Biol Invasions
DOI 10.1007/s10530-017-1465-6

FOREST INVASIONS

A risk categorisation and analysis of the geographic and temporal dynamics of the European import of plants for planting

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Received: 11 October 2016 / Accepted: 30 May 2017

Abstract The international trade in plants for planting (P4Ps) is a major pathway for the introduction of plant pests. The global trade in P4Ps is both voluminous and highly diverse, but there is little detailed knowledge about its diversity and dynamics. This makes it difficult to assess the risks associated with this trade and to prioritise high-risk commodities (genus-origin combinations) for detailed inspection or regulation. Using the ISEFOR database, this paper describes the diversity and dynamics of P4P imports into the EU, based on genus-level data for lots imported into fourteen Member States that provided this data for different periods between 2005 and 2014, totalling over 30Bn plants and over 7500 commodities. There was great variety, as well as complementarity, in terms of the imported genera, origins and commodities among the countries. Two-thirds of the imported commodities changed every year. Based on the 10-year data from the Netherlands, the greatest importer of live plants in the dataset, we developed a risk categorisation approach for prioritising the highest risk commodities, based on risk associated information concerning the imported genus and the history of trade with respect to the exporting countries, genera and type of plant material traded. Application of this risk categorisation led to the identification of a modest number of commodities that represent elevated risk, to which more inspection resources can be allocated

Guest Editors: Andrew Liebhold, Eckehard Brockerhoff and Martin Nuñez / Special issue on Biological Invasions in Forests prepared by a task force of the International Union of Forest Research Organizations (IUFRO).

Electronic supplementary material The online version of this article (doi:10.1007/s10530-017-1465-6) contains supplementary material, which is available to authorized users.

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Published online: 07 June 2017

while lower-risk commodities could be subject to less-intensive phytosanitary inspections.

Keywords Plants for planting · Harmful organisms · Pathway risk analysis · International trade · Biosecurity · Prioritisation

Introduction

The volume of the international trade in plants for planting (P4Ps, i.e. 'Plants intended to remain planted, to be planted or replanted'; FAO 2012), which include rooted and unrooted plants, cuttings, bulbs and tissue cultures, has increased strongly in the past decades (Liebhold et al. 2012) and so has the annual number of new alien pests recorded in many countries (e.g. Waage et al. 2009; Aukema et al. 2010; Liebhold et al. 2012; Xu et al. 2012; Eschen et al. 2015d; Yamanaka et al. 2015). Many pests have been introduced via the import of P4Ps (Work et al. 2005; Kenis et al. 2007; Liebhold et al. 2012; Santini et al. 2013) and may cause serious economic and environmental damage.

National Plant Protection Organisations (NPPOs) of importing countries can stipulate that exporting countries implement phytosanitary measures aimed at reducing the risk of introducing pests via the trade in P4Ps, which may include pre-export treatments, restrictions on the season of import or the type and origin of plant genera (Sequeira and Griffin 2014; Eschen et al. 2015b). Decisions by NPPOs to stipulate requirements must be based on pest risk analysis (FAO 1997). Phytosanitary regulations have been shown to limit the rate at which new pests become established (Roques 2010), but there are large differences in regulations and their implementations among countries. Thus, NPPOs play a key role in the prevention of pest introductions, for example by verifying that consignments comply with the phytosanitary requirements set by the importing country (Sequeira and Griffin 2014; Eschen et al. 2015a, b). Yet, the increasingly large number and diversity of imported P4Ps limit the ability of NPPOs to inspect all imported consignments thoroughly with their presently available resources (Waage and Mumford 2008; Liebhold et al. 2012). Consequently, some risk-based categorisation is needed to optimize the inspection capacity of importing countries (see Waage and Mumford 2008).

The best possible way to categorize the phytosanitary risk of an incoming lot of P4Ps might be to estimate the probability of contamination from past interceptions records on lots of the same plant taxon and country of origin (a combination defined here as a commodity, for example *Dracaena*-Costa Rica), because phytosanitary import conditions are often defined at the commodity level (see, for example, Annex IV of Anonymous 2000). However, plant genus specific data is not recorded in many countries and if recorded, the data concerning contamination rates is often incomplete because inspectors focus on regulated organisms. Moreover, usually no records are kept of inspected consignments in which no harmful organisms were found (e.g. Kenis et al. 2007), largely impeding prioritisation of the bulk of the imported commodities.

To cope with the challenges of increasing and dynamic (new) trade the current plant health system in the European Union (EU) may be improved by assigning a risk level to each incoming commodity. The current inspection practice of NPPOs in countries with an open market, where a commodity that is not specifically regulated can be imported, is to target regulated (quarantine) organisms described in short lists (e.g. Eschen et al. 2015b), and to use the past experience to identify high risk commodities. For example, the trading history of exporting countries is used to assess the quality and reliability of the phytosanitary systems in these exporting countries. This method has two drawbacks. First, there is a risk of introducing new (unknown) harmful organisms associated with the new trade of particular combinations of genera and origins. Second, hardly any experience is gained about commodities that are not imported on a regular basis or in small numbers, while those commodities may pose a higher risk of violating compliance. Both are pressing issues in the trade of P4Ps as trade in P4Ps is very dynamic in time and space due to differences in production conditions, production costs and due to the interception of pests (Eschen et al. 2015b). The identity and abundance of arriving pests will change accordingly. Moreover, limited resources that affect countries' abilities to inspect all incoming shipments in detail require prioritisation of commodities for more intensive inspection.

Based on an analysis of recent pest outbreaks that could be associated with the import of P4Ps, pest risk criteria for the import of P4Ps were identified and used in a decision support scheme to identify priorities for commodity Pest Risk Analysis (PRA) for P4Ps (EPPO 2012). The study reviewed over fifteen examples of recent pest outbreaks in the EPPO region and identified factors related to the pests and their host plants that may have facilitated the pest introductions. In our study we used four of these factors: whether a species is used indoors or outdoors, the time the plant has been grown in the country of origin and will be grown in the importing country, the range of pests associated with a plant genus and how often such a plant genus is traded (EPPO 2012). As a proxy for the time the plant has been grown in the country of origin we considered a division between woody and herbaceous plant genera, because woody plants are generally older when traded and have been exposed to pests for a longer period of time prior to export compared to herbaceous plants (EPPO 2012). Other factors that were identified in the previously mentioned study as being important, such as the conditions in which imported plants are produced or evidence of spread of latent pests imported on plants of particular origins or genera were not studied further because the available data were either sparse or largely anecdotal. To explore the feasibility of such a risk categorization approach, the proportion of import of P4Ps that falls into these high risk groups needs to be identified. Yet, most of the available data does not capture the identity and diversity of the traded P4Ps: most countries collect data on P4P imports for customs, i.e. tax purposes, and such national data is collated in international databases, such as the UN trade database Comtrade (http://comtrade.un.org/) that comprises trade statistics of over 170 reporter countries, from as early as the 1960s for some countries. But the custom code for P4Ps (e.g. the Harmonised Systems code HS0602, part of a standardised naming system to classify traded products for taxation and record keeping purposes) reveals very little about the type of plants that were imported, as only a few subcategories are used. For example, according to the Comtrade database, Italy imported live plants from Brazil for US$3,419,908 in 2010, but no detail is provided about the genera and types of plants or the number of lots that were imported. Similarly, an analysis of the intra-EU trade in P4Ps revealed the large number of trade linkages, but without detail about the types of plants (Dehnen-Schmutz et al. 2010). Consequently, many countries have a limited understanding of the diversity, the origins and the traits of the imported P4Ps.

The aim of this paper was to show the quantity, diversity and the dynamics in the P4P trade to individual EU Member States, and to develop a risk categorization method to prioritize import inspection under resource constraints. In this paper we provide, using the newly compiled ISEFOR database (see Methods), a detailed description of the diversity of the current trade in P4Ps, taking into account the origins and genera imported, as well as the number of plants and the number of lots of each imported commodity. We also describe how these combinations change from year to year (i.e. trade dynamics), as this provides information about phytosanitary risk and the potential number of pathway risk analyses to be carried out on new commodities, a procedure common in many countries outside the EU, including China, the US and New Zealand (Eschen et al. 2015b). In addition, we develop a method that may assist in prioritising inspection in imported P4P commodities in case no or limited information on their pest is available. This method is based on the characteristics of the imported genera and on the trade dynamics of commodities.

Data and methods

Data collection

The database used for this study was constructed within the frame of the EU FP7 research project ISEFOR (2011–2014: http://www.isefor.com). It has since been transferred to the European Food Security Authority (EFSA). Genus-level data on imports of plants for planting from non-EU countries between 2004 and 2014 were requested from national plant protection organisations in all EU countries. Data from fourteen of the 27 EU member states (MSs) were received. Two MSs indicated that such data was not recorded in a country-wide database. Consequently, the records for some MSs, such as Italy or Belgium, do not represent all imports during the years for which the data were provided. The number of years for which data were obtained varied from one to ten; data for 2010 were obtained from eleven of them (Table 1). Most of the data included the following attributes for each imported lot: year of importation, the importing and exporting country, the type of entry point (road, airport or sea port), genus and the number of plants in the lot. The data was anonymised so that neither exporting, nor importing companies could be identified. For all but 1992 lots (0.38%) it was also indicated what type of product the plants represented (plants for planting bonsai, bulbs and seeds, cuttings, multiple, tissue culture and "other"), but this classification differed between countries and this particular information was taken into account for the Netherlands and France only. Genus names were not provided for 1435 lots (0.28%), including all data from Denmark, and the data from Cyprus only contained genus names for a small number of the imported lots. The data provided by the UK did not record the exporting country, so we assumed that the country of origin was the exporting country. Across the entire dataset, for 246 lots the country of origin was not indicated and those were excluded from the analyses. This primarily concerned lots imported into Cyprus, Denmark and Lithuania. For each lot we defined the genus-origin combination. In addition, data from The Netherlands included detailed custom codes, which allowed us to determine the plant type, i.e. cuttings, rooted plants, outdoor plants, etc. (Appendix 1 of Electronic supplementary material).

Data description and analysis

To check the correct nomenclature of the imported plant genera we used a list of 17,000 genera from the Plant List (http://www.theplantlist.org/) to further assign a number of traits to the imported genus, including life form, intended use and the potential to host organisms recommended for regulation. The plants in each genus were also classified as predominantly woody (including the class "herb/shrub") or non-woody, based on information in the TRY database (Kattge et al. 2011). In addition, a binary classifier was added on whether a plant genus is a host plant of a quarantine organism (EPPO A1 or A2), using the EPPO global database (http://gd.eppo.int/). Because we didn't take global pest distributions into account, we overestimate the risks for a particular plant genus. We also assessed whether the plants were intended for indoor or outdoor planting by looking at the custom codes of the Dutch imports for 2010 (Appendix 1 of Electronic supplementary material).

We summarised the P4P imports for each MS by calculating the mean annual number of plants, lots, countries of origin, genera and commodities, as well as the standard errors around those means. The

Table 1 International differences in trade networks

	Years	Period	Plants	Lots	Origins	Genera	Commodities
Belgium	4	2008–2011	9,947,077 ± 4,683,173	2011 ± 942	9 ± 3	48 ± 17	59 ± 21
Cyprus	1	2010	317,146 ± 0	16 ± 0	7 ± 0	1 ± 0	1 ± 0
Czech Republic	3	2010–2012	11,121,569 ± 1,437,199	816 ± 264	15 ± 4	135 ± 36	182 ± 56
Denmark	1	2011	13,634,716 ± 0	270 ± 0	17 ± 0	–	–
Estonia	8	2004–2011	191,812 ± 167,583	65 ± 31	6 ± 0	7 ± 1	8 ± 1
Finland	2	2010–2011	3,230,887 ± 476,715	103 ± 7	9 ± 0	4 ± 2	4 ± 2
France	6	2005–2010	84,265,005 ± 9,225,827	6112 ± 931	26 ± 2	160 ± 7	302 ± 17
Germany	1	2010	668,784,440 ± 0	2407 ± 0	53 ± 0	719 ± 0	1651 ± 0
Italy	2	2009–2010	94,095,206 ± 8,791,758	2893 ± 17	31 ± 1	244 ± 2	861 ± 98
Lithuania	1	2012	503 ± 0	7 ± 0	1 ± 0	7 ± 0	7 ± 0
Netherlands	10	2005–2014	3,200,030,058 ± 138,798,242	43,684 ± 3992	51 ± 1	859 ± 42	2491 ± 157
Poland	5	2007–2011	63,104 ± 22,705	15 ± 4	4 ± 1	9 ± 1	11 ± 2
Slovakia	8	2005–2012	48,511 ± 10,027	6 ± 2	2 ± 0	3 ± 1	4 ± 1
United Kingdom	1	2011	10,508,914 ± 0	27,972 ± 0	26 ± 0	366 ± 0	574 ± 0
Total	–	–	3,042,648,283 ± 338,867,848	47,391 ± 6563	92 ± 17	1078 ± 165	2874 ± 423

Summary of import statistics for plants for planting into fourteen EU countries, showing annual means and standard errors. Denmark provided no genus names. For data from the United Kingdom we assumed that the country of origin was entered as "Expedition Country" significance of the relationships between these country means were assessed using Pearson correlation of $\log_{10}$-transformed data. R 3.1.2 (R Core Team, 2014) was used for all analyses.

The dynamics of the P4P imports were described by calculating the average annual number of new genera, origins and commodities, as compared to the previous year, for the nine MSs that provided data for multiple years. Specifically, for each country we calculated the annual number of new genera, origins and commodities (Table 2). For The Netherlands, which had the longest time series and imported the largest volume of P4Ps, we calculated how the average annual number of new genera, origins and commodities changed when the reference period was increased from one to up to 7 years. Moreover, we analysed the changes in the number of plants and lots imported from all continents by The Netherlands over the 10-year period.

Criteria used for prioritising high risk commodities

Prioritisation based on genus characteristics

The phytosanitary risk of imported plant material depends on the growth form, intended end-use, known pest associations and the type of imported material (e.g. with or without soil media; EPPO 2012). These risk factors can, therefore, be used as identifiers for high-risk shipments based on general characteristics of the imported genera. Pest risk usually increases with plant age and size, as older plants have had longer exposure to potential pests and larger plants have a larger diversity of pests. The presence of soil increases the risk of introducing soil organisms. Hence, the different sizes, forms and life stages of imported P4Ps can be classified in order of increasing phytosanitary risk (i.e. in vitro, seeds, cutting, seedling, young plant, half-grown plant, full-grown plant). This information can to some extent be gleaned from the custom codes of the lots (Appendix 1 of Electronic supplementary material). Genera that include plant species with woody tissues (mainly trees and shrubs) were identified. In addition, plants were categorised by their end-use. For example many plant genera intended to be used as ornamental plants indoors pose a lower risk to the natural environment, as the chance of harmful organisms establishing on and damaging indigenous plant species is lower. To analyse the impact of the application of these risk profiles on the number of lots that may be considered for intensive inspection, we applied them, alone and in combination, to data from all MSs. To analyse the proportion of imported plants that match with a particular risk profile, the following risk factors were considered: (a) woodiness, (b) outdoor use, (c) pathway for regulated organisms, and (b + c), and the three factors (a + b + c). The combination of pest risk factors was taken as an indication of the highest risk.

Prioritisation based on trading history

Experience based on the history of importation of a commodity could be used as a proxy to classify commodities as high or low risk and may be used to

Table 2 The annual number of new genera, origins and commodities imported into nine EU countries, indicating annual means and standard errors

	Years	Period	Origins	Genera	Commodities
Belgium	4	2008–2011	5.0 ± 2.5	33.3 ± 18.6	46.7 ± 21.4
Czech Republic	3	2010–2012	1.0 ± 1.4	61.0 ± 46.0	105.0 ± 85.0
Estonia	8	2004–2011	1.1 ± 0.6	3.6 ± 0.9	5.0 ± 1.2
Finland	2	2010–2011	0.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0
France	6	2005–2010	6.8 ± 0.6	38.4 ± 12.8	116.6 ± 17.0
Italy	2	2009–2010	6.0 ± 0.0	78.0 ± 0.0	450.0 ± 0.0
Netherlands	10	2005–2014	5.7 ± 0.8	215 ± 15.6	920.9 ± 51.2
Poland	5	2007–2011	3.0 ± 2.0	7.5 ± 1.9	10.8 ± 3.0
Slovakia	8	2005–2012	0.8 ± 0.2	2.5 ± 1.6	3.0 ± 1.3

The values are relative to the preceding year only and do not reflect that certain genera or origins may not be represented in all subsequent years but reappear later in the dataset for a given country prioritise lots for intensive inspection. We assumed that stable commodities, i.e. those that are traded every year, represent lower risk than commodities that are traded either intermittently, infrequently or incidentally (one-off, unique occurrence of the commodity), because the pests may be better known and measures stipulated to mitigate the risk of introducing the most harmful ones. We analysed the plant trade dynamics with the dataset from the Netherlands. We determined the stability of a trading relationship by calculating the number of periods (a period is defined as a single year or multiple, consecutive years) in which each genus, origin and commodity was traded over the recorded time span and the average duration of those periods.

Results

Overall means

Differences between importing countries

The ISEFOR dataset contains records of the import of 33,469,131,118 plants in 521,296 lots, with an average of 3042,648,283 plants imported in 47,391 lots annually (Table 1). There were very large differences in the import volume among the 14 studied MSs. For instance, in 2010 ca. 0.1% of the plants were imported by Cyprus, Estonia, Poland and Slovakia together, while more than 96% were imported by The Netherlands and Germany. Significant positive correlations were found between the average annual number of plants and the average annual number of lots ($\rho = 0.87$), the average annual number of genera ($\rho = 0.81$), the average annual number of countries of origin ($\rho = 0.96$) and the average annual number of commodities imported by each MS ($\rho = 0.82$; all $P < 0.001$). The annual number of imported lots, genera and commodities varied also widely among MSs (and years), with The Netherlands importing from the largest number of countries and importing the largest number of lots and commodities, and Cyprus, Estonia, Poland and Slovakia importing the least.

Type of imported plant material

Of the imported P4Ps into France and The Netherlands in 2010, 98.5 and 66.3% contained unrooted cuttings, respectively. For the Dutch imports we identified, based on the custom codes, which of the remaining plants were woody or non-woody, and whether they were destined for indoor or outdoor use. A comparison of the value of plants imported in 2010 into all EU MSs and only into the Netherlands (Appendix 1 of Electronic supplementary material) indicates that, despite some differences, the overall pattern in imported plant types is similar, with the vast majority imported as rooted or unrooted cuttings, slips and young plants. Woody plants for outdoor use were only imported in 327 lots, containing 3,878,709 plants. The average number of units in lots with cuttings or bulbs was larger than the average number of units in lots containing larger live plants (110,210 and 49,667 vs. 14,422 plants per lot). The numerically most important genera in this year in France and the Netherlands were, respectively, *Begonia* (17,709,090, or 37.3% of all imported plants) and *Chrysanthemum* (1,570,666,073, or 45.6% of all imported plants).

Diversity in genera

The 4,265,719,261 plants in 57,626 lots imported by all MSs in 2010 belonged to ca. 1200 genera and 236 families. Hence, on average, plants of ca. five genera per family were imported. The genera *Chrysanthemum*, *Pelargonium*, *Dendranthema*, *Kalanchoe* and *Euphorbia* were dominant in terms of the number of imported plants (together 67.4% of the imported plants and 11.8% of the imported lots). Of all the imported plants, 0.4% were cacti (Cactaceae), 1.6% belonged to genera with aquatic plants and 6.9% belonged to genera with trees or shrubs. Plants of the latter category belonged to a total of 46 Orders and 111 families. 1.1% of the trees and shrubs were Gymnosperms and the remainder Angiosperms (3,223,524 and 291,884,751 plants in 661 and 13,427 consignments, respectively). Palms (Arecaceae) represented 1.1% of the imported trees and shrubs. More than 13% of the imported plants belonged to genera with plant species that are invasive in parts of the world. The number of trees in the same genera as those in European managed forests (i.e. 95% of European forests, genera taken from Table 2 in Brus et al. 2011) was small (225,669; Table 3). *Castanea mollissima* represented the largest number of a single genus, with 192,000 plants imported in one consignment from China.

Table 3 The number of plants and consignments containing plants belonging to dominant tree genera of European managed forests imported in 2010

Genus	Consignments	Plants
Abies	1	6800
Betula	3	2698
Carpinus	2	275
Castanea	1	192,000
Eucalyptus	3	800
Fagus	1	25
Fraxinus	6	2085
Pinus	19	9835
Quercus	15	5430
Populus	1	2000
Pseudotsuga	2	280
Robinia	7	3441

Diversity in origin

In the period 2004–2014, the vast majority of plants were imported from Africa (83.1%), in particular East Africa (78.3%), followed by Asia (9.4%) and Latin America (6.8%; Fig. 1). However, the percentage of lots imported from Africa was lower (42.0%), and those imported from Asia and Latin America were higher (in particular Central America–21.1%). This was due to the import of large lots of cuttings from Uganda, Kenya, Tanzania and Ethiopia, such as *Chrysanthemum*, *Pelargonium* and *Dendranthema*, which represent over 20Bn (ca. 61%) of the imported plants in the dataset, but less than 8% of the lots. The largest fraction of lots of a single commodity was that of *Dracaena*-Costa Rica (3.9% of all imported lots). Large differences in the diversity of genera imported from different regions were found: Plants imported from Asia belonged to almost 1500 genera, while Africa and Latin America were the source of ca. 900 genera each, North America of ca. 700 genera and plants imported from Oceania belonged to merely 271 genera. Of the ca. 747Mn plants of which the point of entry into the importing MSs was known, 86.3% arrived in airports, 13.7% in harbours and 17,645 arrived at border checkpoints.

The average annual number of origins, genera and commodities of the fourteen MSs combined was larger than the average of any MS individually, indicating that each MS imports specific genera from specific countries, and that these latter complement each other. In 2010, East Africa was the main source for plants imported by Germany and the Netherlands, while Central America was an important source of plants imported into Belgium and France (Fig. 2; Appendix 2 of Electronic supplementary material). Western Asia (mainly Israel) was a major origin of plants imported by the Czech Republic, Finland, France and Italy. East Asia was the main source of plants imported by Cyprus and Poland. This was somewhat reflected in the association of imported genera with certain countries. For example, *Pelargonium* was a main genus imported in the Czech Republic and Slovakia and *Dracaena* one of the main genera imported by Belgium. The largest number of genera came from Western and South-East Asia, followed by Central America.

Trade dynamics

Important changes in import volumes over the period for which data were available were found for some MSs, but not for others. Most notably, the annual imports into Estonia appeared to decline by more than 99.9% and into France by 55% over 8 and 6 years, respectively, while imports into The Netherlands increased by over 60% over a 10-year period (Appendix 3 of Electronic supplementary material). However, the changes observed for Estonia and France may be an artefact of the data that were analysed, which are probably incomplete for some of the countries and do not include details of all imported plants. A similar pattern was found in the number of imported lots, although the increase in the number of lots imported by The Netherlands was even greater than the increase in the number of plants (ca. 150%). The data from The Netherlands reveals shifts in the relative importance of different continents as sources of the imported plants (Fig. 1). While there was a strong overall increase in the number of lots and plants that were imported in the years 2005–2014, the increase was strongest in the number of lots from Africa and North America. The number of plants from Asia increased also during this period, but the number of plants imported from Oceania and Latin America declined. From North America, more lots were imported, but these contained on average fewer plants.

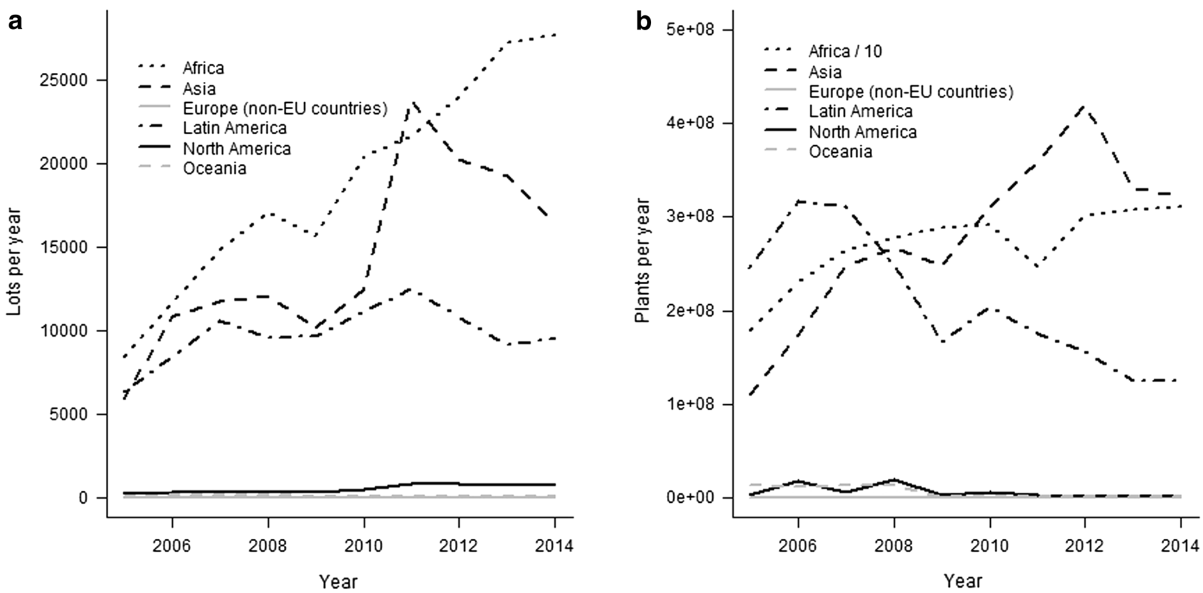

Fig. 1 The annual number of lots **a** and plants **b** imported from different world regions into the Netherlands. Note that the number of plants from Africa has been divided by 10

On average, 28.7% (±8.0 SEM) of the countries from which an MS imported were different from the previous year (Table 2). Similarly, on average 58.6% (±10.3) of the imported genera were different from those the previous year. Each year 68.9% (±8.8) of the commodities were new compared to the previous year, which was primarily due to the number of newly imported genera and not due to the number of new origins.

Prioritisation based on genus characteristics

A sizeable proportion of the imported plants belong to genera that include woody species (Fig. 3, Appendix 4, 5 of Electronic supplementary material). A quarter (25.0%) of the imported genera includes woody species and 21.7% of the commodities, 29.9% of the lots and 6.3% of the volume of plants included genera that include woody species. The proportion of plants that are destined to be planted outdoors is relatively small with 12.5% of all genera, 8.7% of commodities, 5.8% of the lots and 4.8% of the plants. Taking into account all the host plants that could be a pathway for harmful organisms of important outdoor plants in the EU, 388 (A1 + A2) and 260 (A1) imported plant genera can be a pathway. Application of this list revealed that 18.8% of all genera, 19.0% of commodities, 26.3% of the lots and 70.7% of the plants might harbour pests recommended for regulation by EPPO. The combined risk criteria "outdoor use + known pathway for harmful organisms" represented 5.7% of all genera, 3.0% of commodities, 0.8% of the lots and 0.9% of the plants.

When, among the woody plants destined for outdoor use, only the genera that can be hosts for listed organisms were considered, a strong reduction was achieved. Application of these three criteria led to the selection of 1.6% of the lots, less than 0.1% of the plants and 5.2% of the commodities. From the total dataset, 4586 lots with 54 genera were highlighted as high-risk using the application of all criteria simultaneously. In The Netherlands, for example, the average annual number of imported lots of plants that represent a high risk with respect to the entry of listed harmful organisms of woody plants was 413 (±77), or ca. 0.8% of all the imported lots. This concerned lots with plants of 54 genera from 44 countries over the 10 years (Appendix 5 of Electronic supplementary material). High-risk commodities imported in the largest volumes were *Hibiscus* from Viet Nam, Uganda, Israel, Zimbabwe, China, Egypt, Costa Rica, Turkey and other countries (over 48.9Mn plants in 2152 lots), *Acer* from China, South Korea, New Zealand and Japan (2Mn plants in 274 lots–there was a strong decrease in imported numbers during this period: Eschen et al.

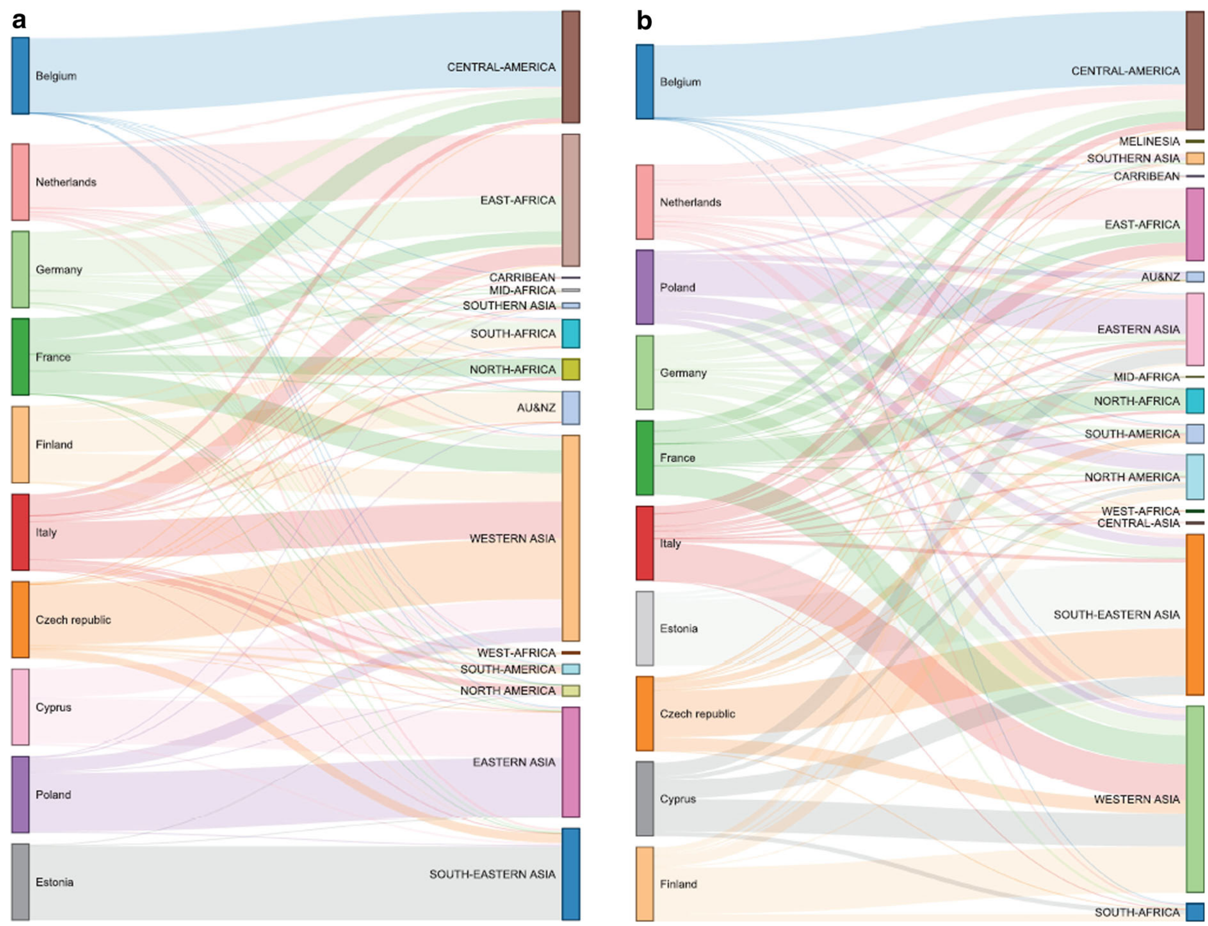

Fig. 2 The regions of origin of P4Ps imported into ten EU countries in 2010 by volume and diversity of genera (**a**, **b**, respectively). Import volumes were standardised among the EU countries to highlight the relative importance of exporting regions as origins of the imported P4Ps

2015c), *Ligustrum*, mainly from China (1.1 Mn plants in 491 lots), *Magnolia* mostly from China, Kenya and Uganda (almost 1Mn plants in ca. 100 lots) and *Cotoneaster* largely from Uganda (802,828 plants in 94 lots). Other commodities were imported in small numbers, such as *Picrasma* from Costa Rica (2 plants), *Larix* from the USA (25 plants in one lot) and *Crataegus* (75 plants from Japan and Korea in 14 lots).

Prioritisation based on trade history

The dataset of The Netherlands was used to analyse the trade dynamics in detail. Almost three quarters of the total of 7552 commodities were imported during only one period of which 8% (491) during all 10 years and 56% in only 1 year (Appendix 5 of Electronic supplementary material). Ca. 25 percent of the commodities were imported during two, three or four periods (Fig. 4, Appendix 6 of Electronic supplementary material). For example, the Netherlands imported plants from 36 (42.9%) of the 84 countries every year of the studied period, i.e. without interruption during 2005–2014, and 18 countries sent plants in only 1 year. The increase in the Dutch import volume in the period 2005–2014 has been mainly linked to the increase in the number of commodities, from 1594 in 2005 to 2975 in 2014 (Appendix 3 of Electronic supplementary material). Only sixteen countries were the origin of plants for two or three periods during the study period (thirteen and three, respectively). Similarly, 48.2% of the genera were imported during only one period of 1–9 years and 18.9% were imported every year. The genera that were imported during 10 years almost all originated from multiple countries,

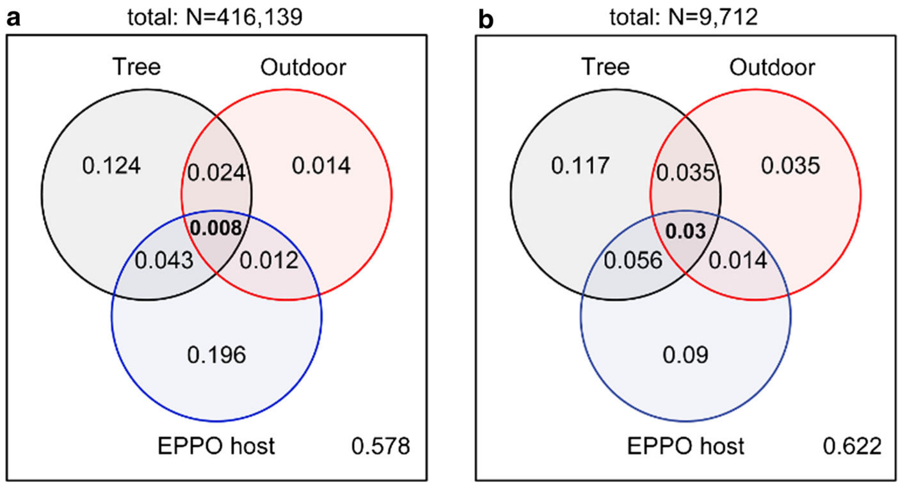

Fig. 3 Venn diagrams showing how the application of risk filters, either individually or in combination–indicated by the overlapping areas of the polygons–lowers the fraction of lots (**a**) and commodities (**b**) prioritised for more intensive inspection. The three filters were whether (1) plants belong to a genus with woody species (Tree), (2) imported plants are destined for outdoor use (Outdoor), and (3) the genus is known to be a host of harmful organism recommended for regulation by EPPO (EPPO host). The number in the *lower right corner* of each figure indicates the fraction of lots or commodities that contain non-woody species intended for indoor use and which are not known to be potential hosts for harmful organisms recommended forregulation

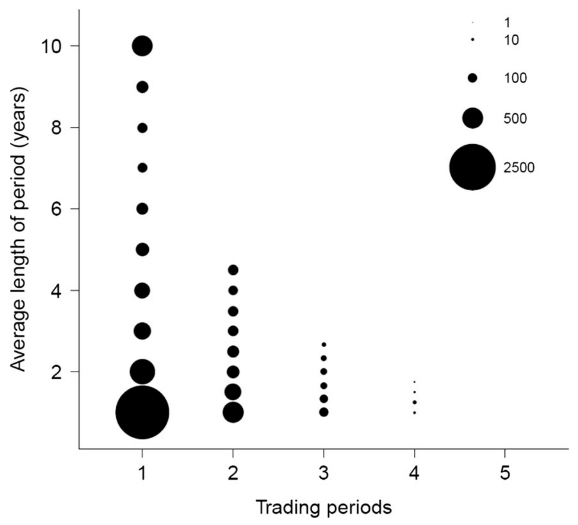

Fig. 4 Risk triangle filled with data on plants for planting commodities imported into the Netherlands in the period 2005–2014. The *size of the dots* indicates the number of commodities, plotted as a function of the number of trading periods (one or multiple consecutive years) during which they occurred and the average length of those trading periods

up to 31, during this period (Fig. 5). A quarter of the genera (25.7%) were imported only 1 year and a single genus was imported every second year from three different countries (*Epimedium* in nine shipments from China, Japan and the USA, totalling 18,538 plants). Over the period 2005–2014, a third of the genera were imported from a single country (36.1%: Fig. 5). Comparatively few genera were imported from a large number of countries, with ten percent of the genera imported from thirteen up to 36 countries.

Focussing on the commodities, a positive relationship between the average duration of the trading periods and both the number of imported plants and the number of lots was found ($F_{1,26} = 15.55$, $P < 0.001$, $R^2 = 0.37$ and $F_{1,26} = 30.64$, $P < 0.001$, $R^2 = 0.54$), indicating that more stable commodities, those with on average longer and fewer trading periods, are associated with larger volumes and more frequent imports.

Overlaying the high-risk genera, origins and commodities, that were identified through the application of the three risk criteria simultaneously, revealed that most high-risk genera and origins were traded for relatively few periods (fewer than four and three, respectively), but the high-risk commodities were not limited to short or few periods. Most plants of high-risk genera were imported during one single 10-year period. The high-risk genus that was imported in largest numbers was *Hibiscus*, followed by *Acer* and *Juniperus* (50, 2 and 1 Mn plants over 10 years, respectively). Excluding the large number of imported *Hibiscus* plants, the number of plants imported in a

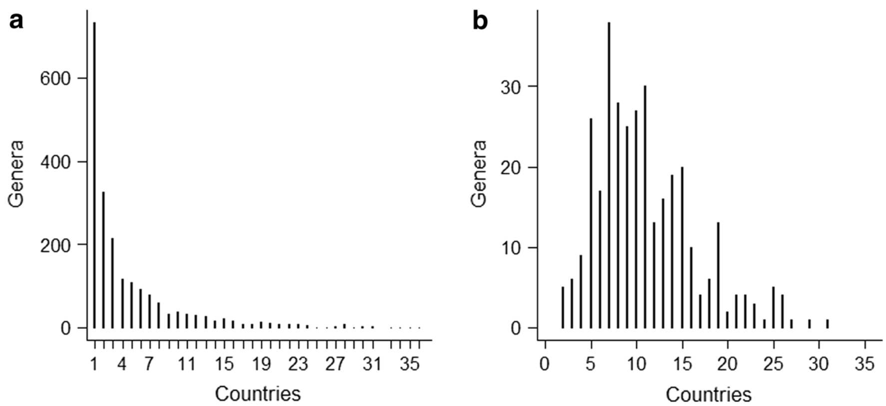

Fig. 5 The frequency distribution of the number of countries of origin for each genus imported into the Netherlands in the period 2005–2014 (**a**). Most genera were imported from a single or two countries and fewer were imported from up to 36 countries. The number of countries of origin of genera that were imported into the Netherlands for ten consecutive years (2005–2014: **b**). All genera were imported from multiple countries, some from as many as 31 countries

single period of 10 years was still five times larger than the number of plants in the second-largest category (two trading period of on average 4.5 years each). High-risk genera imported in short periods (single periods of 1–3 years or two periods of on average 1.5 years) were imported in comparatively small numbers: ca. 188,000 plants per category. Hence, some of the genera that were assigned to a high-risk class based on the genus characteristics were in lower risk classes as defined through trade history, e.g. the eight genera that were imported in each year of the 10-year study period, although plants of a given genus were often imported from different countries during this period. Eleven and six genera, respectively, were only imported during 1 or 2 years. By far, most plants of high-risk genera were imported from multiple countries during the study period. For example, *Acer* plants were imported from ten countries in one or two periods of 1–10 years each. Comparatively small numbers of plants of high-risk genera were imported during single periods of 1–4 years from the Democratic People's Republic of Korea, Lebanon, Vanatu, Tunisia, Ukraine and Burundi. High-risk genera were imported during two periods of on average 3.5 years from Iceland and Morocco.

Almost half of the high-risk commodities were imported during 1 or 2 years, 94 and 26 respectively, and ten of the high-risk commodities were imported during the whole studied period. These latter included, for example, *Hibiscus* from Costa Rica, Egypt, Israel and Turkey, while the former included *Vaccinium* from Australia, *Fraxinus* from South Korea and *Fagus* from the USA. Numerically, high-risk commodities that were imported over longer periods were dominant, with less than 500,000 plants imported during up to 3 years of the studied period and more than 50Mn plants imported during 7 years or more. As an illustration of the range of origins of some high-risk genera, a total of nine MSs imported 243,007 fruit trees of the genera *Malus*, *Pyrus* and *Prunus* (all in the family Rosaceae) from eighteen non-EU countries, on all continents and with climates ranging from temperate to tropical, during the period studied.

Discussion

In this paper we illustrate the quantity, diversity and the dynamics of P4P imports by individual EU Member States, and describe a method to prioritize import inspection under resource constraints. The import data presented here show that P4P imports are very diverse and dynamic in terms of origin and destination, taxonomy and volume. This confirms the findings of smaller-scale studies (e.g. Dehnen-Schmutz et al. 2007, 2010; Areal et al. 2008). The ISEFOR dataset used in this study is representative of the imports of the 28 EU MSs, as it contained data from countries that together represent more than 90% of the import volume (based on comparison of HS0602 codes in EUROSTAT, the EU statistics database). Analysis of the P4P trade showed three important patterns: (1) most of the MSs import a unique set of commodities. This emphasises the importance of the current collaboration of MSs on border biosecurity through the harmonised import plant health regime, as most P4Ps can be moved freely among MSs once allowed entry into the EU. (2) The diversity in traded genera is huge, with ca 1200 imported genera in 2010, and comparable in complexity to P4P imports into the US (Liebhold et al. 2012; Bradley et al. 2011). (3) The vast majority of imported P4Ps are unrooted cuttings (48.2% of the imported volume of the 27 EU member states, see Table 2). The data from The Netherlands and France revealed that these were mainly lots with unrooted cuttings of *Chrysanthemum*, *Pelargonium* and *Dendranthema* from East Africa. These plants represent a relative low phytosanitary risk, because of their young age, the relatively clean production and shipping conditions, the long-standing relationships between trading companies (which led to an optimisation of the production chain) and the incentive to produce high quality rootstock for further propagating in EU (EPPO 2012).

The number of shipments that need to be inspected is very large (Liebhold et al. 2012) and thorough physical inspection of all consignments is impossible as a result of limited time and resources. This is particularly an issue in countries that import many different P4P commodities, such as the US (Liebhold et al. 2012) and The Netherlands. However, most countries presumably experience resource constraints and need to prioritise inspection to high risk commodities (Waage and Mumford 2008). Although import inspections are a check that the import requirements are met, and not intended to find all harmful organisms in a shipment, a method to assign a risk profile to incoming commodities would enable NPPOs to allocate resources more effectively. For this reason, we designed a method that is composed of a series of risk criteria to identify high risk commodities. The criteria applied in this study were based on the biological characteristics of the genus and on the dynamics of the trade in a commodity. These were among the criteria identified in a study of recent pest outbreaks (EPPO 2012) and we believe that biological characteristics and trade dynamics represent the two most important, easily measurable factors for risk categorization, making the method suitable for any country if the required data are available.

Applying the combined risk criteria to the imported genera resulted in a relatively manageable number of high-risk genera and commodities, which could be targeted for urgent risk assessment (0.04% of commodities across countries; Appendix 5 of Electronic supplementary material). The results also suggest that the large majority of imported plants pose a relatively low phytosanitary risk, because they belong to genera that are used for indoor planting and as annual bedding plants. Such low-risk commodities could be subject to less-intensive phytosanitary inspections, as is currently done for fruit and vegetable commodities in the EU. For regulated fruit and vegetable trade flows that have a safe trade history (i.e. the number of interceptions at import is below a set limit), only a specified percentage of consignments is inspected (Anonymous 2004; note that this regulation does not apply to P4P). This may correspond to 5% of the imported consignments of a particular commodity and 95% of the consignments would not be inspected, as opposed to 100% inspected consignments under the current regulation.

Orthogonal to the filters based on the genus characteristics, we applied a criterion that reflects commodity trading experience. Experience is based on the frequency of import inspections (i.e. in EU all P4P consignments are inspected) and the number of interceptions of consignments with harmful organism (i.e. rejection). The rationale of this criterion is that the phytosanitary risk for the countries, genera and commodities that are traded in fewer years or periods is higher, or less predictable, than for more continuous, established trade because more experience is build up with frequently traded commodities. Infrequently imported or new genera and commodities could be subject to risk analysis and, if the outcome of the risk analysis predicts a high risk, to additional phytosanitary measures such as intensified inspection or sampling and testing.

The level of risk associated with a commodity may determine the phytosanitary measures taken. The highest risk category would need immediate risk assessment, because all risk criteria are met: perennial half-grown plants/trees that are destined to be planted outdoors, that belong to genera that include hosts of harmful organisms recommended for regulation by EPPO and that are imported from new trading partners. For commodities that score 3 out of 4, the specific combination of risk components may determine the specific risk mitigation measures prior to export and at import. For example, measures for commodities that are traded regularly could be focused on pest-free production methods and surveillance at the production sites, while for new trade post-entry inspections and a quarantine period could be more appropriate.

The number of plants and lots of less frequently traded commodities was smaller than those of continuous trade. Overlaying the results of both prioritisation methods, which combine the assumption of knowledge about commodities based on the trade history with the ranking based on characteristics of genera, revealed that many of the high-risk genera were imported as commodities that are traded on an infrequent or incidental basis and/or small numbers. Similarly, Bradley et al. (2011) showed that roughly 50% of the lots in the US were small (<US$ 100). These patterns suggest that the risk of the infrequent trade may not be as high as we initially hypothesised, because of the lower pest approach rates associated with less frequent import events, even if these events involve presumed high-risk commodities. However, as the information on pest-host associations is incomplete, this risk linked to infrequent trade may be underestimated. It would be valuable to further investigate the infestation level or the fraction of non-compliant consignments of infrequent and incidental trade, in order to better understand the real phytosanitary risk.

Small lots in the presented dataset may consist of a few large trees with root balls but may equally contain few plants that were sent as a sample or germplasm of a new variety to start domestic production from. Drew et al. (2010) showed that an increasing consumer demand and interest in novel and exotic ornamental plants is an important driver of the horticultural industry in the US. Novelty can produce premiums for the industry, so there is a constant pressure for breeders to produce new plant cultivars (Drew et al. 2010). Plant characteristics desired by the industry include ease of propagation, stress tolerance, large flowers, long blooming season and easy care (van Valkenburg et al. 2014). Analysis of the trade history showed that only 12–20% of the new genus-origin trade flows developed in a regular trade flow. This irregular (discontinuous) trade very often has a low trading frequency, but higher risk due to the uncommon genera that are traded. More detail in the recorded information, or more detailed analysis would be required to clarify the contents of, and assess risk associated with small lots of P4Ps.

Our results showed that many countries do not collect detailed data on the imported plants and the presence/absence of (un)regulated pests. There is a wealth of undocumented knowledge, unavailable in the public domain, as well as experience of inspectors regarding the likelihood that a shipment is compliant or whether there is a likelihood that harmful organisms may be found during inspections. For example, inspectors may recognize certain trade flows and company names as being "clean and safe" (R.P.J. Potting, pers. obs.). These trade flows often involve highly professional providers of propagative material in the form of (unrooted) cuttings often derived from intro vitro culture. This information, although very valuable, is often unavailable for objective, science-based prioritisation. Our results illustrate that there is a clear benefit of genus-level import data over the nonspecific data collected for customs purposes and we recommend that importing countries collect genus-level data to inform PRA and decisions about phytosanitary measures. Recording data that can be relatively easily collected can be used to identify a small, comparatively manageable number of lots and commodities that represent a high phytosanitary risk. These high-risk commodities could be targeted for more intensive inspection at the point of entry. In addition, the proposed method is a step towards more rigorous and transparent risk categorisation and the presented risk categorisation models represent hypotheses that can be tested and falsified, in particular if detailed information on trade and infestation of lots were to become available. Moreover, the independence of the risk factors (e.g. trade dynamics and genus characteristics) provides the opportunity to make small sets of high risk categories.

Independent validation through recording pest density across the possible range of commodities and through linking establishment records to imported commodities is needed to make this approach evidence based. This is particularly relevant in light of the Agreement on Sanitary and Phytosanitary Measures, which stipulates that regulations and phytosanitary measures should be based on science (WTO 1995). In particular the risk categorization by linking the genus to a list of pests (EPPO list) may not be specific enough. For example, if a particular plant genus is a host plant of a quarantine organism, this does not automatically imply that the plant genus is a pathway for introduction. This largely depends on the plant species, area of origin, production method and plant type that is imported. Phytosanitary measures are already now stipulated for import of some of the high-risk P4P commodities. In EU plant health legislation (EU 2000/29) it is specified that deciduous trees and shrubs can only be imported in a dormant state and without leaves (Anonymous 2000). Risk categorization at genus level may hold if the plants belong to a genus that is not known to include potential hosts of regulated harmful organisms. However, there is limited knowledge of (potentially) harmful organisms for most genera, as illustrated by the short lists of regulated organisms in countries that regulate harmful organisms and commodities based on knowledge of the impact of the pest (Eschen et al. 2015d; García-de-Lomas and Vilà 2015). For example, the EU only regulates ca. 350 species or genera. As a consequence of the limited knowledge about which organisms can become pests, the criterion whether a genus is a host of harmful organisms recommended for regulation by EPPO probably underestimates the risk associated with many genera. This indicates that there is a need to identify more harmful organisms in the country of origin, e.g. by monitoring of pests and diseases in sentinel plantings (Britton et al. 2010; Kirichenko et al. 2013; Tomoshevich et al. 2013; Roques et al. 2015; Vettraino et al. 2015), to inform PRAs and decisions on phytosanitary measures.

Acknowledgements The authors owe thanks to the countries that provided the data. This work received funding through the EU-funded research project ISEFOR, COST Actions PERMIT (FP1104) and Global Warning (FP1401) and from the Netherlands Food and Consumer Product Safety Authority and the Swiss State Secretariat for Education and Research. RE received a grant of the OECD to present this work during the meeting of the IUFRO Task Force on Biological Invasions in Forests in Shepherdstown, WV, on 18–21 July 2016. We are grateful to two reviewers for their time and constructive comments.

References

Anonymous (2000) Council Directive 2000/29/EC of 8 May 2000 on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community

Anonymous (2004) Commission Regulation No 1756/2004 of 11 October 2004 specifying the detailed conditions for the evidence required and the criteria for the type and level of the reduction of the plant health checks of certain plants, plant products or other objects listed in Part B of Annex V to Council Directive 2000/29/EC

Areal F, Touza J, MacLeod A, Dehnen-Schmutz K, Perrings C, Palmieri M, Spence N (2008) Integrating drivers influencing the detection of plant pests carried in the international cut flower trade. J Environ Manag 89:300–307

Aukema J, McCullough D, Von Holle B, Liebhold A, Britton K, Frankel S (2010) Historical accumulation of nonindigenous forest pests in the continental United States. Bioscience 60:886–897

Bradley B, Blumenthal D, Early R, Grosholz E, Lawler J, Miller L, Sorte C, D'Antonio C, Diez J, Dukes J, Ibanez I, Olden J (2011) Global change, global trade, and the next wave of plant invasions. Front Ecol Eviron 10:20–28

Britton K, White P, Kramer A, Hudler G (2010) A new approach to stopping the spread of invasive insects and pathogens: early detection and rapid response via a global network of sentinel plantings. N Z J Forest Sci 40:109–114

Dehnen-Schmutz K, Touza J, Perrings C, Williamson M (2007) The horticultural trade and ornamental plant invasion in Britain. Cons Biol 21:224–231

Dehnen-Schmutz K, Holdenrieder O, Jeger M, Pautasso M (2010) Structural change in the international horticultural industry: some implications for plant health. Sci Hort 125:1–15

Drew J, Anderson N, Andow D (2010) Conundrums of a complex vector for invasive species control: a detailed exaination of the horticultural industry. Biol Invasions 12:2837–2851

EPPO (2012) EPPO technical document no. 1061, EPPO study on the risk of imports of plants for planting. EPPO, Paris

Eschen R, Rigaux L, Sukovata L, Vettraino A, Marzano M, Grégoire J-C (2015a) Phytosanitary inspection of woody plants for planting at European Union entry points: a practical enquiry. Biol Invasions 17:2403–2413

Eschen R, Britton K, Brockerhoff E, Burgess T, Dalley V, Epanchin-Niell R, Gupta K, Hardy G, Huang Y, Kenis M, Kimani E, Li H, Olsen S, Ormrod R, Otieno W, Sadof C, Tadeu E, Theyse M (2015b) International variation in phytosanitary legislation and regulations governing importation of plants for planting. Environ Sci Policy 51:228–237

Eschen R, Grégoire J-C, Hengeveld G, de Hoop B, Rigaux L, Potting R (2015c) Trade patterns of the tree nursery trade in Europe and changes therein following findings of citrus longhorn beetle, *Anoplophora chinensis* Forster. Neobiota 26:1–20

Eschen R, Roques A, Santini A (2015d) Taxonomic dissimilarity in patterns of interception and establishment of alien arthropods, nematodes and pathogens affecting woody plants in Europe. Div Distr 21:36–45

FAO (1997) International Plant Protection Convention. FAO, Rome

FAO (2012) International standards for phytosanitary measures no. 5. Glossary of phytosanitary terms. IPPC, Rome. https://www.ippc.int/largefiles/adopted_ISPMs_previousversions/en/ISPM_05_En_2012-05-07(CPM-7).pdf. Accessed 10 October 2016

García-de-Lomas J, Vilà M (2015) Lists of harmful organisms: are the national regulations adapted to the global world? Biol Invasions. doi:10.1007/s10530-015-0939-7

Kattge J, Díaz S, Lavorel S et al (2011) TRY–a global database of plant traits. Global Change Biol 17:2905–2935

Kenis M, Rabitsch W, Auger-Rozenberg M-A, Roques A (2007) How can alien species inventories and interception data help us prevent insect invasions? Bull Entomol Res 97:489–502

Kirichenko N, Péré C, Baranchikov Y, Schaffner U, Kenis M (2013) Do alien plants escape from natural enemies of congeneric resident? Yes but not from all. Biol Invasions 15:2105–2113

Liebhold A, Brockerhoff E, Garrett L, Parke J, Britton K (2012) Live plant imports: the major pathway for the forest insect and pathogen invasions of the US. Front Ecol Environ 10:135–143

R Core Team (2014) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

Roques A (2010) Alien forest insects in a warmer world and a globalised economy: impacts of changes in trade, tourism and climate on forest biosecurity. N Z J Forest Sci 40(suppl): S77–S94

Roques A, Fan J, Courtial B, Zhang Y, Yart A, Auger-Rozenberg M-A, Denux O, Kenis M, Baker R, Sun J (2015) Planting sentinel European trees in eastern Asia as a novel method to identify potential insect pest invaders. PLoS ONE 10:e0120864

Santini A, Ghelardini L, De Pace C, Desprez-Loustau M-L, Capretti P, Chandelier A, Cech T, Chira D, Diamandis S, Gaitniekis T, Hantula J, Holdenrieder O, Jankovsky L, Jung T, Jurc D, Kirisits T, Kunca A, Lygis V, Malecka M, Marcais B, Schmitz S, Schumacher J, Solheim H, Solla A, Szabo I, Tsopelas P, Vannini A, Vettraino A, Webber J, Woodward S, Stenlid J (2013) Biogeographical patterns and determinants of invasion by forest pathogens in Europe. New Phytol 197:238–250

Sequeira R, Griffin R (2014) The biosecurity continuum and trade: pre-border operations. In: Gordh G, McKirdy S (eds) The handbook of plant biosecurity. Springer, Berlin, pp 119–148

Tomoshevich M, Kirichenko N, Holmes K, Kenis M (2013) Foliar fungal pathogens of European woody plants in Siberia: an early warning of potential threats? For Pathol 43:345–359

van Valkenburg J, Brunel S, Brundu G, Ehret P, Follak S, Uludag A (2014) Is terrestrial plant import from East Asia into countries in the EPPO region a potential pathway for new emerging invasive alien plants? EPPO Bull 44:195–204

Vettraino A, Roques A, Yart A, Fan J, Sun J, Vannini A (2015) Sentinel trees as a tool to forecast invasions of alien plant pathogens. PLoS ONE 10:e0120571

Waage JK, Mumford J (2008) Agricultural biosecurity. Phil Trans R Soc Lond B 363:863–876

Waage JK, Woodhall JW, Bishop SJ, Smith JJ, Jones DR, Spence NJ (2009) Patterns of plant pest introductions in Europe and Africa. Agric Syst 99:1–5

Work T, McCulough D, Cavey J, Komsa R (2005) Arrival rate of nonindigenous insect species into the United States through foreign trade. Biol Invasions 7:323–332

WTO (1995) Agreement on the application of sanitary and phytosanitary measures. World Trade Organization, Rome

Xu H, Qiang S, Genovesi P, Ding H, Wu J, Meng L, Han Z, Miao J, Hu B, Guo J, Sun H, Huang C, Lei J, Le Z, Zhang X, He S, Wu Y, Zheng Z, Chen L, Jarošík V, Pyšek P (2012) An inventory of invasive alien species in China. Neobiota 15:1–26

Yamanaka T, Morimoto Y, Nishida GM, Kiritani K, Moriya S, Liebhold AM (2015) Comparison of insect invasions in North America, Japan and their Islands. Biol Inv. doi:10.1007/s10530-015-0935-y