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Trade patterns of the tree nursery industry in Europe and changes following findings of citrus longhorn beetle, *Anoplophora chinensis* Forster

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Abstract

The trade in plants for planting is a major pathway for the introduction and further spread of alien plants, pests and diseases. Information about the structure of plant trade networks is not generally available, but it is valuable for better assessing the potential risks associated with the trade in live plants and the development of prevention and mitigation measures and policy. The discovery of two larvae of *Anoplophora chinensis* (citrus longhorn beetle – CLB) in 2009, at a nursery importing *Acer palmatum* from China in one of the major Dutch tree nursery areas, has resulted in the creation of a detailed dataset on the intra-European Union trade in its potential hosts. This study describes European imports of the primary host of *A. chinensis*, *Acer* spp., into the Netherlands (1998-2012) and the effects of the finding in a tree nursery area. In addition, shipments of *Acer* spp. from 138 producers in the nursery area in 2009 were analysed in a one-off analysis of intra-EU trade. The volume of *Acer* spp. imports from Asia was stable early during the studied period, and declined to 5% of the initial imports after a period of interceptions, illustrating the effect of regulations. The number of notifications of *A. chinensis* infestations in imported consignments of

Acer spp. increased sharply in the years up to 2007, then declined as imports also reduced. Although plants were shipped to destinations throughout Europe, each producer shipped plants only to few destinations in few countries. Most of the plants were shipped to nurseries in EU countries. These patterns could make it easier to target these high risk destinations for control measures. The lack of transaction records makes it difficult to trace the destination of plants. More systematic electronic record keeping by traders and growers and the data being collated in a database that can be made available to regulatory authorities, together with further studies of plant trade data using network approaches, would be beneficial for improving trace-back and trace-forward and provide better safeguards for plant health and quality.

Keywords

Citrus longhorn beetle (*Anoplophora chinensis* Forster), International trade, Invasive alien insects, Japanese maple (*Acer palmatum* Thunb.), Plants for planting

Introduction

The international trade in plants for planting is a major pathway for the introduction of alien tree pests and diseases (Levine and D'Antonio 2003, Brasier 2008, Roques 2010, Liebhold et al. 2012). The European Union (EU) imports a large volume and diversity of plants for planting every year, and the value of imported plants for planting has increased 60% over the past fifteen years (inflation corrected data from FAOSTAT; R. Eschen unpublished data). The annual number of new alien tree pests and diseases recorded in Europe increases (Roques 2010, Santini et al. 2013), despite national and international regulations aimed at reducing the introduction of new alien species. Alarmingly, however, trade movements of plant material into and within the EU are not well documented. The best available data about movements of plant material into the EU come from customs authorities, and these data inform the selection of consignments for phytosanitary inspections. These inspections are primarily intended as checks for compliance with prescribed phytosanitary measures in the country of origin, not at quantifying pest abundance. Phytosanitary inspections of EU plant material are carried out at nurseries during the growing season, but, like in other countries (Li et al. 2014), no routine phytosanitary inspections are carried out on EU internal traded plant material. Since 1992, when controls on the movement of goods within the EU were abolished and the EU became a territory without internal frontiers, it has been difficult to obtain data on internal EU trade. This holds true for the plant and tree nursery trade with its wide network throughout Europe and great number of plant species and varieties. Yet, information on destinations of traded plants and the number of destinations of plants from individual producers is extremely important for understanding and quantifying the potential risks associated with the trade in live plants and the development of mitigation measures and policy (Koch et al. 2014, Shaw and Pautasso 2014).

During the first decade of the twentieth century, Japanese maple (*Acer palmatum* Thunb.) became an increasingly popular plant for both outdoor and indoor gardening. Garden retail companies, but also multinational supermarkets, placed large orders with importing companies. However, from 2008–2010 the tree nursery industry in

Europe was disrupted by an increasing number of interceptions of *Anoplophora chinensis* Forster (Insecta: Coleoptera; Citrus Longhorn Beetle – CLB) on *Acer palmatum* originating from China. The taxonomy of this species remains a little confused, with some taxonomists still referring to *A. malasiaca* as distinct from *A. chinensis*. It is possible that *A. chinensis* interceptions and outbreaks in Europe may be from two closely related species or a species complex (Iwaizumi et al. 2014). CLB is native to East-Asia and interceptions of the species are typically associated with imports of live plants such as *Acer* spp. and bonsai (Haack et al. 2010). In the EU CLB is regulated as a quarantine species, based on the high probability of establishment and potential damage (MacLeod et al. 2002). The larvae bore into the wood of live trees, thereby reducing the quality and value of the wood and causing the death of trees. Infested live trees are difficult to recognise as a result of the cryptic lifestyle of the larvae. An important risk compounding factor is that infested plants can remain undetected for up to three years in the cooler climates of the northern Europe (e.g. Netherlands and the UK). Countries in southern Europe present better conditions and the development time is only 1–2 years (Haack et al. 2010, Van der Gaag et al. 2010). In East Asia, adults also emerge after 1–2 years of larval development, mate and lay eggs on new hosts which can be of a large number of broadleaved genera (Lingafelter and Hoebeke 2002), including common European genera such as *Acer*, *Alnus*, *Betula*, *Populus* and *Pinus*. Dispersal distance is limited, and infestations rarely spread further than 500m in five years (Van der Gaag et al. 2010). CLB has been intercepted in Europe since 1980, both during import inspections and post-entry in various countries (Haack et al. 2010). Haack et al. (2010) reported that only three of the European interceptions (5%) between 1980 and 2008 were made at ports of entry into the EU. The remaining interceptions were made at locations past the port of entry in various EU countries, for example in warehouses or nurseries.

Greater focus on CLB by European authorities following a small outbreak of CLB in the Westland area in the Netherlands in 2007 (NPPO 2008) led to more findings and eradication programmes in the following years, including in Germany, France, Italy, Switzerland and the United Kingdom. In all cases, direct links to earlier imports from China confirmed the high risk of this pathway (Haack et al. 2010). Eradication measures were taken in four European countries after discovery of CLB, but the success has varied and was dependent on the time since establishment, host plant density and climate. The eradication in France and the Netherlands is presumed to have been successful, while the eradication and surveys in Italy and Croatia are on-going.

Another discovery of CLB took place in December 2009 in the Boskoop area in the Netherlands (52°4'N, 4°39'E), one of the most important tree nursery areas in the Netherlands. The greater Boskoop area (Greenport Boskoop; Gemeente Boskoop, undated), which is close to Rotterdam, harbours hundreds of tree nursery companies in an area of ca. 400 km^2 with an annual turnover of at least Euro 200 million. After the finding, the potential conifer hosts *Pinus* spp. and *Cryptomeria* spp., all woody broadleaved plants, which included hundreds of other known host plants, were removed in a radius of about 100 metres. All plants were individually examined and no signs of CLB were found. Also, an intensive survey within 600 metres from the infested area did not reveal any signs of the pest. Repeated, intensive monitoring surveys within a radius of 1 km surrounding the finding have not revealed any further signs, indicating that *A. chinensis* had neither spread nor established in the area.

Until this event it was presumed that CLB could not establish in the Netherlands, *inter alia* based on a pest risk analysis (PRA) suggesting that the pest was unlikely to establish in southern England, unless two hot summers occur in sequence (Baker and Eyre 2006; but see Van der Gaag and Scholte 2007). A subsequent PRA (van der Gaag et al. 2008) demonstrated that the import of Japanese maples originating from China into the Netherlands had increased to approximately one million units per year and there was also evidence from the UK and the Netherlands that CLB could extend its development time to 3 years. Based on this PRA, EU emergency measures were taken at the end of 2008, which stipulated that additional phytosanitary measures at the places of production in countries where CLB is known to occur and more detailed and destructive sampling upon import into the EU be implemented (Commission Decision 2008/840/EC: European Commission 2008; amended in European Commission 2010 and updated in European Commission 2012). Costs related to destructive sampling of imported consignments were directly charged to importing companies. In 2010, an EU import ban on *Acer* spp. from China was implemented (Commission Decision 2010/380/EU: European Commission 2010). The import ban was lifted in 2012 and host plants from countries where CLB occurs can only be imported under strict phytosanitary measures including destructive sampling prior to export. Due to the long-term risk of earlier imports and trade from China, the Netherlands was requested by the European Commission in early 2010, to provide details of all deliveries, covering a two year period from mid-2008, from the 2km-radius buffer zone around the initial finding of CLB in Boskoop ("demarcated area", Food and Veterinary Organisation 2010) with shipments to other EU Member States. This has resulted in a detailed database of trade in live trees in Europe, documenting each transaction, ranging from single trees to large consignments, including long distance trade to the outer reaches of the EU and short-distance trade within Boskoop itself. Following the communication of the transaction information, many other EU Member States investigated these plants but no further findings of CLB were made, apart from one lot of two *Acer* plants which could be directly traced to originate from China.

Using this database, this paper describes the trade in woody plants for planting through the Netherlands with particular focus on CLB and *Acer* spp. Although the data relate to one country only, the Netherlands are the main importing and producing country for live plants in the EU (Dehnen-Schmutz et al. 2010). It must be noted that for woody perennial plants Italy is also an important importing country in the EU. Models have shown that super-connected nodes increase the likelihood for a disease to spread in the system and targeting of such super-connected nodes makes control more effective and efficient (Moslonka-Lefebvre et al. 2011, Pautasso and Jeger

2014). We combine information on imports from non-EU countries into the Netherlands, notifications of pest interceptions and the database that was established in response to the recent CLB outbreaks in the Netherlands. Moreover, we assess the relationship between the number of *Acer* plants from Boskoop and the abundance of potential host plants in the receiving regions. This combination of data enables us to describe the trade in *Acer* spp., an important pathway for the introduction of CLB into Europe, concerning both the import and further movement of the plants within the EU. We discuss how patterns in trade, including the number of destinations to which a producer delivers plants, may affect the risk of spreading pests and diseases and the management of outbreaks.

Methods

Import of plants from third countries

Data about the import of all *Acer* species from third countries into the Netherlands were extracted from the import inspection database of the National Plant Protection Organization of the Netherlands (NPPO) for the years 1998–2012. The database includes details on the numbers of imported plants per genera or even species level, as well as data on consignor and consignee. Although not publicly accessible, this database includes much greater detail as compared to the public databases maintained by the statistical bureau of the European Commission (Eurostat) or the United Nations (UN Comtrade: http://comtrade.un.org/db/), because the codes in the latter are too generic to trace individual plant species or genera.

Notifications, pest interceptions, outbreaks

The best available data about the movement of pests into the EU come from pest interceptions during phytosanitary import inspections at the port of entry and findings away from the point of entry. Interceptions of pests regulated in Annex Ia and IIa of Council Directive 2000/29/EC (European Commission 2000) and pests recommended for regulation by the European and Mediterranean Plant Protection Organisation (the EPPO A1 and A2 lists; http://www.eppo.int/QUARANTINE/quarantine.htm) are recorded in centralised databases by EU countries. For this study, notifications of interceptions of CLB during the period 2000–2012 were obtained from the EUROPHYT database, which contains notifications of interceptions related to trade. There were twenty interception records in 2008 from Lithuania. It was understood that this interception concerned twenty CLB in one consignment from Japan (Bram de Hoop pers. obs.) and we considered this a single interception. Only interceptions on plants that were recorded as originating from non-EU countries (including Switzerland) were retained.

Intra-European trade

Data about all transactions by producers and traders in the Boskoop area for a two-year period (July 2008–June 2010) were digitised and included the identity (genus and species), number, origin and destination of all shipped plants. Only the transactions for 138 producers in 2009, the year with the largest number of records, were analysed, because of the incompleteness of the records for 2008 and 2010 in the database. In some instances the same plants have been traded within the Boskoop area itself and later to customers outside the Boskoop area. Therefore the total number of plants is lower than recorded in the database, but it is impossible to identify plants that were traded multiple times.

In order to minimize the possibility that individual recipients could be identified and to facilitate working with the large number of recipients, as well as graphical representation of the data, the post codes of the recipients were assigned to the corresponding Nomenclature of Units for Territorial Statistics (NUTS) regions. NUTS regions were established by Eurostat and correspond to administrative regions of EU, acceding EU, candidate EU, as well as European Free Trade Association (EFTA), countries at three hierarchical levels. The lowest level (3) was used in this study as it provides high resolution, although it does not correspond to the same administrative level or average surface area in all countries. For example, NUTS 3 corresponds to "départements" in France, and to the usually much smaller "Kreise" in Germany. Plants of all genera combined were shipped to 800 of the 1,453 NUTS 3 regions, but *Acer* spp. was only shipped to 727 of those regions.

The recipients of *Acer* spp. in thirteen of the countries (Belgium, Bulgaria, the Czech Republic, Estonia, Spain, Finland, Italy, the Netherlands, Norway, Poland, Portugal, Slovenia, the United Kingdom) were classified into seven categories: nurseries, garden centres, landscapers (including garden designers and landscape gardeners), traders, private persons, web shops and other recipients, which included local councils. The identification of the categories has to be taken as an approximation, since some recipients may fall into more than one category. The shipments to these countries represent 85.1% of the *Acer* spp. recorded in the database. The recipients in the remaining countries could not be classified based on the available information.

The relationships between producers and the destinations of shipped *Acer* spp. were described as the average number of destinations to which a producer shipped plants (either a country or NUTS 3 region; generality: Tylianakis et al. 2007) and the realised fraction of possible linkages between all producers and destinations (connectance: Dunne et al. 2002).

The relative abundance of eighteen tree genera, that included the most common European tree species, and two miscellaneous groups with the remaining conifer and broadleaved species were taken from Brus et al. (2012), who modelled their distributions on a 1 km^2 resolution. Distribution data for trees of genera with potential host plants of CLB (as in European Commission 2008: *Alnus*, *Betula*, *Carpinus*, *Fagus*, *Populus* and the "Miscellaneous broadleaved" genera, which we assumed to include the remaining potential host genera) were assigned to the corresponding NUTS 3 regions. The relationship between the number of *Acer* plants delivered to each NUTS 3 region and the relative abundance of potential host genera in the same region was calculated using Spearman rank correlation. If more plants were delivered to regions with many potential host trees in the natural environment, this would be interpreted as an indication of the risk associated with the trade in plants for planting. Data on population size and area of each NUTS region were obtained from Eurostat and the relationships between those and the number of *Acer* plants delivered to each NUTS 3 region were calculated using Spearman rank correlation.

The distribution of the *Acer* plants shipped from Boskoop to destinations in Europe was plotted on a cylindrical map using the package "sp" (Pebesma et al. 2012) and the graphical representation of the relationships between producers and destinations of the plants, as well as the description of these relationships were done using the package "bipartite" (Dormann and Gruber 2012), both in R 2.13.0 (R Core Development Team 2011).

Results

Import of plants from third countries

During the period 1998–2012, the total number of *Acer* plants imported from non-EU countries into the Netherlands was greater than 21M, in 1244 consignments (Suppl. material 1). The annual number of imported *Acer* plants was more or less stable until 2005 (ca. 2M), but declined sharply to fewer than 100,000 in 2011 and 2012 (Fig. 1). The pattern for the size of consignments was similar. The type of plants varied between large quantities (tens or hundreds of thousands) of seedlings with a diameter of 1 to 2 cm, ready-for-sale "pseudo-bonsai", i.e. seedlings rooted in shallow trays for retail sales, and larger older trees of at least 5 cm diameter (Bram de Hoop pers. obs.). The majority of *Acer* plants are exported packed in crates as bare rooted stems with a diameter of approx. 1 to 2 cm. One crate can contain hundreds of individual stems. At the nursery that receives the *Acer* consignment the bare rooted stems are planted in individual pots and maintained in a greenhouse to allow root setting and growth to a plant strong enough for sale. This takes at least several months. A limited number of companies (14) imported *Acer* spp. from third countries in 2011 as opposed to 26 and 27 companies in 2007 and 2005 (Suppl. material 1).

In 1999–2002 the main source of *Acer* imports into the Netherlands was Hungary, which became a member of the EU in May 2004 and trade from Hungary is thereafter considered intra-EU. From 2002 onwards the number of *Acer* plants imported from countries where *A. chinensis* is present, such as South Korea and China, became dominant, with imports from China reaching 95% just before the EU banned imports from China. *Acer* imports from Asia declined sharply after 2007. An increasing percentage of imported *Acer* plants came from New Zealand (81,107 of the total 89,070 imported *Acer* plants in 2012), although the actual number of plants is very small in comparison to total imports in earlier years (>2M in 2004). In 2009 ca. 10% of the *Acer* plants imported from China went through the Boskoop area.

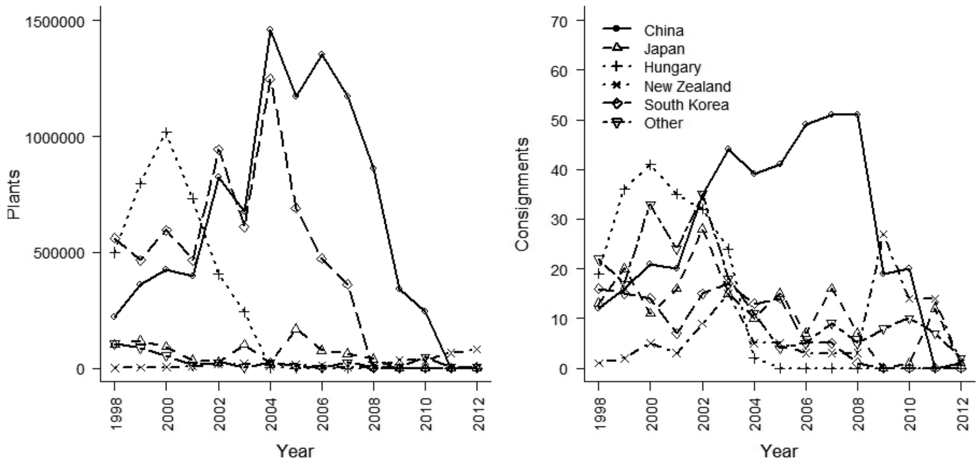

Figure 1. The number of imported *Acer* plants and the number of consignments into the Netherlands by origin. Imports of the remaining 11 countries accounted for a small minority of plants and consignments during this period and are not shown.

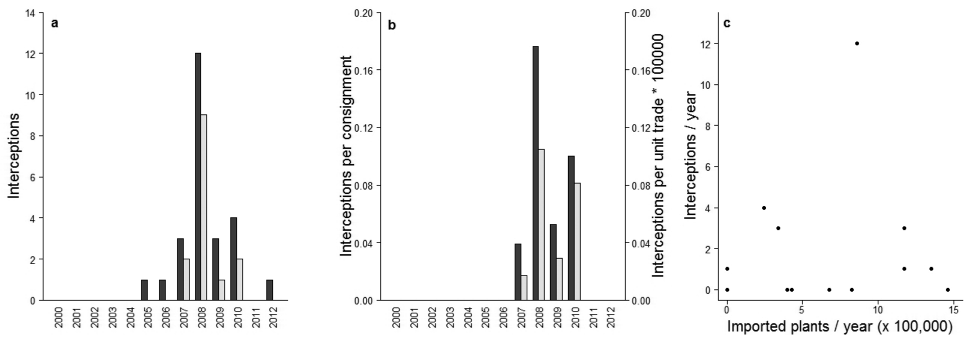

Figure 2. Interceptions of *Anoplophora chinensis* Forster in consignments from non-EU countries in ports of entry into the European Union between 2000 and 2012. a. The total number of *A. chinensis* interceptions of *A. chinensis* in all EU countries combined (black bars) and interceptions of *A. chinensis* from China into the Netherlands only (grey bars). Interceptions after the points of entry, i.e. within the EU, are not included. b. The number of interceptions of *A. chinensis* on Acer from China imported into the Netherlands, per consignments and per imported plant (black and grey bars, respectively). c. The relationship between the annual number of imported *Acer* spp. plants from China and interceptions of *A. chinensis* in the Netherlands (2000–2012).

Notifications, pest interceptions, outbreaks

From 2000 to 2012 CLB was intercepted by EU member states on 24 occasions, mainly on imported planting material from China (Fig. 2). The majority of the findings were in *Acer* plants imported from China and a few in bonsai plants from Japan. More than half of the interceptions of CLB were made by the Netherlands. The number of interceptions increased rapidly from 2005 to 2008, but then declined thereafter and no

CLB were intercepted in 2011. No relationship between the number of notifications and trade volume were found ($P > 0.2$). In the course of 2012 two interceptions of *A. chinensis* were recorded on *Acer* plants for planting by Member States of the European Community. One interception concerned a consignment of only two bonsai plants originating from China (Fig. 2). The other interception concerned one *Acer* plant which was intercepted during EU internal movement. The plant had been imported in 2007 from China, prior to enactment of EU emergency measures.

From 2006 to 2010, 190 consignments, containing a total of 3,971,805 *Acer* plants from China arrived in the Netherlands, i.e. ca. 20,900 plants per consignment. In 15 consignments (4.9%) CLB was detected at import inspection and all the plants (269,107) of these consignments were destroyed. One rejected consignment of 44,000 plants was thoroughly investigated by slicing the stems of 16,000 plants to find feeding tunnels and CLB larvae. This method found 9 CLB larvae and another 11 feeding tunnels without larvae, corresponding to an infestation level of 0.056–0.13%.

Intra-EU trade

In 2009, 2,738,974 *Acer* plants were shipped by 138 producers in 34,075 consignments (Suppl. material 2). Typically for Boskoop, only a few companies traded large quantities (7 producers traded more than 250,000 plants per year). The great majority of companies traded relatively small volumes, less than 15,000 plants. Forty-nine producers shipped fewer than 1,000 plants. Over half of the plants from four producers in the Boskoop area were recorded as originating in non-EU countries, and all plants of 104 producers were declared as originating in the Netherlands. The average size of intra-EU consignments is considerably smaller than for import from third countries (318 vs. ca. 18,000 plants) and a great number (19,804) of intra-EU consignments contained 100 or fewer plants.

Thirty-six of the Boskoop producers shipped *Acer* spp. of foreign origin, but only five producers shipped plants of Chinese origin. Of the 23,941 *Acer* plants of Chinese origin (0.87% of the plants traded within the EU), 34.5% remained in the Netherlands, 41.8% went to Germany, 7.1% to Austria and 4.2% to Poland. Small numbers (<1%) were exported to Belgium, Switzerland, the Czech Republic, France, Hungary, Italy and Luxembourg. 68.0% and 31.5% of these plants were shipped by two producers; the remaining 131 plants were shipped by three companies. Two-thirds of the *Acer* plants of Chinese origin were delivered to traders and about one third to nurseries. In 2009 340,696 *Acer* plants were imported from China by traders across the Netherlands; ca. 10% of the Chinese *Acer* plants went through the Boskoop area.

Plants were delivered to 27 countries (Fig. 3). These plants were made up partly from *Acer* arriving in 2009 but also Acer imported in previous years and grown on. Three quarters of the *Acer* plants were delivered to destinations within the Netherlands (2,062,404), 8.8% to Germany, 7.1% to the UK and 2.2% to France. It is unknown what proportion of the plants delivered to destinations within the Netherlands in 2009 was exported in subsequent years. The local trade constituted close to a third of the *Acer* plants: 866,028

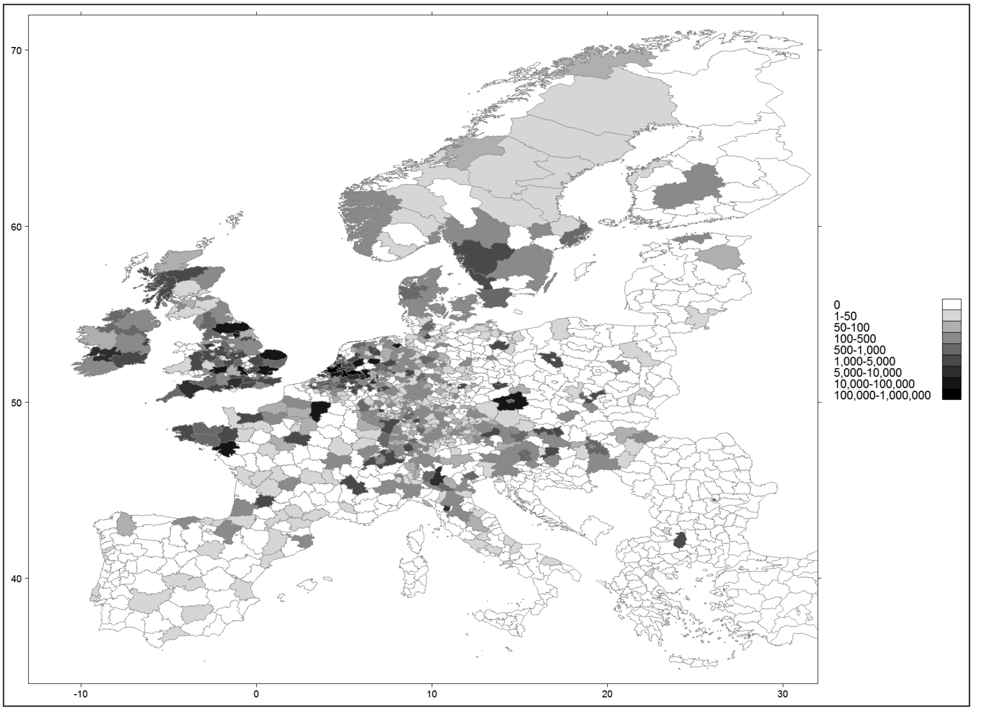

Figure 3. The number of *Acer* plants shipped by 138 producers in the Boskoop demarcated area to NUTS 3 regions throughout Europe in 2009. The darkness of the colouring increases with the number of shipped plants. No data were available for exports to Turkey, because these were not in the database. Map projection is cylindrical.

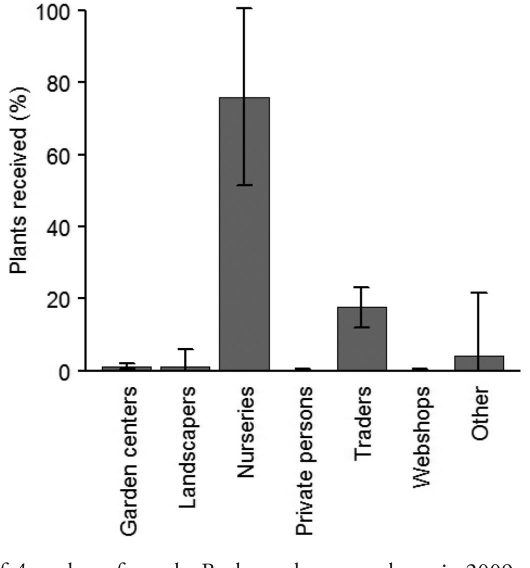

Figure 4. Recipients of *Acer* plants from the Boskoop demarcated area in 2009, as percentage of the total number of shipped plants (2,738,974). Bars indicate average percentages per country and error bars SE.

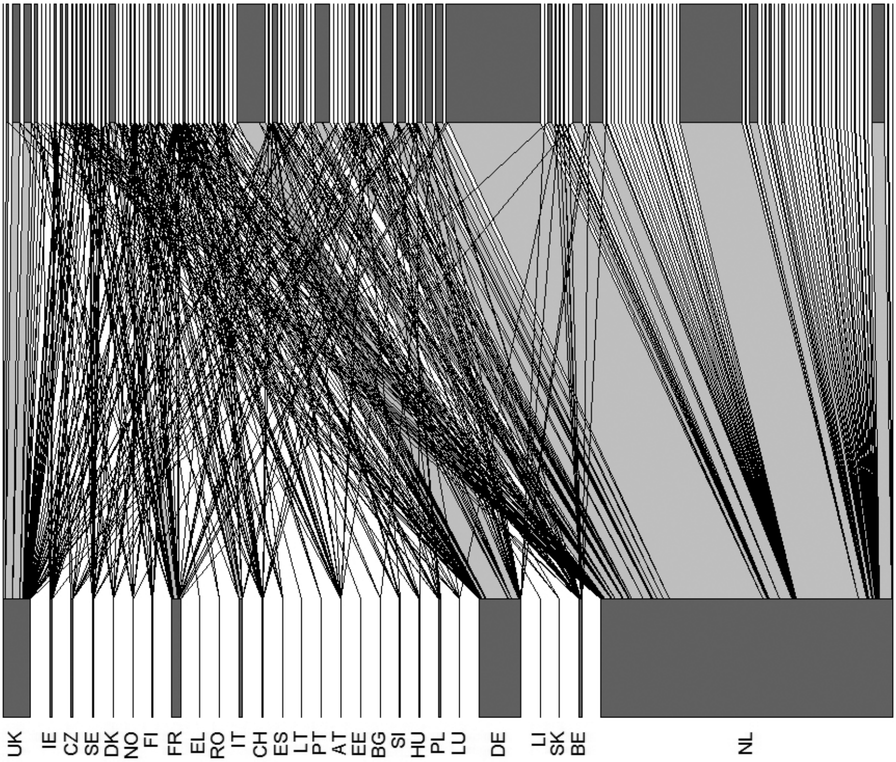

Figure 5. Trade flow of *Acer* plants from individual producers in the Boskoop demarcated area in 2009. Producers are represented by the grey bars on the top of the figure and destination countries by grey bars at the bottom, and the lines between the bars at the top and bottom of the figure indicate the trade in *Acer* plants. The width of the bars and lines indicates the number of plants. The realised fraction of possible linkages between producers and destination countries is 11.3% and 36.7% of the producers only shipped plants to destinations within the Netherlands.

plants were delivered to recipients in Boskoop and Hazerswoude-Dorp in 2,708 consignments; ca. 1,750 to nurseries and 350 to traders (749,402 and 115,291 plants, respectively). Deliveries in Boskoop and Hazerswoude-Dorp involved the majority of the *Acer* producers (101), but it was impossible to identify whether these plants were shipped to a different destination as part of another consignment and some double counting will have taken place. Of the identified destinations in the thirteen countries, an average 75.9% of the plants went to nurseries and 17.6% to traders (Fig. 4). The only exception to this pattern is Bulgaria, where, out of 1,566 plants, 93.5% were delivered to traders. Of the remaining 6.5%, 1.1% went to garden centres and 1.2% landscapers and 4.2% to recipients in the "other" category. Trade to private people and web shops generally involved small numbers of plants per recipient and a very small fraction of the total trade.

Twenty-one producers sold *Acer* spp. only to foreign countries, 66 delivered plants within the Netherlands and also exported and the remaining 51 producers only delivered to destinations in the Netherlands (Fig. 5). The 87 companies that exported *Acer* spp. each delivered to 1.4 countries on average (generality; Fig. 5). The plants of each exporting producer went to, on average, 5.0 NUTS 3 regions. This number was lower when only exports were taken into account (1.7). Hence, there were large differences between regions and producers (Suppl. material 2). The realised fraction of potential linkages between producers and destination countries (connectance), including the Netherlands, was 11.3% (2% when calculated using NUTS 3 regions). A significant, but very weak, negative correlation between the relative abundance of trees of potential host genera in each NUTS 3 region and the number of *Acer* spp. plants delivered in 2009 was found (Spearman rank correlation n = 687, $P = 0.008$, rho = -0.100). In addition, a negative correlation between the number of *Acer* plants delivered and the population size of each NUTS 3 region was found ($P < 0.001$, rho = -0.232).

Discussion

Dutch *Acer* imports from third countries

In order to better understand and manage invasions by tree pests through the trade in plants for planting, analysis of trade networks is urgently needed, but detailed data on this trade are rarely available (Jeger et al. 2007). The data presented here provide a detailed description of the import of *Acer* spp. into the Netherlands and of the intra-European trade in plants for planting. Although import quantities of *Acer* spp. into all of the Netherlands were large at some stage (2 million *Acer* plants imported in 2008–2010), this was small in comparison to trade of all tree nursery products to other parts of the European Union from the Boskoop area alone. Only a few international traders in Boskoop imported tree nursery material from third countries, and in particular China. However, Dutch traders imported relatively large consignments: for *Acer* spp. the average consignment contained 2,000–100,000, up to 384,980 plants. Larger Japanese maple trees were imported in smaller quantities (usually up to 1,000 pieces). However, some of the importers tried to go for optimising profits by selling large quantities to retailers in the Netherlands or other European countries. The description of the imports of *Acer* spp. from third countries reveals the large variability in the origins and quantities imported each year, which was initially driven by the demand for cheap plants. As the interceptions of CLB increased, imports from high-risk origins were reduced by stricter rules on the import of *Acer* plants.

Phytosanitary import inspections are aimed at confirming compliance with prescribed phytosanitary measures in the exporting country, not at quantifying pest abundance. Hence, notifications cannot usually be interpreted as a quantitative measure of pest infestation rate, but in this case it has been possible to directly relate import volume to inspection frequency and infestation rates in Europe, based on data collected through the destructive sampling of thousands of plants in these consignments as stipulated in the EU emergency measures, which is a more reliable detection method than the standard visual inspections. One in twenty imported consignments of *Acer* from China was infested, which confirms the risk associated with the import of *Acer* spp. from countries where CLB occurs naturally and justifies the emergency measures for this particular pathway. The measures were particularly relevant, due to the low fraction of infested plants in each consignment, as revealed by the destructive sampling. It is unlikely that pests can be found during routine inspections if the levels of infestation are this low. However, the economic cost of the destructive sampling of plants in each of the shipments was considerable. Large bundles of small plants (20–50 pieces of up to 2cm diameter) could be cut with large machines and so the staff cost was limited. However, the economic cost due to loss of plant material was high, approximately Euro 10–50 per plant, depending on plant size. Incursions or early stages of infestation of CLB in Croatia, France, Italy and the Netherlands clearly demonstrate that in some cases it is possible that emerging adults find a mating partner, which could lead to establishment (van der Gaag et al. 2010). This suggests that the high cost of the destructive sampling for detailed inspections is justified. It may, however, be more cost-effective to focus even more on pre-export measures aimed at reducing pest prevalence in consignments.

Intra-EU trade

The vast majority (99%) of the *Acer* plants that were shipped from the Boskoop area in 2009 was declared as originating from the Netherlands, which is risk-free with respect to the potential spread of CLB because the species is not established there. The greatest risk of CLB spread is associated with *Acer* plants originally from China, i.e. less than 1% of the *Acer* plants, but we chose to include all trade in *Acer* plants from the outbreak area, because this provides a better view of the trade in live plants. The plants of Chinese origin were also distributed to destinations throughout Europe (to 14.5% of the NUTS 3 regions). We suspect that some year-to-year variation occurs in the intra-EU trade. However, we were unable to assess and quantify this, because the description of the intra-European trade included only transactions in 2009, restricting our ability to generalise our results, but it is the only year for which we are confident that the data are complete.

A study of the nursery trade for landscapers and retailers in the US indicated that the dominant characteristic of buyer preference was plant quality (Foltz et al. 1993). Other factors which significantly influenced buyer behaviour were offering a diversity of plant species, plant size, origin of the plant, plant price, and the option to pay for purchases with cash. The same study concluded that nursery retailers can best focus on maintaining an existing customer base and hence focus on ensuring a high plant quality. This appears to be reflected in our study by the large number of small trade contacts between companies within Boskoop itself. Such contacts are needed for companies to assemble specific tree packages and satisfy their trade contacts across Europe. Indeed, most Boskoop companies had few relationships with destinations in other parts of Europe. In other words, recipients in other EU countries will normally not obtain plants from several providers in the Boskoop area, at least not during the period when trade data was assembled. Although *Acer* plants were sent to half of the NUTS 3 regions in one year, the low number of destinations per producer (generality) and the low fraction of potential linkages (connectance) that are realised (Fig. 5) limit the chance that pests and diseases are spread widely by any single producer. This is information that should be taken into account when assessing the risks associated with the trade in live plants, but also when considering risk mitigation options.

The majority of *Acer* plants were sent to destinations in the Netherlands, Germany and the UK and comparatively few plants were sent to southern EU member states, which appears to indicate that there is little demand for *Acer* plants in these countries, or that there are no trade connections. For example, although Italy is a large importer of plants for planting (US$ 289M in 2009; data from FAOSTAT), the value of plants for planting imported from the Netherlands in 2009 was only a third of the value of imports from France (US$ 29M imported from the Netherlands). The distribution of the plants to regions within EU countries was uneven, with some regions receiving very large numbers of *Acer* plants from Boskoop and others only few plants. Some studies have used the economic productivity, the length of the road network or the number of airline passengers to explain the number of alien plant pests in a region (e.g. Roques 2010, Paini et al. 2010). In our study, however, there was no obvious link between the number of plants shipped (a proxy for pest approach rate) and the economic output or human population size of a NUTS3 region. Rather, some regions received many plants because of the presence of retailer distribution centres while in other regions, especially in the Netherlands, UK and Italy, there were relatively large or many nurseries. Hence, the distribution pattern of *Acer* plants described here does not necessarily reflect the final planting location of the plants.

Regions with many or large nurseries or retail distribution centres may act as highly connected nodes in the European plants-for-planting trade network, with only few trading steps between the point of import into Europe and the consumer (Shaw and Pautasso 2014) and this small-world network is likely highly effective at distributing pests rapidly throughout the continent. The map in Figure 3 may help to identify the location of such highly connected nodes, but the plants may not stay in those centres for very long and the environment may not be favourable for pest establishment. The onward distribution of the plants from nurseries or distribution centres to retailers and end consumers is likely to lead to a rapid reduction in the number of host plants in a single location, but the data presented here do not allow a description of the further distribution. The dilution of possible infested lots of plants may lower the chance that more than one beetle emerges at the same time and that mating can take place, but it is unlikely that this can avoid establishment of beetles, as indicated by the outbreaks of CLB in Italy. The risk may be higher when members of the public order plants directly from suppliers in East-Asia, for example through the internet. Internet sales were uncommon in comparison with sales through European garden centres or nurseries, although these are increasing (Giltrap et al. 2009, Lenda et al. 2014). The reported findings of individual beetles in private gardens rarely lead to the establishment of natural populations, but it is not impossible. Examples such as the findings of individual beetles emerging from infested plants originating from imported consignments reported by EU member states (in Germany twice each in 2008 and 2009) highlight the risks associated with this pathway.

It can be argued that consignments that are split up as the plants are distributed throughout Europe are difficult to regulate or control in terms of quality and plant health. High risk locations are nurseries that grow vast amounts of host plants imported from areas where CLB is present, of which there were not many in Boskoop. The imported plants may stay for several months to several years at a nursery for root setting before they are ready for sale. In particular in these high-risk nurseries, more than one beetle may emerge from infested plants, mating may occur and mated females can oviposit on other host plants in or outside the nursery. There are several reports where this has taken place. In France, several beetles were found in a nursery and in Guernsey 10 adults were caught in one greenhouse. At two locations in the Netherlands, infested outdoor trees were found in the neighbourhood of nurseries growing vast amounts of *Acer* plants imported from China for several consecutive years. Also, the outbreaks in Italy are related to nurseries importing and growing *Acer* plants from China or Japan. Hence, recipients of large numbers of plants have an increased risk of receiving infested plants and mating of emerging beetles occurring, which may lead to establishment or further spread of CLB. However, the long development time of *Anoplophora* (2 to3 years) can desynchronise emergence of beetles at Northern European nurseries, which reduces the risk of establishment and may result in lower growth rates of establishing populations.

Once large consignments are imported, they are either directly marketed via wholesale companies or become increasingly fragmented and it is difficult to trace plants to their true origin. The lack of traceability makes the management of an outbreak more difficult as it takes more time and effort to discover the origin of the plants and the destination of other plants from the same consignment or producer. The experience with data collection following the outbreaks in the Boskoop area revealed that a large number of producers only kept paper records of plant movements, which had to be entered into an electronic database when other Member States demanded that the Netherlands provide these in the aftermath of the Boskoop incident. The absence of readily available transaction records may cause delays in the tracing and management of outbreaks outside tree producing areas. Hence, it is essential that electronic records of transactions are kept, possibly in centralised databases, in order to access such data when required by NPPOs for the purpose of *a priori* risk assessment or tracing of potentially infested plants in the case of an outbreak. Electronic record keeping would also be beneficial for the industry, as rapid eradication and limitation of further spread of pests may mitigate the potential economic and reputational damage of such an event.

Raising awareness and quality levels to reduce the risk of CLB establishment may best be attained by focussing on checks for larger consignments, that is, before they become fragmented (Pautasso et al. 2010). In addition, plant propagation certification systems, as already established for most fruit trees in Europe and elsewhere, may be beneficial for promoting plant health and quality levels of tree nursery products. The significant but weak negative relationships between the number of delivered plants and the abundance of potential host plants in the natural environment and the population size in the NUTS 3 regions do not provide information that could be used for the assessment of the risk to the natural environment related to the EU-wide shipment of *Acer* spp. *Acer* plants from the Boskoop area are mainly grown as garden plants and it is likely that many of the plants delivered to nurseries for further growth, before sale to consumers or garden centres, would eventually be planted in urban areas. This appears to be in conjunction with the location of the European outbreaks so far, that occurred close to nurseries that traded in *Acer* spp., in particular from China, and not in forests (Roques 2010). It may also be argued that urban trees might be more stressed and more vulnerable to CLB attacks, or that pests are more likely to be detected as a result of the larger number of observers. The higher incidence of CLB in urban areas, or close to nurseries, has positive implications for the chances of eradicating CLB in outbreak areas: the fact that many consignments went to nurseries, most likely for further growth prior to resale, may enable the detection of previously unnoticed CLB infestations, but also poses a greater invasion risk as a result of the increased likelihood that emerging beetles find a mate for reproduction. However, the short dispersal distance of CLB (van der Gaag et al. 2010) may limit spread from the outbreak area, which also facilitates eradication.

Conclusion

It is clear from our data on trade in *Acer* plants from the Boskoop area that live plants are distributed throughout Europe and this illustrates how infested plants could spread CLB far and wide. This is also relevant for the potential spread of other pests and pathogens through the live plant pathway. Despite the detail in the trade dataset presented here, it is impossible to relate the data on intra-EU trade to outbreaks of invasive pests or diseases. This study showed that detailed data on the trade in tree nursery products are valuable for the assessment of risks associated with the movement of large numbers of plants into, and then further through the EU, because the point of entry or production of these products often is not the final destination. Such data may improve the design of spread models and mitigation methods. Moreover, in particular for the benefit of plant health and quality, more systematic electronic record keeping by growers and traders would be supportive for improving trace-back and trace-forward.

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Supplementary material 1

Table S1

Authors: René Eschen, Jean-Claude Grégoire, Geerten M. Hengeveld, Bram M. de Hoop, Ludovic Rigaux, Roel P. J. Potting

Data type: measurement

Explanation note: Summary of dynamics of the import of *Acer* plants into the Netherlands in 1998–2012. The number of importing companies relates to the confirmed importers of *Acer* spp. HU indicates Hungary, AS indicates East-Asia and NZ indicates New Zealand.

Supplementary material 2

Table S2

Authors: René Eschen, Jean-Claude Grégoire, Geerten M. Hengeveld, Bram M. de Hoop, Ludovic Rigaux, Roel P. J. Potting

Data type: measurement

Explanation note: Summary of the intra-European trade in *Acer* plants from 138 producers in the Boskoop demarcated area in 2009, broken down by country.