned.

Conclusion: *Toumeyella parvicornis* is a known pest of *Pinus sylvestris* but since its impact in the area at risk is expected to be limited to nurseries and ornamental trees, it was ranked lower than the highest ranked pests. The likelihood of invasion was assessed as relatively low but ornamental *Pinus* plants from Italy are a potential pathway of entry. Further work could evaluate the need to regulate this pest as a regulated non-quarantine pest.

Pest species ranked highest for impact

The following pests all received a high rank for potential impact but a relatively low invasion rank for the assessed pathway of introduction.

Heterobasidion irregulare *(impact rank 1, HV impact indicator 0.96).* Heterobasidion irregulare is a fungal pathogen causing root and butt rot. It is native to North America and has been introduced into Italy where it is reported to currently have a restricted distribution (EPPO, 2019). The main hosts belong to the Pinaceae and Cupressaceae, especially species belonging to *Pinus* and *Juniperus*. Both *Pinus sylvestris* and *Picea abies* have been confirmed as hosts in inoculation studies (EPPO, 2015 and references therein). In 2015, a PRA was conducted for the EPPO region where the risk was assessed to be high with a moderate uncertainty (EPPO, 2015). It was considered that the pathogen could possibly establish as far north as the native species *Heterobasidion annosum* s.s. (62°N) and could add to the high impact caused by it (EPPO, 2015). *Heterobasidion irregulare* has a higher saprophytic ability and a higher production of fruit bodies than *Heterobasidion annosum* s.s., and the two species have also been reported to commonly hybridize with unknown consequences (EPPO, 2015 and references therein). The pathogen is not reported to be associated with plants in nurseries and the likelihood of entry on plants for planting was assessed to be low in the EPPO PRA. The assessment was, nevertheless, highly uncertain and the likelihood of entry would be highest for larger plants (EPPO, 2015). The pathogen has been a quarantine pest in Morocco since 2018 (EPPO, 2019).

Conclusion: A PRA for the EPPO region was performed in 2015 and the risk was assessed to be high and the pathogen is included in the EPPO A2 list. Commodities other than ornamental plants are more likely pathways of entry (EPPO, 2015).

Lambdina fiscellaria *(impact rank 1, HV impact indicator 0.96).* Lambdina fiscellaria, hemlock looper, is a polyphagous moth native to North America (CABI Plantwise Knowledge Bank, 2019b; CABI, 2019c). The pest has not been reported from other parts of the world (CABI, 2019c). The pest causes periodic outbreaks and is considered a serious defoliator in Canada (Natural Resources Canada, 2019b). *Abies* spp. and *Tsuga* spp. are the main hosts but during outbreaks other species, such as *Picea* spp., are also defoliated, but the susceptibility of *Picea abies* is not known (Tuffen *et al*., 2019; CABI, 2019c). A rapid PRA for Ireland and Northern Ireland from 2019 states that the pest poses a considerable risk to coniferous forests in the EPPO region, where the climate is suitable for establishment (Tuffen *et al*., 2019). The likelihood of entry for all pathways assessed (plants for planting, cut foliage, mosses and lichens, and wood) was rated as very unlikely or unlikely with varying uncertainty (Tuffen *et al*., 2019).

Conclusion: The recent PRA performed for Ireland and Northern Ireland indicates that the pest poses a considerable risk for coniferous forests. The potential impact was ranked the highest, but the potential impact on *Picea abies* is highly uncertain since it has not been confirmed as a host.

Orthotomicus erosus *(impact rank 1, HV impact indicator 0.96). Orthotomicus erosus*, Mediterranean pine beetle, is found in Europe, particularly in the southern parts, in Asia and North Africa, and as an introduced pest in Fiji, South Africa, Swaziland and the USA (CABI, 2019d). The bark beetle breeds in species belonging to the genus *Pinus*, including *Pinus sylvestris* (CABI, 2019d). It is normally regarded as a secondary pest infesting wood that recently died and stressed trees, but it has also been reported to attack healthy trees following population build-up (CABI, 2019d and references therein). The risk of this pest has been assessed for the USA (USDA Forest Service, 2018). In the current study, entry to the area at risk via the pathway ornamental plants was assessed to be very unlikely. However, entry through pathways other than plants for planting may be more likely since the pest has been intercepted, for example in Gävle harbour in 1988 on imported wood from France (ArtDatabanken, 2019), and in CABI (2019d) bark, stems and wood packing material with bark are mentioned as a possible pathway whereas plants for planting is not.

Conclusion: The assessed potential magnitude of impact was high but associated with a high uncertainty. Commodities other than ornamental plants are more likely pathways of entry.

Tetropium gracilicorne *(impact rank 2, HV impact indicator 0.76).* Tetropium gracilicorne, finehorned spruce borer, is a long-horned beetle found in the northern parts of Asia and across Russia to Europe; from the Russian Far East to central Russia (EPPO, 2019). There is, however, an ongoing discussion on whether or not *Tetropium gracilicorne* is synonymous with *Tetropium gabrieli* since there are no reliable characteristics that can be used to distinguish the species from each other (Danilevsky, 2019). Historically these species have been separated based on their different distribution ranges, but *Tetropium gabrieli* has recently expanded its range in Europe to areas rather close to the distribution range of *Tetropium gracilicorne* (it is now established in Sweden and possibly also in Finland close to the border of Russia (Kahanpää, 2017)). *Pinus sylvestris* is listed as one of the preferred hosts of *Tetropium gracilicorne*, as well as other species of *Pinus*, *Picea*, *Abies* and *Larix* (EPPO, 2002). A PRA was performed in 2015 for the United Kingdom (Tuffen, 2015) and there is an older short PRA from EPPO (2002). The pest is mainly considered a secondary pest of stressed trees often found together with other pests (Tuffen, 2015). Most reports of impact are on *Larix* spp. (Tuffen, 2015). Plants for planting are considered a potential pathway mainly if the commodity consists of larger plants of conifers (EPPO, 2005). The beetle has been intercepted on wood (Tuffen, 2015) and entry through wood commodities may be more likely (EPPO, 2005).

Conclusion: It is not clear if *Tetropium gracilicorne* is the same species as the already established *Tetropium gabrieli*. The PRA from 2015 assessed the potential impact for the UK as small. The potential magnitude of impact on *Pinus sylvestris* assessed here was highly uncertain. Wood commodities may be a more likely pathway of entry than the pathway ornamental plants.

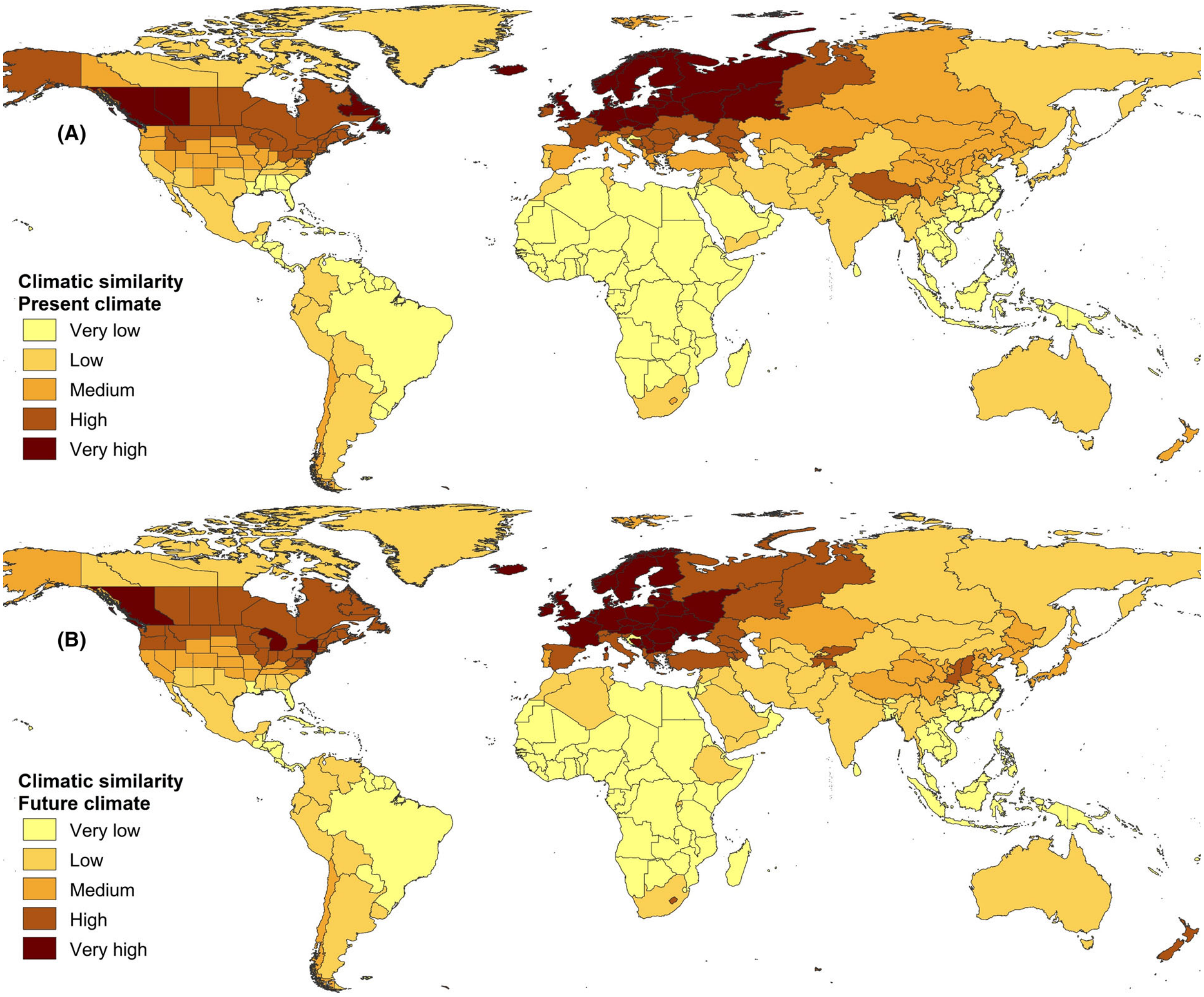

Fig. 5 Climatic similarity at country/state level for (A) present and (B) future climate. [Colour figure can be viewed at wileyonlinelibrary.com]

Gnathotrichus retusus *(impact rank 2, HV impact indicator 0.76). Gnathotrichus retusus*, western pinewood stainer, is an ambrosia beetle present in western North America, from Canada through the USA to Mexico (Atkinson, 2019). Both deciduous and conifer tree species are reported as hosts, including both *Pinus* spp. and *Picea* spp. (Atkinson, 2019). The pest colonizes and excavates galleries in recently cut logs, vectors blue stain fungi and is regarded as an economically important pest of stored timber in western North America (Liu & McLean, 1993; Deglow & Borden, 1998; Hollingsworth, 2019). The pest is not expected to attack living trees. The likelihood of entry to the area at risk from the USA through the pathway ornamental plants was here assessed as very unlikely. The pest has been intercepted in Australia and New Zealand and on wood commodities and packaging material from the USA (USDA, 2011b) and entry through these pathways is considered more likely than entry through the pathway ornamental plants.

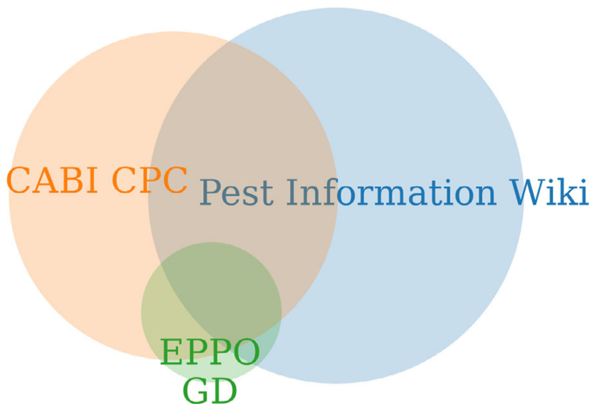

Fig. 6 Area-proportional Venn diagram of the overlap of pest species in the databases. [Colour figure can be viewed at wileyonlinelibrary.com]

Conclusion: The impact is expected to be limited to effects on timber quality during storage. Other pathways than ornamental plants are more likely.

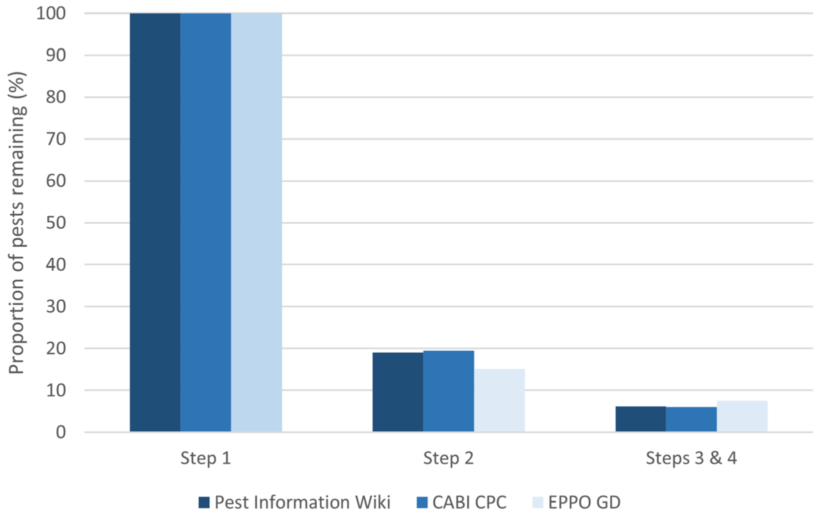

Fig. 7 The proportion of pest species included in the different databases remaining after the different steps in the screening procedure. [Colour figure can be viewed at wileyonlinelibrary.com]

Pseudocoremia suavis *(impact rank 4, HV impact indicator 0.66). Pseudocoremia suavis*, common forest looper, is a moth native to New Zealand (Berndt *et al*., 2004). It has also been introduced into the UK (James, 2019). There are also sporadic reports from the USA but whether or not the pest is established needs to be confirmed (iNaturalist, 2019). The pest is polyphagous and can feed on and defoliate both broadleaved and conifer tree species (Alma, 1977; Berndt *et al*., 2004). *Pinus sylvestris* is recorded as a suitable host for the pest (Dugdale, 1958). In New Zealand, it is not considered a major pest of native trees, but has caused outbreaks in exotic conifer forests, e.g on *Pinus radiata* (Berndt *et al*., 2004 and references therein). It is thought that these outbreaks were associated with hosts stressed by, for example, drought and fungal disease, and they appear to have been short lived (Alma, 1977). The moth has already spread to Europe (UK) and could be associated with plants for planting.

Conclusion: The impact assessment was highly uncertain. The likelihood of invasion was assessed as relatively low, but the pest has been introduced to the UK.

Additional analyses

Comparing present and future climate

The CLIMEX analysis based on the present climate, using a 30-arc minute spatial resolution, showed that 39% of the world's terrestrial area has a medium to very high similarity with the climate in Finland, Sweden or Norway (Composite Match Index values ≥0.7). The analysis of the future climate scenarios for the time period around 2050 showed that this was the case for 36% of the area. However, when the 30-arc minute spatial resolution analyses were converted into a country, or smaller region, level climatic similarity ranks, the situation changed. The similarity ranks were higher for the future climate in 35 countries and 30 regions (of Russia, Canada, the USA and China), and lower only in 3 countries and 10 regions (Fig. 5). Moreover, more than 30% of the rated 211 pests and more than 15% of the 65 ranked pests got higher ratings in the future climate than in the present climate, while none of the pests got a lower rating in the future climate.

Exploration of the used pest databases

As expected, there was an overlap of pest species included in the three pest databases and there was a large difference between the number of pests obtained from each database (Fig. 6). In total 1062 pests were initially included in the current study. The database Pest Information Wiki (2017) contained 759 of these pests, the CABI Crop Protection Compendium (2018) contained 581 of these pests and the EPPO Global Database[1] (EPPO, 2018) contained information that *Picea* or *Pinus* was a host for only 106 of these pests (Fig. 6). Thus, a strikingly large proportion of the pests was only found in one of the databases.

Interestingly, there was no indication of any differences between the characteristics of the pests included in the different databases, i.e. the proportion of pests remaining after each step in our screening was similar in all three databases (Fig. 7). There were no indications that stricter requirements had been used for defining a species as a pest in the databases which contained fewer pests. On the contrary, the database from which most pests were obtained was the one with the highest proportion of pests classified to have a high recorded impact, i.e. 44% of the pests from the Pest

[1]Note from the Editor: The EPPO Global Database (EPPO GD) contains basic information for 785 out of the 1062 pests considered. We remind readers that the focus of EPPO GD is on regulated pests and does not intend to register all host plants but to focus on the most important hosts.

Information Wiki, 26% from CABI CPC and 28% from the EPPO Global Database. Consequently, the benefit of using several databases was stronger than expected, i.e. 41 out of the 65 ranked pests that remained after the screening procedure were only found in one database. Furthermore, three out of the eight pests that received the highest risk ranks in the FinnPRIO assessments were only included in one database.

There was no indication of any differences between the databases with regard to the proportion of different types of pests. In all three databases more than half of the pests were insects and approximately a quarter were fungi. Furthermore, the screening procedure did not change the proportions of the different types of pests retained.

Discussion

The field of pest risk analysis has been criticized for being reactive rather than proactive (Brasier, 2008). The focus tends to be on pests that have already caused damage outside of their native region. The current study is an attempt to proactively identify all pests, including those that have not yet established outside their native region, which could pose a risk to the health of the coniferous forests of Finland, Sweden and Norway. There are many trade requirements and import bans of living plants in the plant health legislation that protect the coniferous forests of the Nordic countries from new pest incursions. Nevertheless, our study revealed many pests of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) that potentially could be introduced into the area at risk, i.e. Finland, Sweden and Norway, via international trade in ornamental plants.

Most of the pests that were identified to potentially constitute a significant risk to the Nordic coniferous forests are present in Europe. This is partly a result of a high likelihood of introduction due to the free movement of most ornamental plants in the EU's internal market. Because many of these pests are widely established in Europe, they are unlikely to become regulated as Union quarantine pests in the EU. However, whether they fulfil the criteria to be regulated as quarantine pests in Norway and/or as protected zone quarantine pests in Finland and Sweden needs to be assessed. The study also revealed several pests that are not present in Europe but could potentially be introduced via the trade in ornamental plants. The sufficiency of the current phytosanitary requirements for preventing the introduction of these pests and the need for additional requirements is not known. Further studies, e.g. full PRAs, may be targeted to some of the identified pests or to some of the host plant commodities of these pests.

The ranked pests

The hypervolume approach was used to rank the pests based on the FinnPRIO scores, but risk management prioritization should not be based solely on the rankings. The information on the biology and the ecology of the pests and other information that was initially used to assess the pests should also be taken into account. Such information was summarized for the 14 top ranked pests in section 3.3.

For some of the 65 ranked pests, relevant PRAs that could be used to guide risk management decisions already exist. Among the top ranked pests, PRAs for the EPPO region have been performed for *Heterobasidion irregulare* (EPPO, 2015) and for *Tetropium gracilicorne* (EPPO, 2002). In addition, PRAs are available for *Lambdina fiscellaria* for Ireland and Northern Ireland (Tuffen *et al*., 2019), *Coleosporium asterum* s.l. and *Tetropium gracilicorne* for the UK (Tuffen, 2015; Sansford, 2015), a quick PRA for *Xylosandrus germanus* for Sweden (Björklund & Boberg, 2017) as well as an express PRA for *Orgyia leucostigma* for the EU (Wilstermann & Schrader, 2018).

Comparison of the FinnPRIO impact assessments of the 65 ranked pests with the four reference pests indicated that the expected impact of some of these pests is in the same range as that of the quarantine reference pests. These pests are thus especially relevant for further investigations considering their potential to cause damage to the Nordic coniferous forests. Some of the pests that ranked high for expected impact were ranked relatively low for the likelihood of invasion and thus did not get a high risk rank. One of the main reasons for the low likelihood of invasion rank for many of these pests was their low likelihood of association with ornamental plants. However, for several of these pests, such as *Orthotomicus erosus* and *Gnathotrichus retusus*, other pathways than ornamental plants may be more likely and might deserve further assessment given the pests' high expected impact on the focal tree species. It should, however, be noted that identification of other possible pathways was not done for all the assessed pests as it was not in the scope of this project.

The assessment of the impacts was limited to the impacts on *Pinus sylvestris* and *Picea abies*. However, some of the identified pests are very polyphagous and although they were ranked low here, they could pose a serious risk to some other host plants present in the area at risk.

There are indications that some of the identified pest species may already be present in Finland, Sweden or Norway but due to lack of reliable information they were considered not established in the area at risk. This was the case for three fungal species, *Cytospora kunzei*, *Dactylonectria macrodidyma* and *Truncatella hartigii*, which were among the 14 top ranked pests. Further investigations are needed to confirm whether these pests are already established in the area at risk.

General pest patterns

The geographic distribution of the pests should be considered when planning further work with the identified pests. The 65 ranked pests were not evenly distributed around the world but stratified into certain countries. For example, 58% and 43% of these pests are present in the USA and Canada, respectively, while only 22% of them are present within the countries of Africa. Presumably, these differences are at least partly related to the distribution of the species in *Pinus* and *Picea* genera. Of the European countries, the highest number of the ranked pests (22) is found in Italy, which accounts for almost 60% of all the ranked pests that are present in Europe.

The climatic similarity analysis indicates that the climate in the Nordic countries will become more suitable in the future for many of the pests that are still absent from this region. For many areas where the pests are currently present, the climatic similarity ratings were higher for the future climate than for the present climate. Some of the pests got higher ratings for the future climate than for the present climate, while none of the pests got a lower rating for the future climate. However, because the assessments were based only on presence data of the pests at a high spatial resolution, they are highly uncertain. A more certain estimate on the likelihood of establishment would require either information on the precise distribution of the pests within the countries or an analysis of the pests' response to various climatic variables.

Several pest databases were used to create the initial list that aimed to contain all known pests of *Picea* spp. and *Pinus* spp. The benefit of using several databases was stronger than expected since 41 of the 65 ranked pests were only found in one of the three used databases. This is noteworthy since that there was no indication of any difference between the types of pests that were included in the different databases. Thus, our study indicates that, when possible, several databases should be used in studies like this one.

Future outlook

In this study 65 pests that could potentially become significant pests of *Picea abies* or *Pinus sylvestris* in the Nordic countries were identified. These pests were ranked with the FinnPRIO model, and the 14 pests ranked highest for risk and/or impact were described in more detail. It is, however, apparent that factors other than these ranks should be considered when deciding what should be done next. For example, PRAs are already available for several of the top ranked pests, namely *Coleosporium asterum* s.l., *Heterobasion irregulare*, *Lambdina fiscellaria*, *Orgyia leucostigma*, *Tetropium gracilicorne* and *Xylosandrus germanus*. For these pests, the next step should be evaluating if new PRAs are needed. For some pests, namely *Cytospora kunzei*, *Dactylonectria macrodidyma* and *Truncatella hartigii*, further investigation is needed to confirm whether or not they are already established in the area at risk. The likelihood of invasion of *Gnathotrichus retusus* and *Orthotomicus erosus* via other pathways, such as wood, might deserve attention since they were assessed to have high impact, albeit a low likelihood of invasion via the trade in ornamental plants. For *Chionaspis pinifoliae*, *Pseudocoremia suavis* and *Toumeyella parvicornis* the next step should be to further investigate their likelihood of introduction since those assessments were highly uncertain.

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Sélection et classement d'organismes associés au commerce de plantes ornementales potentiellement nuisibles aux forêts nordiques de conifères

Les organismes nuisibles aux végétaux transportés via le commerce de plantes ornementales pourraient également constituer une menace pour les forêts. Dans cette étude, les organismes nuisibles aux végétaux potentiellement associés à cette filière ont été passés au crible afin d'identifier ceux qui pourraient représenter un risque élevé pour les forêts de conifères de Finlande, de Suède et de Norvège. L'objectif était plus précisément de trouver des organismes nuisibles remplissant potentiellement les critères pour être réglementés en tant qu'organismes de quarantaine. L'approche développée dans l'étude sur les marchandises de l'OEPP, qui comprend plusieurs étapes de sélection, a été utilisée pour identifier les organismes nuisibles qui sont les plus susceptibles de devenir importants sur *Picea abies* ou de *Pinus sylvestris*. À partir d'une liste initiale de 1062 organismes nuisibles, 65 organismes ont été sélectionnés et classés à l'aide du modèle FinnPRIO, ce qui a abouti à une liste de 14 principaux organismes nuisibles, à savoir *Chionaspis pinifoliae, Coleosporium asterum* s.l, *Cytospora kunzei, Dactylonectria macrodidyma, Gnathotrichus retusus, Heterobasidion irregulare, Lambdina fiscellaria, Orgyia leucostigma, Orthotomicus erosus, Pseudocoremia suavis, Tetropium gracilicorne, Toumeyella parvicornis, Truncatella hartigii* et *Xylosandrus germanus*. Les classements des organismes nuisibles, ainsi que les informations recueillies, peuvent être utilisés pour

hiérarchiser les organismes nuisibles et les filières au cours d'évaluations plus approfondies.

Скрининг потенциальных вредных организмов северных хвойных лесов, связанных с торговлей декоративными растениями

Вредные для растений организмы, перемещающиеся с торговлей декоративными растениями, могут также представлять угрозу для лесов. В этом исследовании, с целью выявления вредных организмов, представляющих высокий риск для хвойных лесов Финляндии, Швеции и Норвегии, был провереден скрининг, тех вредных организмов, которые потенциально связанны с этим путём распространения. В частности, цель состояла в нахождении вредных организмов, потенциально отвечающих критериям для признания их регулируемыми карантинными вредными организмами. Для идентификации вредных организмов, которые с наибольшей вероятностью могут стать опасными для *Picea abies* или *Pinus sylvestris* использовался подход ЕОКЗР для изучения товаров, включающий несколько этапов скрининга. С использованием модели FinnPRIO, были выявлены и определён рейтинг 65 вредных организмов из первоначального списка 1062 видов. В результате этого был составлен список 14 приоритетных вредных организмов, а именно *Chionaspis pinifoliae, Coleosporium asterum* s.l., *Cytospora kunzei, Dactylonectria macrodidyma, Gnathotrichus retusus, Heterobasidion irregulare, Lambdina fiscellaria, Orgyia leucostigma, Orthotomicus erosus, Pseudocoremia suavis, Tetropium gracilicorne, Toumeyella parvicornis, Truncatella hartigii* и *Xylosandrus germanus*. Этот рейтинг вместе с собранной информацией может быть использован для приоритизации вредных организмов и путей их распространения, с целью проведения дальнейшей оценки.

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Supporting Information

For readers looking at the paper or pdf version of this article, please see the html version to access the Supporting Information.

File S1. The rating criteria were based on the EPPO Secretariat's approach for commodity studies (EPPO, 2016) but adapted to the aim of the current project.

File S2. The procedure for the FinnPRIO assessments.

File S3. Potentially relevant pests for the study.