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ORIGINAL PAPER

Phytosanitary inspection of woody plants for planting at European Union entry points: a practical enquiry

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Abstract Phytosanitary import inspections are important to avoid entry of harmful pests on live plants. In the European Union (EU), all consignments of live plants must be inspected at the first point of entry, and plants allowed entry can be moved without further inspection among the 28 Member States and Switzerland. It is important that inspections in EU countries adhere to the same standard to avoid introduction of harmful organisms through countries with weaker methods. We tested whether sampling intensity and confidence in the inspection results were the same across these countries. Questionnaires were sent to inspectors in all countries, asking about inspections of individual consignments of woody plants for planting. Data about 102 lots, inspected at 13 points of entry in six countries, were analyzed. We used hypergeometric and binomial statistics for small and large consignments, respectively, to calculate the probability that <1 % of the plants were infested. The duration of the inspection increased with lot size, but the probability that the infestation level was below 1 % of the plants was lower for small than for large lots. Moreover, large international differences in inspection intensity and the probability that the inspections could detect a level of infestation below 1 % were found: the probability was consistently above 0.95 in one country, while the average probability was below 0.6 in the other countries. We suggest that the EU Member States adopt common maximum acceptable infestation levels and harmonized, statistics-based sampling protocols for plants for planting.

Keywords European Union · International standards for phytosanitary measures (ISPM) · International trade · Invasive alien species · Phytosanitary inspections · Quarantine species

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Introduction

Biological invasions by invasive alien species (IAS) cause significant damage to forests. Biological diversity and ecosystem services have been affected (Vitousek et al. 1997; Mack et al. 2000; Pimentel 2002; Kenis et al. 2009), as well as the economy of the invaded areas as a result of decreases in the market value of timber, declines in forest productivity, recreational or esthetic value or increased pest management costs (Perrings et al. 2000; Holmes et al. 2009; Williams et al. 2010). According to Smith et al. (2007), the live plant trade accounts for 90 % of the human-mediated introductions of non-native invertebrate species in the United Kingdom, while Santini et al. (2013) estimated that 57 % of the alien pathogens of trees have been introduced into Europe on live plants. Similarly, Liebhold et al. (2012) reported that 70 % of the damaging insects and pathogens established in the United States between 1860 and 2006 had most likely entered with imported live plants. The increasingly large trade volumes and passenger numbers have led to a mounting propagule pressure on previously isolated ecosystems (Levine and d'Antonio 2003). The trade volume and the numbers of air passengers correlated with the number of pests and diseases established in a country or region (Roques 2010; Paini et al. 2010). Safe trade, international and national treaties and phytosanitary regulations aimed at reducing introduction of harmful organisms through international trade in live plants are, therefore, of great importance.

In Europe, plants for planting, i.e. plants intended to remain planted, to be planted or replanted (FAO 2012), represent the second most important pathway where regulated organisms are intercepted during phytosanitary import inspections (Roques and Auger-Rozenberg 2006). For example, Kenis et al. (2007) found that 52.7 % of the interceptions of insect pests in Switzerland and Austria were related to the ornamental trade, with 14.9 % linked to plants for planting and 4.2 % to bonsai, which is similar to the fraction of alien pathogens of trees that have been introduced into Europe on live plants (Santini et al. 2013). The import of live plants into the European Union (EU) is regulated in the EU Plant Health Directive (Commission Directive 2000/29/EC; European Commission 2002). Consignments of live plants imported into the EU must be free of the harmful organisms listed in Annexes I.A and II.A of the Directive, must not contain the prohibited plant species listed in Annex II.A and III, and must in certain cases (Annex IV) have been submitted to a specific treatment. All consignments of live plants must be inspected at the first point of entry where the consignment enters the EU. The plants can then be moved within the 28 EU Member States without further inspection at country borders if the consignment has been found to be compliant with the import regulations, i.e. the consignment was practically free of regulated pests and, where especially specified (FAO 2011), additional requirements were met. Some plant species can only be moved within the EU if accompanied by a plant passport, the EU-internal equivalent of a phytosanitary certificate, and the inspector at the point of entry will issue such document if needed. The phytosanitary regulations of Switzerland are nearly identical to those of the EU and within the present discussion Switzerland can, from a phytosanitary perspective, be considered part of the EU.

Phytosanitary inspections at the point of entry are intended as checks to verify that producers in exporting countries comply with the phytosanitary measures required by the importing country (FAO 2011). These inspections are not usually considered as a phytosanitary measure in itself to reduce infestation of consignments or to prevent the entry of pests and diseases (Sequeira and Griffin 2014). The import inspections are a central tool in biosecurity, but in most cases only a fraction of the plants in a consignment can be inspected and not all pests can be detected. One aim of the inspections is, thus, to verify that pest infestation levels are below a level deemed acceptable by the importing country.

The International Standard for Phytosanitary Measures (ISPM) No. 31 (FAO 2009) provides guidance on the determination of the number of plants to be sampled in individual consignments to verify compliance with the phytosanitary requirements set by an importing country. Fixed-proportion sampling results in inconsistent detection levels between large and small consignments, and thus differences in confidence in the result of inspections. Hence, it is preferable to adapt the proportion of plants sampled in a consignment to the number of plants in this consignment (FAO 2009). Sampling without replacement, as done during phytosanitary inspections, has a larger impact on the theoretical chance of finding harmful organisms on the remaining number of plants in small rather than large consignments. ISPM 31 therefore recommends using a sampling protocol based on a hypergeometric distribution for relatively small lots, for example when a sample of more than 5 % of the lot size is taken, and a binomial-based sampling protocol for larger lots. The annexes to ISPM 31 contain tables to facilitate selection of the appropriate sample size for a given consignment, for different levels of confidence and maximum infestation levels that a country may consider acceptable.

Many countries that keep records of pest interceptions do not register the total number of inspections, which makes a precise assessment of the proportion of infested shipments impossible. The Animal and Plant Health Inspection Service of the United States Department of Agriculture uses the Agricultural Quarantine Inspection Monitoring protocol (AQIM; USDA 1998), in part to estimate the difference between the actual infestation rate and the estimated number of infested consignments as captured in standard inspection practice. Standard inspection practice in the USA is based on the rule-of-thumb that 2 % of the items in a shipment should be inspected. By contrast, AQIM uses a hypergeometric-based sampling process for some agricultural commodities, including live plants, to verify with 95 % confidence that <10 % of the items in a shipment is infested. Because of the volume of live plant imports, this protocol can only be implemented on a fraction of the shipments and thus does not replace the standard inspections. Venette et al. (2002) discussed the theoretical basis for sampling during standard and AQIM inspections, in order to optimize the chances to detect harmful organisms in the inspection units (e.g. a container) given a certain level of infestation with a fixed confidence level. The comparison of the AQIM procedure and the 2 % sampling method illustrated that the latter method fails to detect pests in small consignments and overestimates sample size for larger shipments.

The EU Plant Health Directive stipulates that Member States must inspect consignments of live plants and their packaging "meticulously" (European Commission 2002), but the Directive does not specify what is meant by "meticulously". Specific sampling instructions are only stipulated for dwarfed plants, such as bonsai (a random sample of at least 300 plants from a given genus where the number of plants of that genus is not more than 3,000 plants, or 10 % of the plants if there are more than 3,000 plants from that genus) and *Dendranthema* spp. (a minimal sample of 10 % of the consignment; Annex IV.A.I to European Commission 2002). In addition, the Commission Decision "on emergency measures to prevent the introduction and spread of *Anoplophora chinensis* (Forster)" states that the recommended size of the sample shall be as such to enable at least the detection of 1 % level of infestation with a level of confidence of 99 % (European Commission 2010). Using binomial statistics, it can be calculated that the latter requires the sampling of all plants in consignments of up to 459 plants and the sampling of 459 plants in larger consignments.

Discrepancies in the sampling methods for all other live plants between member states may affect the EU's whole biosecurity status (Brasier 2005). An importing country with no reliable sampling strategy may be a weak link and a point of entry for quarantine pests. Countries with stricter border controls may see their biosecurity weakened by imports of infested goods that entered the EU through another country with less stringent procedures. This is especially important given the unequal distribution of imports across EU countries and the wide range of climates and host availability. To ensure that all Member States inspect consignments in an adequate way, the Food and Veterinary Office (FVO), which assists the European Commission in the application of phytosanitary regulations, audits the plant inspection systems in each Member State. Their recent reports revealed differences and shortcomings in the inspection practices in audited countries (FVO 2011a, b, 2012a, b), such as a lack of guidelines for visual inspections, different levels of inspection of the same commodities depending on the points of entry, non-random sampling (e.g. just the easily-accessible boxes or only the suspicious cases are inspected) and biased sampling, indicating that the inspected commodities were those where previously many harmful organisms were intercepted. However, although the FVO reports provide qualitative information on how the audited inspections were carried out, they do not provide quantitative information that allows comparison of inspection intensity or the level of confidence in the results of inspections.

Here, we report the results of questionnaires that were sent to phytosanitary inspectors at points of entry in EU Member States and Switzerland, which addressed the procedures followed during the inspection of lots of woody plants for planting imported from non-EU countries. We tested the hypothesis that the confidence in the sampling was equal among the EU Member States. We compared the number of inspected plants in the consignments with the number that should have been inspected in order to detect a minimal threshold of infestation with a certain probability given the size of the consignment, as established from either the binomial or the hypergeometric distribution. To our knowledge, this study is the first that describes inspection practices regarding plants for planting in the EU. The imported lots studied here represent only a tiny fraction of the total number of lots imported each year in the European territory. However, even if not fully representative of all member states, our study includes major importers from Northern, Southern, Eastern and Western Europe.

Methods

Questionnaires

We collected information regarding inspections of consignments of woody plants for planting using questionnaires sent to the National Plant Protection Organisation (NPPO) of each EU member state plus Switzerland from January 2012 to June 2013. The NPPOs transmitted the questionnaires to their inspectors at the different entry points. The questionnaires were completed anonymously by the inspectors during, or immediately after the inspections had taken place. We collected the following information: country, point of entry, type of point of entry (land crossing, airport or harbor), point of inspection (if different from point of entry), date and approximate duration of the inspection, number of inspectors for the inspection, country and point of origin, type of point of origin (land crossing, airport or harbor), country of final destination (if different from the country of entry in Europe). For each lot in the consignments, the questionnaire asked inspectors to list the plant species, the approximate size of the plants, the type of product (bonsais, potted plants, bare-rooted plants, cuttings, seeds, other), the quantity of plants or seeds in the lot, the occurrence of an identity check of the plants, the type of inspection (visual, sample taken for analysis, other), the sampling unit (entire plant, seed, branch, leaf, other) and the sample size (e.g. the number of inspected units in the lot), as well as the presence or absence of pest(s) and/or symptom(s), the pest species and higher taxon (arthropod, mite, nematode, bacteria, fungus, virus, other), the number of sampling units found with pest(s) or symptom(s) and the decision (lot or consignment released, retained, treated or destroyed). For the analyses, we only considered inspections taking place at the entry points in the EU and not those performed in approved inspection place at the final destination. The results of the countries that returned questionnaires are kept anonymous due to the sensitive nature of the information. The inspection effort (per plant) was calculated as the number of inspectors multiplied by the time spent for an inspection, divided by the number of sampled plants.

Calculation of the maximum level of infestation

Six out of the 28 countries originally contacted (Belgium, Poland, Spain, Sweden, Switzerland, and the United Kingdom) returned questionnaires with information regarding 102 inspected lots. Two other countries that returned questionnaires were excluded, because inspectors in one country provided information about one inspected lot only and the information provided by inspectors in another country did not include the number of sampled plants. The information about these lots was sufficient to assess the inspection effort and to calculate the maximum pest infestation level and the sample size required to ascertain whether the infestation level was below a given threshold. Because of insufficient information about individual consignments and in order to keep the sampling rules as simple as possible, we assumed that infested plants were randomly distributed throughout the consignments. Non-random distribution of pests would require larger sample sizes to achieve the same level of statistical certainty about the potential maximum infestation levels.

We calculated the number of plants that should be sampled to ascertain a given maximum infestation level and statistical certainty for large lot sizes, where <5 % of the plants in the lot was sampled, using binomial statistics (Venette et al. 2002; FAO 2011).

For small lots, where more than 5 % of the plants were inspected, we used hypergeometric statistics to determine the probability that the level of infestation was below the maximum acceptable level (FAO 2009).

Statistical analyses

The statistical analysis was done using R (R Development Core Team 2013) and the hypergeometric calculations were performed using the function *dhyper*. The significance of the difference in confidence in the sampling of small and large lots was tested with a Wilcoxon signed-rank test. The duration of the inspection, the number of sampled plants and the probability that the infestation rate was below 1 % were used as response variables, and the data analyzed with linear mixed effects models using the function lme(). Inspecting countries, product types (bonsai, bare-rooted or potted plants) and the types of entry point (land crossing, airport or harbor) were included as fixed factors, without their interactions, and points of entry as random factors in the analyses. The effect of inspecting countries and types of entry point was tested against points of entry and the product type was tested against residuals. The number of plants per lot, the percentage of plants sampled and inspection effort were $\log_{10}$-transformed. No suitable transformations of the probability data and inspection time were found and the ranks of these data were analyzed instead. Tukey HSD was used for post hoc comparison of levels of significant factors. The average inspection time spent per plant per inspector (inspection effort, $\log_{10}$-transformed), only available for a single point of entry per country, was analyzed using a general linear model. We visually checked that the model assumptions were met using histograms and residual and QQ plots, according to Zuur et al. (2009: pp. 542–543). The relationship between the duration of the inspections and lot size was assessed using linear regression. The relationship between inspection effort and confidence in the sampling result was analyzed using Pearson's product-moment correlation.

Results

The inspected lots contained a total of 680,840 plants, belonging to 46 genera from 13 exporting countries. There were large differences in the size of the lots. Five lots contained more than 50,000 plants each, 75 lots contained between 1 and 1,000 plants and 41 lots consisted of 250 or fewer plants. The lots inspected in country C were significantly larger than the lots in country D ($F_{5,7} = 4.81$, $P = 0.032$; Table 1). No other significant differences in lot size between countries were found. Lots inspected at the only land crossing in the comparison did not contain significantly more plants than lots inspected at harbours but not airports ($F_{2,7} = 4.65$, $P = 0.052$). Shipments with bare-rooted plants contained significantly more plants than shipments of potted plants ($F_{2,99} = 4.60$, $P = 0.012$), but the number of plants in shipments of bonsai was not different from either. The size of the plants in 75 lots was indicated in the questionnaire responses. The plants in 67 of these lots were up to 1 m tall and the plants in one lot were up to 4 m tall. One nematode, one arthropod, a pathogen and a virus each were found in lots of potted or bare-rooted plants from China, Australia, the USA and Ukraine, respectively.

Inspection intensity

Inspectors in all countries except country G provided information about the duration of the inspections of a total of 91 lots. Thirty-six of the inspections lasted up to an hour and 35 inspections lasted between 5 and 10 h. Although the differences in inspection time were only marginally significant in the overall analysis of the ranked data ($F_{4,1} = 140.39$, $P = 0.063$), the average inspection time in country C was longer than that in country F (Table 1). Inspections lasted more than five times longer in seaports than in airports, but the difference was not significant ($F_{1,1} = 30.05$, $P = 0.115$). The inspection time was longer for bare rooted plants than for bonsai and potted plants ($F_{2,82} = 22.81$, $P < 0.001$). Up to five inspectors were involved in each inspection, but 90 % of the lots were inspected by one, two or three inspectors. A positive relationship was found between the duration of the inspections and lot size ($F_{1,85} = 15.04$, $P < 0.001$, $R^2 = 0.15$).

The number of plants sampled per consignment was significantly larger in country G than in all other countries, the number in country C was intermediate and the number sampled in countries A, D, E and F was lower than either in G or C ($F_{5,6} = 52.86$, $P < 0.001$; Table 1). The number of sampled plants was highest at land crossings and lowest at airports, which was in part due to differences in the size of the lots arriving: the largest lots were inspected at land crossings, and the smallest in airports ($F_{2,6} = 20.93$, $P = 0.002$). The number of sampled potted plants was

Table 1 Summary of the number and size of inspected lots (n and plants per lot) and inspection intensity [sample size (plants) and Inspection duration (min)], by inspecting country, point of entry type and plant type

Country	Points of entry	n	Plants per lot	Sample size (plants)	Inspection duration (min)
A	2	8	$1193 \pm 861^{a, b}$	8.6 ± 3.0^{b}	$121.3 \pm 28.7^{a, b}$
C	3	56	11110 ± 4165^{a}	131.4 ± 38.7^{a}	394.4 ± 17.1^{a}
D	1	7	89 ± 50^{b}	14.0 ± 4.2^{b}	$46.4 \pm 4.8^{a, b}$
E	1	17	$2072 \pm 1315^{a, b}$	12.2 ± 1.8^{b}	$56.5 \pm 2.4^{a, b}$
F	1	9	$519 \pm 401^{a, b}$	6.2 ± 1.0^{b}	32.2 ± 3.6^{b}
G	6	23	$735 \pm 146^{a, b}$	249.4 ± 18.2^{c}	NA
Point of entry					
Airport	5	25	$948 \pm 467^{a, b}$	51.7 ± 21.9^{a}	51.4 ± 16.4
Land crossing	1	6	75800 ± 24354^{a}	568.3 ± 188.6^{b}	NA
Sea port	8	97	2217 ± 964^{b}	93.5 ± 13.6^{a}	277.8 ± 21.0
Plant type					
Bare rooted		81	7950 ± 3422^{a}	126.1 ± 31.3^{a}	250.4 ± 28.5^{a}
Bonsai		27	$1226 \pm 306^{a, b}$	35.8 ± 5.5^{a}	224.1 ± 23.8^{b}
Potted		20	1969 ± 837^{b}	188.2 ± 31.2^{b}	83.8 ± 44.0^{b}

The values shown are mean ± SE. Different letters in any given column indicate significant differences (Tukey HSD: $P < 0.05$)

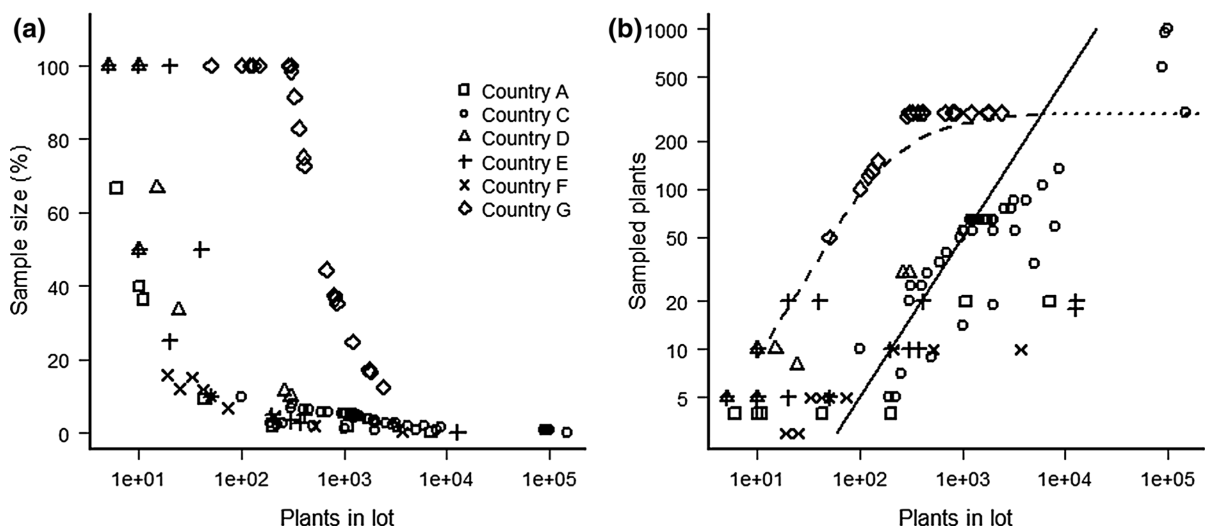

Fig. 1 Relationship between the number of plants in the lot and the fraction of plants inspected for six countries (**a**) and between the number of plants in the lot and the number of sampled plants for six importing European countries (**b**). In the right figure, the *dotted line* represents the minimal sample size when using the binomial distribution, necessary to detect 1 % of infested plants with a 95 % probability ($f = 0.01$; $P = 0.95$). The *dashed line* represents the minimal sample size when using the hypergeometric function with the same parameters. The solid line represents the sample size corresponding to 5 % of the shipment size. For data above this line, we applied the hypergeometric distribution and below this line the binomial distribution

larger than for the two other plant types ($F_{2,86} = 3.58$, $P = 032$). As expected, the inspected percentage of plants in each lot declined with lot size, but the sampling intensity differed between countries (Fig. 1). In country G all plants were inspected up to a lot size of 300 plants and 300 plants were inspected from each larger lot. All other countries inspected fewer plants in lots containing up to ca. 5000 plants.

Inspection effort, i.e. the average time spent by an inspector inspecting a plant in the lot, differed significantly between countries ($F_{4,61} = 10.82$, $P < 0.001$; Fig. 2). The inspection effort was significantly greater in country C than in countries D and F. The information provided by inspectors in country G was insufficient to calculate inspection effort.

Confidence in inspection result

The probability that the infestation rate was below 1 % of the plants in the lot increased with the number of sampled plants, but only up to ca. 300 plants when the probability approaches 1 (Fig. 3). For 33 of the 102 inspected lots for which it was possible to calculate it, the probability was greater than $P = 0.95$. The probability for 60 lots (58.8 %) was equal to or lower than $P = 0.5$. There was a large difference in confidence between small and large lots, i.e. those for which more or fewer than 5 % of the plants in the lot was inspected and for which we calculated confidence using statistics based on binomial and hypergeometric distributions ($P = 0.39 \pm 0.05$ and $P = 0.60 \pm 0.05$, respectively; $P < 0.005$).

There was a significant difference between countries with respect to the probability that the infestation rate was lower than 1 % of the plants ($F_{5,6} = 20.74$, $P = 0.001$; Fig. 4). It was significantly higher in country G (always $P = 1$; Fig. 1) than in the other countries, except country D. The average probability in all countries but country G was below 0.6 and in country F the probability was only around 0.1. Surprisingly, a negative correlation was found between the inspection effort and the confidence in the inspection result (t = −3.27, $P = 0.002$; R = −0.37).

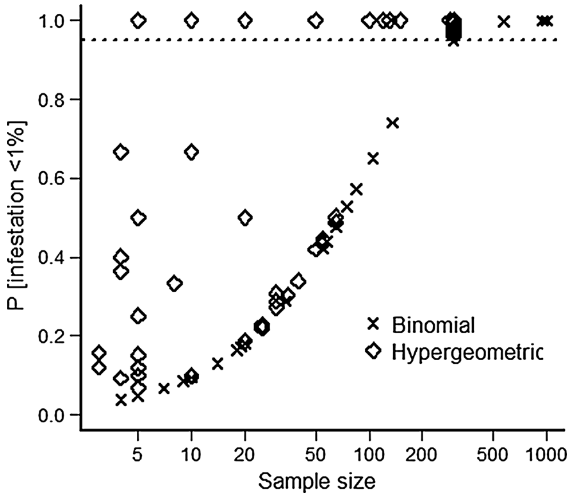

Fig. 3 Relationship between the number of inspected plants and the probability that the level of infestation was below 1 % of the plants in the consignment. The *dotted line* indicates $P = 0.95$

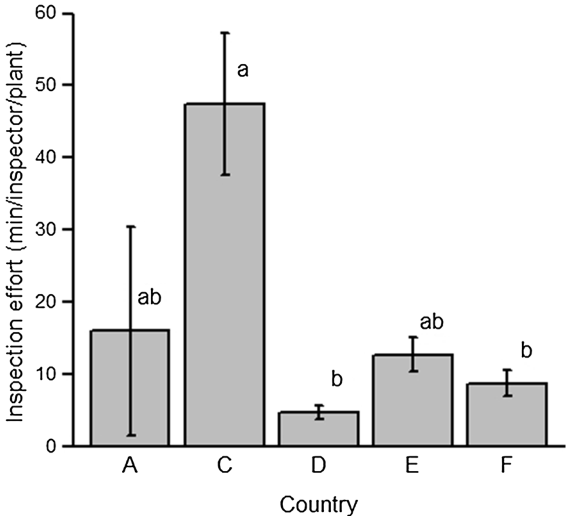

Fig. 2 Inspection effort (average time spent per inspector on each plant) by country. Shown are mean ± SE. *Different letters* above the *bars* indicate significant differences (Tukey HSD: $P < 0.05$)

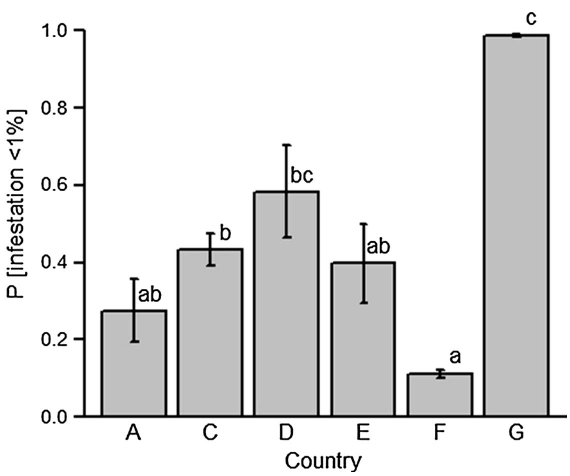

Fig. 4 The probability that the infestation level of inspected consignments was below 1 % of the plants, by country (mean ± SE). *Different letters* above the *bars* indicate significant differences (Tukey HSD: $P < 0.05$)

Discussion

Many goods imported from non-EU origin, including plants for planting, enter through a limited number of member states and are then dispatched throughout the whole EU with no further control. With this in mind, it is clear that inspection methods should be uniform across EU Member States, ensuring a common maximum acceptable infestation level for the safety of the entire free trade area. The evidence reported here was derived from self-completed questionnaires. We were unable to attend inspections to assess the quality of the responses, because most EU countries do not know in advance what consignments will arrive when, and it was impossible to accompany inspectors on short notice when a consignment with plants for planting had arrived at the point of entry. Although there is the danger that reports of inspection efforts were exaggerated, it is unlikely that there was an incentive to mis-report given the assurance that all data would be anonymized. Data from only six countries were analyzed, which was in part because the questionnaires were not always sent to the appropriate person in the NPPO and in part because some of the countries did not provide the data required for the analyses. However, we do not believe that this is too little data for the purpose of assessing whether there are international differences. Regardless of any questions over the accuracies of the data presented, this work provides a first glimpse of inspection effort from major importing countries and highlighted major differences in the intensity of phytosanitary inspections that reflect differences in the maximum infestation level that can be detected. The probability that the level of infestation was below 1 % was high (i.e. >95 %) in only one third of the inspections. Moreover, only one of the countries (country G) that responded to our request for information appeared to follow a systematic approach to deciding on the number of plants inspected in any given shipment. In this country, the probability that the infestation rate was below a set limit was both consistent and high, because the inspectors followed the statistical rules, using either the hypergeometric or the binomial sampling distributions according to the lots' size. In fact, there appeared to be some oversampling (points above the hypergeometric curve in Fig. 1), but this is likely for ease of instructing inspectors. By contrast, the probability was never as high and it varied between inspections in each of the other five countries. The implication of this variability is that there is an increased likelihood of infested shipments being allowed to enter the EU, and a higher risk of introduction of harmful organisms imported into the EU through those countries that have the weakest inspection strategies.

With a few exceptions, the intensity of phytosanitary inspections is only vaguely defined in the Plant Health Directive of the EU, where it is only stated that each shipment should be inspected "meticulously" (European Commission 2002). This broad brush approach may be desirable at the legislative level and more detailed, perhaps context-dependent directions may be defined in regulation or country-specific policy. However, this also leaves room for individual Member States to carry out inspections to different standards, and our study revealed some of these significant differences. The abundant intra-EU trade that is not subject to further phytosanitary inspections (Dehnen-Schmutz et al. 2007) can result in the spread of harmful organisms that have gone undetected during less efficient phytosanitary inspections in countries where there is a lack of certainty that the infestation level in the shipment was below an acceptable level. The differences in inspection intensity between countries could be a result of national policies, but we did not obtain insight into the guidance provided to inspectors in the countries that responded to our questionnaire. Despite the FVO's regular audits of the inspection practices in Member States and its suggestions for improvements, our results indicate that the inspection intensity is nevertheless not uniform.

The apparent lack of a consistent, statistics-based method to determine the number of plants to inspect in a given shipment clearly leads to low statistical confidence in the outcome of inspections in many countries. On the other hand, it can also result in the inspection of too many plants. While inspecting more plants than necessary increases confidence in the inspection results, this may not be the best use of inspection resources, in particular in situations where such resources are limited or where the shipment must be cleared rapidly to preserve the quality of the goods. An example appears to be country C, where the duration of some of the inspections was very long (up to 10 h for 72 inspected plants). The negative correlation between the average time spent inspecting a plant in a consignment and the probability that the infestation level was low indicates that, in our study, a longer inspection time did not improve the quality of the inspection. This suggests that some of the time allotted to these longer inspections may have been better spent on the inspection of additional consignments or on more detailed inspection of high-risk consignments.

Samplings in country G almost perfectly fitted the statistics based on a hypergeometric distribution: up to a consignment size of 300 plants all plants were inspected and above this size the inspectors sampled exactly 300 units. This sampling strategy fits with the recommendations of ISPM 31 and provides a high statistical probability (95 %) that the infestation level of inspected shipments was below 1 %. The required sampling intensity increases as the acceptable infestation levels are lowered and if we had assumed a 0.1 % infestation level as the maximum acceptable, this would have severely reduced the confidence in the results of the inspections in most EU countries in our study. Conversely, if the acceptable maximum infestation level is increased, or the targeted level of confidence in inspection results is decreased, the sampling intensity can be reduced, this being a matter of risk management.

Our study was based on the assumption that pests were distributed randomly in the inspected shipments. Detection of a pest that is patchily distributed within a shipment theoretically requires a higher sampling intensity to obtain an equal level of confidence (Venette et al. 2002 and references therein). We are unaware of any country to date that has implemented sampling rules assuming clustered pest occurrence.

In addition to the statistical limitations outlined above, visual inspections are rarely one hundred percent efficient, i.e. capable of detecting all infestations above, or equal to, the acceptable maximum pest level in the sampled goods. This is especially valid for microorganisms, such as bacteria, viruses, microscopic fungi or phytoplasmas (Brasier 2008). Insects with cryptic life stages may be difficult to detect too (McCullough et al. 2006). For example, plants infested with *Phythophthora* spp. may look healthy during visual inspections and this impression may be reinforced by fungistatic treatments before shipment. The inspectors may thus have the false impression that the lots inspected are pest free after a negative visual inspection. Liebhold et al. (2012) showed that infested material was detected in 3.3 % of the incoming shipments in the United States using standard procedures, and in 11.9 % of the shipments using AQIM procedures, and estimated that 72 % of the infested shipments were wrongly allowed to enter the country during standard, biased and non-random inspections. In New Zealand ca. 43 % of the infestations are unnoticed during import inspections (Tualau and Nair 2008). No such estimate exists for Europe. Inspection efficiency can and should be taken into account when designing a sampling strategy (FAO 2009). This will increase the number of plants that must be inspected in each consignment to achieve the desired level of confidence in inspection results.

Surkov et al. (2007) provided levels of infestation of ornamental plant genera (*Chrysanthemum*, *Dianthus*, *Impatiens* and *Rosa*) imported from 1998 to 2001 from non-EU countries to the Netherlands. The fraction of infested plants in the shipments ranged from $1.05E-07$ to $3.65E-04$. The destructive sampling of *Acer* spp. imported from non-EU countries into the Netherlands as part of the emergency measures consecutive to the *Anoplophora chinensis* Forster (Coleoptera: Cerambycidae) outbreak in the Netherlands in 2008, in which 269,107 *Acer* spp. were destructively sampled, revealed that 4.9 % of the consignments and, on average, <0.005 % of the sampled plants were infested (R. Eschen unpublished). These infestation levels are well below those that can reliably be detected during inspections, suggesting that some quarantine organisms may have gone unnoticed during inspections. Phytosanitary import inspections are not, and are not meant to be, adequate to detect these low infestation levels and alternative approaches to the management of low-risk pathways with very low infestation levels may be needed to avoid the establishment of associated harmful organisms.

An alternative or complementary option to the implementation of statistical approaches to sampling for rare individuals described in ISPM 31 (FAO 2009) is the prioritization of high-risk pathways for intensive sampling and reduced sampling of pathways that are considered to pose a lower risk. This may in particular be necessary in cases where resource limitations prohibit intensive inspection of all consignments. Using an empirical model based on Dutch data on imported ornamentals, Surkov et al. (2007) argued that, under capacity constraints, the inspecting agencies should adapt their inspection efforts in order to equalize the marginal pest risks across importation pathways by investing larger inspection efforts in pathways with larger expected risks. Our results appear to show that inspectors in some countries did indeed prioritise certain consignments for more thorough inspections. In particular, inspectors spent significantly more time when inspecting bonsai plants, a well-known risky commodity, than bare rooted or potted plants.

Conclusion

A better coordination between EU Member States to address biological invasions is urgently needed (Hulme et al. 2009) and, as part of this, the import inspection techniques should be harmonised. We suggest that a statistics-based sampling methodology should be adopted by all EU Member States. In our dataset, one country provided evidence that simple sampling rules can be implemented and some non-EU countries already follow similar rules (i.e. Australia and New Zealand). Such simple guidelines for statistically-based sampling in the EU already exist for specific regulated species, such as the Asian longhorn beetle *Anoplophora chinensis* (European Comission European Commission 2012) and could be extended to the other regulated species. In this way, the confidence in inspection results would be harmonised, or at least comparable if the countries would set the acceptable levels of infestation differently. ISPM 31 (FAO 2009) provides the theoretical background for statistical-based sampling for small and large shipments. NPPOs could refer to this Standard for guidance on sample sizes for a shipment, based on the level of infestation that is deemed acceptable, the desired confidence in the result and the availability of inspection resources. Prioritisation of the inspection efforts depending on the risks represented by each consignment, and their integration within systems approaches with wider room for mitigation measures in the exporting country would appear a possible response to capacity constraints.

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