International variation in phytosanitary legislation and regulations governing importation of plants for planting

Eschen, R.¹, Britton, K.², Brockerhoff, E.³, Burgess, T.⁴, Dalley, V.⁵, Epanchin-Niell, R.S.⁶, Gupta, K.⁷, Hardy, G.⁴, Huang, Y.⁸, Kenis, M.¹, Kimani, E.⁹, Li, H.-M.^{10,11}, Olsen, S.⁵, Ormrod, R.¹², Otieno, W.¹³, Sadof, C.¹⁴, Tadeu, E.¹⁵, Theyse, M.¹⁶

¹ CABI, Rue des grillons 1, 2800, Delémont, Switzerland

² Forest Service Research & Development, USDA Forest Service, 1400 Independence Ave SW, Washington, DC, 20250, USA

³ Scion (New Zealand Forest Research Institute), PO Box 29237, Christchurch 8540, New Zealand

⁴ Centre for Phytophthora Science and Management, School of Veterinary and Life Sciences, Murdoch University, Western Australia, 6150, Australia

⁵ Plants, Food & Environment Directorate, Ministry for Primary Industries, PO Box 2526, Wellington, New Zealand

⁶ Resources for the Future, 1616 P Street NW, Washington, DC 20036, USA

⁷ Division of Plant Quarantine, National Bureau of Plant Genetic Resources, New Delhi-110 012, India

⁸ Pest Risk Analysis Group, Institute of Plant Quarantine, Chinese Academy of Inspection and Quarantine (CAIQ), Beijing, China

⁹ Kenyan Plant Health Inspectorate Service, PO Box 49592-00100, Nairobi, Kenya

¹⁰ MoA-CABI Joint Lab for Bio-safety, Institute of Plant Protection, Beijing 100193, China

¹¹ CABI, Zhongguancun Nandajie 12, Internal Post Box 56, Beijing 10080, China

¹² Plant Health and Biosecurity Programs, Canadian Food Inspection Agency, 1853 Bredin Road, Kelowna BC, V1Y 7S9 Canada

¹³ CABI, Limuru Road, Plot No 9 –Canary Bird, Muthaiga, Nairobi, Kenya

¹⁴ Purdue University, Department of Entomology, Purdue University, Smith Hall, 901 West State Street, West Lafayette, IN 47907-2089, USA

¹⁵ Empresa Brasileira de Pesquisa Agropecuária (Embrapa), Estrada da Ribeira, Km 111 Bairro Guaraituba, CEP: 83411-000, Colombo (PR), Brazil

¹⁶ Fresh Produce Importers Association, PO Box 27019, Gezina, 0031 South Africa

Corresponding author: R. Eschen, r.eschen@cabi.org, Fax.: +41 324 214 871

41

42 **Abstract**

43 The trade in plants for planting (P4P) is one of the major pathways for the introduction of
44 pests. The strong increase in world trade in the past decades appears to have led to an
45 increase in introductions of species transported by this pathway, and highlights the need for
46 effective phytosanitary legislation and measures. The phytosanitary regulations in most
47 countries are based on the International Plant Protection Convention and the World Trade
48 Organisation's Agreement on Sanitary and Phytosanitary Measures, but there are large
49 differences in countries' approaches to managing the risk of introducing invasive alien
50 species through international plant trade. We reviewed elements of the phytosanitary
51 legislations of ten countries on all continents and aimed to find regulations that prevent
52 biological invasions. We found large differences in countries' phytosanitary regulations. New
53 Zealand and Australia have the strictest phytosanitary regulations, while Europe maintains a
54 general authorization for P4P imports. The remaining countries have regulations between
55 these extremes. The evidence is sparse regarding the quality of implementation and
56 effectiveness, and impact of individual phytosanitary measures. We recommend that
57 National Plant Protection Organisations collect detailed information on P4P imports and the
58 effectiveness of phytosanitary measures. Such information could provide a basis to improve
59 a country's phytosanitary regulatory framework or could be used in risk assessments.

60

61 Key words: International trade; live plants; invasive invertebrate pests and microbial
62 pathogens; legislation; IPPC; ISPM; plants for planting; risk analysis; import regulations;
63 invasive alien species

64

64

65 **Introduction**

66 There is increasing evidence that international trade, in particular the trade in live plants for
67 planting (P4P, syn. nursery stock), is a major pathway for the introduction of alien plant pests
68 (both arthropod pests and microbial pathogens; Work et al. 2005, Kenis et al. 2007, Liebhold
69 et al. 2012, Santini et al. 2013). The trade in P4P continues to see a strong increase in
70 volume (Liebhold et al. 2012, Eschen et al. 2014), as well as shifts in the origins of the
71 plants, due to moving nursery operations to countries where production costs are lower and
72 the importation of retail-ready plants. For example, European imports of P4P from China
73 have increased fivefold over the past ten years and are now on a par with the volume
74 imported from North America, which remained static (Eschen et al. 2014). Concomitant with
75 increasing trade will be a similar increase in invertebrate plant pests and infective
76 propagules of plant pathogens (Liebhold et al. 2012, Bockerhoff et al. 2014). There is,
77 therefore, an urgent need to understand the efficacy of existing measures and what
78 measures are needed to reduce and mitigate the risk of introducing pests through
79 intercontinental trade in P4P.

80 National legislation and regulations are fundamental to providing the regulatory framework
81 for protecting agricultural, forest and other plant resources from alien pests, or to manage
82 such threats. There are a number of possibilities to mitigate the introduction of quarantine
83 pests via trade by effective implementation of regulations, such as measures to ensure low
84 pest prevalence in the exporting country, treatment of consignments, importing dormant
85 plants and restricting import to specific seasons, sizes, or plant condition. If such measures
86 do not reduce the risk to an acceptable level, import of the affected commodities is
87 prohibited. These and other measures have been adopted in national legislations world-
88 wide. Phytosanitary legislation and regulation can be effective in reducing the rate of pest
89 establishments (Roques 2010, Hlasny 2012), but the measures prescribed in national
90 legislations vary and it would be valuable to identify those parts of legislations and
91 regulations most effective in reducing risk.

92 The legislation concerning the management of risks associated with the import of P4P and
93 the associated dispersal of pests and diseases is, in most countries, based on international
94 treaties and conventions (MacLeod et al. 2010), in particular the International Plant
95 Protection Convention (IPPC; FAO 1997) and the WTO Agreement on the Application of
96 Sanitary and Phytosanitary Measures (SPS Agreement; WTO 1995). The IPPC stipulates
97 the use of phytosanitary certificates and the right of countries to regulate the import of
98 certain plant species to avoid entry of pests, to inspect or quarantine specific consignments
99 and to define which pest species are not allowed to enter the country. The SPS Agreement

100 stipulates that countries have the right to decide their own level of acceptable risk, and to
101 apply phytosanitary measures as required to protect plant life or health, as long as these do
102 not discriminate against certain countries or foreign commodities and have the minimal
103 necessary impact on trade. Moreover, any limits on trade set under the SPS Agreement
104 have to be based on science or international standards, such as the International Standards
105 on Phytosanitary Measures (ISPMs) set by the IPPC (except for provisional measures).

106 The Regional Plant Protection Organizations (RPPOs) were created as regional
107 organisations of the IPPC and are a platform for regional collaboration and in some cases
108 coordinate harmonisation on phytosanitary issues and develop science-based phytosanitary
109 standards for their respective regions. Ultimately some regional standards for phytosanitary
110 measures are adopted by the IPPC as ISPMs and have a global reach. For example, ISPM
111 36 ('Integrated measures for plants for planting', FAO 2012) was initiated as the North
112 American Plant Protection Organization's Regional Standard for Phytosanitary Measures 24
113 ('Integrated Pest Risk Management Measures for the Importation of Plants for Planting into
114 NAPPO Member Countries', NAPPO 2013). Although ISPMs are not legally binding under
115 the IPPC, WTO Members shall base their sanitary or phytosanitary measures on
116 international standards, guidelines or recommendations, where they exist (WTO 1995).

117 The majority of countries are members of the WTO or contracting parties to the IPPC, and
118 can be expected to comply with their respective obligations, but they have very different
119 approaches to ensuring phytosanitary safety. A country's regulatory design consists of a
120 regulatory framework (phytosanitary legislations, regulations and procedures) and a National
121 Plant Protection Organisation (NPPO) that is responsible for operating the regulation (FAO
122 2004b). The international differences in regulatory designs result from differences in the
123 regulatory framework and approaches to risk management. As a simplification, countries can
124 be divided into those that allow live plant imports until a known pest threat is identified and a
125 risk analysis justifies regulation ("black list") and countries that only allow entry of
126 commodities that have been assessed and are considered safe ("white list"). This divides
127 countries roughly into 1) those managing the risk of known harmful organisms, by identifying
128 black lists of restricted pests that are deemed so harmful that they must not enter the
129 country, and 2) countries managing risk by identifying safe, authorized commodities or
130 pathways, as well as typically longer lists of non-authorized pests (Table 1). In other words,
131 the distinction is based on whether something cannot be imported because it is prohibited
132 (based on a risk analysis) or whether it is not authorised until a process of evaluation can be
133 completed.

134 An international review of approaches to phytosanitary safety may inform the development of
135 legislation and policy to help countries reduce pest risk via P4P, but we are unaware of such

review in peer-reviewed literature or reports. Here, we provide an overview of measures that can be implemented to limit the introduction of non-native pests through trade in P4P and illustrate the measures with examples from the United States of America (USA), European Union (EU), South Africa, India, New Zealand, Australia, Brazil, Canada, China and Kenya. The Electronic Supplement contains a list of consulted national and international legislative texts. These countries were selected to cover a range of organisational complexity, the approach to phytosanitary safety, as well as to cover both primarily importing and exporting countries and to represent all continents. We describe differences among countries and the apparent reasons for international variation in phytosanitary regulatory design. We also discuss evidence for transport of regulated organisms and the effectiveness of phytosanitary measures to reduce the number of transported pests.

Import permits

Countries can issue a general authorisation for the import of P4P or may demand an import permit with specific requirements or official consent that authorises the import of plants of particular genera or origins (FAO 2004b). The IPPC encourages general authorisations to be developed when similar specific authorisations are required for many commodities (FAO 2004b). However, the EU is the only region in our comparison that maintains a general authorisation for P4P imports and does not use import permits (Table 2). Most other countries require individuals or companies that wish to import P4P to apply for an import permit, often irrespective of genera or origins.

The purpose, validity and cost of the permits vary widely among countries. The application for import permits can provide useful information about the plants intended for import. This can motivate regulators to carry out a pathway risk analysis if the application concerns a new commodity or pathway (e.g. genus-origin combination), to decide on whether additional phytosanitary measures for commodities or consignments are necessary, or to prohibit import if deemed necessary. A number of countries, including China, Canada, Kenya and Brazil perform pathway risk analyses when importers apply for import permits for new commodities. The USA uses import permits as a means to inform importers of regulations and requirements related to the imported commodity and serves as a basis for legal action if regulations are breached. In the USA, permits for the import of plants of a specified species from one origin are issued for a period of five years and in Canada for a period of three years in the majority of cases. This differs from most other countries, where permits are issued for individual shipments. Permits are issued free of cost to the applicant in China and the USA, but the cost of a permit is Rs300 in India (at the time of writing ca. €3.5), KSH600 in Kenya (ca. €5), \$166.62 in New Zealand (ca. €102) and \$185.00 in Australia (ca. €125).

Pest Risk Analysis and Pathway Risk Analysis

The aim of risk analyses, carried out on pests or pathways, is to determine whether the risk posed by a pest or pathway is such that it requires regulation and what measures would be effective to mitigate these risks (FAO 2004, 2007). Such measures may then be prescribed in legislation, regulations, or bilateral agreements as a condition for entry of a commodity or for a pathway. In the case where no measures are identified that would ensure an acceptable level of risk, a country may decide to prohibit entry of the identified commodity. For example, the EU has prohibited the import of *Populus* spp. plants with leaves from North American countries (Annex III, part A in Anonymous 2000), China has prohibited the import of *Pinus* spp. from DPR Korea, Japan, France, Canada and the USA (Anonymous 2007), and Kenya has prohibited importation of fruits and fruit trees from China, Japan, Korea and Manchuria (Anonymous 1961).

Pest risk analyses are a common basis for establishing quarantine pest lists, but in cases where they are only carried out on organisms that are known or suspected to be harmful, they poorly contribute to the mitigation of the risk posed by unknown, poorly known or underestimated pests (Simberloff 2005; Kenis et al. 2007). A good pest risk analysis should capture and highlight the uncertainty associated with poorly known or underestimated pests and can be performed well, even if based on little or unreliable data (Sequeira and Griffin 2014). Pathway risk analysis may be a more appropriate approach for imported commodities such as P4P than pest-by-pest risk analysis, as different commodities will have different risks for the same pests and a single commodity may be a potential pathway for many pests (Evans 2010).

In the EU, risk analyses are generally based on single pests; often those that have just entered EU countries or are invading other continents. In contrast, many other countries and regions carry out pathway risk analyses on all new plant commodities before allowing their importation (Table 2). In addition, some countries carry out a preliminary risk analysis on unexpected and unknown pests found during inspections at the port of entry (POE) and come to a quick decision about the release of a consignment to the importer or about required provisional measures. A full risk analysis must be carried out at a later date to satisfy the requirements of the SPS Agreement. The variation in the number of regulated pests (Table 1) may in part be due to this difference in approach to risk analysis, the national plant health regulations or the NPPO's appetite for risk.

The USA has recently introduced a new regulatory category for P4P, Not Authorised Pending Pest Risk Analysis (NAPPPRA; Fed. Regist. 319.37-2a) as part of a transition from a black list approach to a white list approach for new commodities: new pathways are subject to risk analysis prior to a decision on whether to allow import and identification of additional

import requirements. In effect, any country that requires risk assessment prior to issuance of import permits for new pathways has NAPPRA in place.

Pest free area and pest free places or production sites

If a pest does not occur, or is very rare in a region or production site then the chance of a consignment becoming infested may be negligible. However, if a pest has been recorded from part of a country, the importing country may require that the exporting countries provide evidence that the area of production is free of the pest of concern (FAO 1995). Excluding the pest of concern from the production site can effectively manage the risk of some pests through, for example implementation of screens or other physical barriers, cultural methods, or general site hygiene (FAO 1999). The recognition of pest free areas is an administrative process involving the exporting and importing country, but the NPPO of the exporting country is responsible for maintaining surveillance of pest free areas (FAO 2009b). Pest free sites of production are established by producers in compliance with the requirements of the exporting country's NPPO. The pest's absence can be demonstrated, for example, through trapping or surveys, for which the NPPO is responsible (FAO 1999). Many countries use pest free requirements to mitigate risks associated with specific pathways, and the differences depend on the outcome of risk analyses.

Shipping in specific seasons or plant growth stages

Pests and diseases have the best chances of establishment if the climates in the importing and exporting countries are similar and seasonally aligned. Limiting importation to particular seasons may limit the prevalence of particular pest types, such as leaf-feeding insects or some foliar pathogens, on dormant plants. However, the risks may be lower or less-easily identifiable if the seasons in exporting and importing countries are asynchronous, for example if the plants are moved in spring or autumn between climatically similar regions on the Northern and Southern hemispheres.

The EU requires that plants of certain genera, such as *Malus*, *Pyrus* and *Rosa*, do not have leaves at the time of import (Annex III part A in Anonymous 2000). These deciduous plants may not have leaves at the start of spring if they are imported from climatically similar regions in the Northern hemisphere. The USA requires that plants authorized for importing in growing media, all of which must be grown under a systems approach and do not include deciduous species or species with true dormancy, have been actively growing and protected from pests through physical exclusion structures in the period prior to export (7 CFR 319.37-8). The aim of this requirement is to increase the likelihood of detecting pathogens and other inconspicuous pests. The New Zealand Standard for Importation of Nursery Stock stipulates that the plants must be actively growing throughout the post-entry quarantine period (Anonymous 2012), again aimed at optimising the chances of detecting disease symptoms,

but some horticultural commodities, such as *Malus*, *Prunus* and *Vitis*, are required to be imported in a dormant state. Kenya and South Africa do not have measures based on differences in growing season or climate with exporting countries and restrictions on the season of import is seldom used in China as it is a large country with a range of climates.

Import of soil

In a phytosanitary context, soil is considered a high risk because of the pathogens, cryptic insect life stages and nematodes that it can contain, but it may also contain seeds or root fragments that may allow the establishment of unwanted plants and the presence of soil makes the inspection of plants more difficult. Most countries therefore prohibit the import of soil, with potential exceptions made for imports for scientific purposes. Many countries also prohibit the import of plants with soil attached. Plants in sterilized media usually are acceptable.

The USA distinguishes soil from growing media and packing material. For instance, soil is not allowed (except from Canada); rooted cuttings may be shipped bare root in sawdust as an approved packing material but it becomes a growing medium and is regulated differently if the plants are established in the sawdust. New Zealand requires whole plants (including cuttings) that have been grown in soil to be dipped in Fenamiphos prior to export, or an additional declaration that the whole plants were raised for seed/cuttings in soil-less media in containers maintained out of contact with the soil. The EU and some other countries, including India, allow enough soil to sustain the plants during transport. Moreover, the volume of soil attached to imported trees can be substantial, thus dramatically increasing the chance of it harbouring unwanted pests or pathogens. In Europe, where there is no limit on the size of imported plants, some trees are imported with more than a hundred litres of soil and in effect an entire ecosystem is being transplanted.

Treatment of plants prior to export or at entry into the importing country

Measures aimed at reducing the presence and prevalence of pests on P4P in the exporting country, i.e. preventing entry into the pathway, are more effective and provide a higher level of safety than management of pests that have arrived or established in the importing country. Chemical or physical treatments or combinations thereof can effectively prevent or lower the risk of infestation of plants, but there are fewer options available for treating P4P once they are infected. Fumigation and pesticide treatments can and are applied, but these may not be effective against pests living inside the plants. Heat or cold treatments, which are used to treat other commodities such as fruits or wood, are not as suitable as they may damage the plants, in particular small plants.

New Zealand requires chemical treatment of live plants in the exporting country prior to shipping. All live non-dormant plants must be submerged in a bath containing two insecticides and acaricides each of different chemical classes; fumigation (for example with methyl bromide) is required for some species to target scale insects in cases where dips have been shown to not be effective. Treatment with fungicides is prohibited, as this can merely suppress symptoms and make it more likely that pathogens go unnoticed during inspections, with the exception of some mandatory fungicide treatments for root rots and rusts (e.g. section 2.2.1.8. of Anonymous 2012). Australia requires fumigation of all live plants using methyl bromide prior to entry into the country, which is done after inspection. We are unaware of a similar requirement for chemical treatments of all P4P elsewhere, although some countries require treatment for specific pathways.

Phytosanitary certificates

A common requirement for import of P4P is a phytosanitary certificate, with which the NPPO of the exporting country certifies that inspection prior to export has established that all the requirements of the importing country are met and, optionally, that the consignment is practically free of those pests that are regulated by the importing country (FAO 2011). All countries in our comparison require shipments of live plants to be accompanied by a phytosanitary certificate.

Post-entry Quarantine

Phytosanitary inspections are not 100% effective for finding all harmful organisms in a consignment, because of the small number of sampled plants and short time available for inspecting each plant (Work et al. 2005, Liebhold et al. 2012). Moreover, inconspicuous invertebrate pests with cryptic life stages and plant pathogens are difficult to detect during visual inspections. Post-entry quarantine in the importing country provides more time for the development of pests and the expression of symptoms. During the quarantine period, there are inspections by official inspectors, in addition to regular checks by the quarantine facility operator. If harmful organisms are found, the consignment may be treated or destroyed. If no harmful organisms are found, the official inspector releases the consignment from post-entry quarantine and the plants can enter the country.

The interpretation and implementation of post-entry quarantine varies among countries. A quarantine facility may be an open-field plantation, a greenhouse with mesh screening to prevent the escape of invertebrates, or a fully closed facility with filters preventing the escape of microbial pathogens. These differences are usually based on risk analysis, the target pest(s) and plant growth form, with more secure facilities and longer quarantine periods stipulated for commodities of great economic importance (grape vines, for example).

The period that plants must remain in a post-entry quarantine facility also varies, roughly from three months to several years. In New Zealand, all P4P (except some tissue cultures, dormant bulbs, and *Phalaenopsis* whole plants from Taiwan) must go into post-entry quarantine for a minimum of three months, and up to three years. New Zealand allows horticultural germplasm (e.g. budwood) from certified facilities with reduced post-entry quarantine requirements (e.g. nine months active growth instead of 24 months for *Prunus*). Similarly, the post-entry quarantine period in Australia ranges from months to years, depending on plant species. In the USA, most imported fruit trees go into post-entry quarantine for two years. As an exception, *Prunus* from Europe must come from certified facilities, and import from other sources, except Canada, is prohibited. In the USA post-entry quarantine constitutes of an open-field plantation, in which the trees are regularly inspected for pests. In Brazil, all nursery stock must go for three months into post-entry quarantine, which can range from open field to closed facilities, depending on perceived risk. In the EU, plants of only a few genera require three months post-entry quarantine (for example dwarfed plants of *Chamaecyparis*, *Juniperus* and *Pinus*, originating in Japan: Annex of Anonymous 2002). India requires post-entry quarantine for imported cuttings and plants for propagation, from 45 days to one year, depending on the species and the pest risk involved. Kenya stipulates that certain shipments must go into quarantine before they are allowed into the country. The quarantine facilities often belong to the importers, allowing import of larger numbers of plants and providing the best care for the quarantined plants, which are commonly imported for propagation. Ultimately, however, inspections are carried out by government officials. Finally, the post-entry quarantine period may start only when the plants are actively growing (as in New Zealand), with the aim of increasing the likelihood of detecting pests.

Integrated measures (systems approaches)

Integrated measures for the management of harmful organisms require two or more phytosanitary measures independent of each other (FAO 2002). In some cases, integrated measures make it possible to meet the required level of protection in cases where no adequate single treatment exists. In other cases, an integrated measure may provide equivalent protection against harmful organisms as an alternative single measure or treatment, but may be less trade-restrictive. The implementation of effective integrated measures requires analysis of the pathway to identify critical points for pest reduction and management.

ISPM 36 proposes integrated measures specifically aimed at P4P (FAO 2012). These measures are all implemented in the exporting country, reducing the chance of harmful organisms being carried on the exported plants. Only a few countries, particularly New

Zealand and Australia, require integrated measures for the import of live plants in general. For imports into the EU, specific plant genera, often from particular origins, may require a combination of specified treatments, such as *Acer* spp. from China. Other examples are the import of plants in growing media to the USA, which requires a complex systems approach (Federal Register 2012a), and the import of whole *Phalaenopsis* plants in growing media from Taiwan into New Zealand without the need for PEQ, as all risks are managed pre-export. The limited number of countries demanding integrated measures may be in part due to the relatively recent acceptance of such an approach towards phytosanitary security, as illustrated by the recent adoption of ISPM 36.

Pre-export clearing programmes

Cooperative efforts between plant producers in exporting countries and regulatory agencies provide a way to reduce risk of moving pests while allowing continued trade of problematic P4P. For example, Costa Rica now exports *Dracaena* to the USA through a pre-export clearance program. Over 11,000 pest interceptions were recorded on *Dracaena* spp. from Costa Rica from 1984 to 2011 (Colpetzer et al. 2011). In 2006 a set of integrated practices were implemented in a pilot program to reduce the number of infested shipments into the USA by participating producers that substantially reduced pest interceptions (Hidalgo et al. 2013). These include pest management practices for field production as well as plant inspection protocols for packing houses, worker training, minimum lighting requirements and physical screen barriers to protect clean inspected plants. As a result of an auditable bilateral work plan accepted by both Costa Rica and the USA in 2012 (Federal Register 2012b), all *Dracaena* shipments require a phytosanitary certificate including a statement that specified integrated practices have been followed. In addition to continued access to the USA market, growers are induced to participate in this program by a change in the rules that allows them to sell larger and more valuable plants.

Inspections at the point of entry

The POE for plants for planting through which all plants for planting must enter the country are listed in several of the countries' legislative texts or appendices of those (for example for India and New Zealand). On arrival, plants can be subject to phytosanitary inspection, a procedure primarily intended as a check of compliance with the importing country's requirements. POE inspections, which include checks of the paperwork and physical inspection of the imported consignment, can establish that the infestation level is indeed low, but cannot confirm the absence of pests. The same is true for export inspections for the issuance of a phytosanitary certificate. Because they are not aimed at reducing pest infestation levels, these inspections are strictly speaking not a measure. For the reasons mentioned earlier, inspectors cannot detect all pest and pathogen infestations and the

percentage of detected infestations is not well known. Low prevalence of pests as a result of treatments or other measures before the plants enter the country is obviously desirable, but the practical limitations of inspection for detecting pests restrict the ability to detect very low infestation levels during inspections at POE. Moreover, detection efficiency may vary with inspector, commodity, workload, etc. Imperfect detection affects the statistically estimable maximum infestation level (FAO 2009b). This variability should be taken into account when designing sampling for inspections and when interpreting inspection results.

While several of the comparison countries did not provide instructions or guidelines for inspectors in their legislation, there are large differences in inspection practices across countries. These differences result in equally large differences in the statistical likelihood that the level of infestation is below a level that is deemed acceptable by the importing country. For example, Australia stipulates inspection of all plants in a consignment. In New Zealand inspectors inspect all plants of each species or variety in a consignment up to 600 plants. The USA has historically followed a sampling guideline of 2% of the units in a consignment during regular inspections and in Europe sampling intensity is highly variable among countries (Eschen et al. 2015). The sampling intensity of inspections carried out as part of the Agricultural Quarantine Inspection Monitoring programme in the USA, which is restricted to a few selected genera, are based on hypergeometric statistics, meaning that the sample size is calculated based on the consignment size, acceptable level of risk, and the required level of confidence in the sampling outcome. The consignment size and all inspections outcomes are recorded, allowing calculation of infestation rates and various other analyses (Venette et al. 2002). In addition, the USA is piloting a programme to sample all genera using hypergeometric sampling, rather than the 2% guidance.

Discussion

Our review illustrates that, despite the common basis in international standards, there are large differences in how countries regulate imports of P4P. In fact, only two of the measures and procedures described here are required by all countries: phytosanitary certificates and import inspections, but even the import inspections are not carried out with the same intensity everywhere. All other measures are either not required by all countries or apply only to specific genera, exporting countries or commodities. In addition, certain measures may not be practical in some countries, such as season-dependent imports in tropical or very large countries. Each country in this comparison applies a unique set of phytosanitary measures (Table 2), which reflects variation in approaches to risk and differences in regulatory design.

The largest differences are between the countries with the strictest measures and all the other countries. The current EU legislation appears to have the most open approach, as it is

the only region in the comparison with general authorisation for P4P. Australia and New Zealand have the strictest legislations: no other countries have strictly white list approaches to regulation, or stipulate both pesticide treatment and post-entry quarantine for all imported P4P. Strict regulations presumably reduce the number of new pest entering the country or establishing, but there have been new pests recently establish which have not been traced to imports of P4P (e.g. *Pseudomonas syringae* var. *actinidae* on kiwifruit; Anonymous 2011).

Because of the cost and practicalities of putting plants through post-entry quarantine, this may be primarily suitable for relatively small consignments. As a consequence, countries with strict post-entry quarantine regulations may import mostly smaller volumes for breeding and propagation. In addition, quarantined plants do not enter the market of the importing country immediately. Thus, post-entry quarantine requirements may restrict the trade in certain plant species or types, in particular those that are short-lived. Countries where the nursery industry relies on the import of nursery stock from warmer or cheaper-labour countries and that import billions of plants per year, such as the Netherlands and the USA, are logistically unable to implement strict measures, such as wide application of post-entry quarantine.

Under the SPS Agreement, each country has the right to set its own level of risk. New Zealand and Australia base some of their national identity on flora and fauna, which is not routinely found in the rest of the world, and support a strong plant protection program and it is a priority of the two governments to prevent further introductions. Countries with land borders may have less control over the establishment of pests than islands, in particular those pests that have been introduced into neighbouring countries and continue spreading naturally. This difference affects regulation, because it may be impossible to stop secondary spread from neighbours, and a focus on increased biosecurity at shared points of entry may be more effective than focussing on land crossings between individual countries. For example, the phytosanitary regulations of Switzerland and EU are almost fully harmonized, and the regulations of three East-African countries as well, with Uganda and Rwanda accepting import of consignments arriving by boat in Mombasa that have complied with the regulations of Kenya. Several countries, including the Netherlands, are global trading hubs for P4P, which may be particularly exposed to pests as a result of the large import volume and diverse pathways, and it is important that the phytosanitary practices in these countries meet high standards in order to limit the spread of pests through trade.

National and international phytosanitary legislations in their present form are often relatively recent and some less-developed countries have outdated legislation that does not yet reflect the SPS Agreement and the updating of the IPPC. One reason for the slow changes may be that changing legislation is time consuming as it has to be accepted by Parliament. A lack of

phytosanitary capacity may be another reason for the slow uptake of the IPPC and SPS Agreement. The IPPC capacity development section provides support to update older legislations, but the acceptance of such revised legislation by Parliaments may still be a slow process. In the short term it may be most effective to introduce regulations and policy that amend existing legislation (Sequeira and Griffin 2014) or to promote good practice among producers. Our study has likely missed aspects of some countries' phytosanitary policies because of our focus on legislation. For example, Canada's Plant Protection Act and regulations are more of a "tool box" of powers and administrative procedures, while the details of the plant protection program are found in policies and databases, such as policy directive D-01-01 "Phytosanitary Requirements to Prevent the Entry of *Phytophthora ramorum*". The USA lists plants, pests, origins and procedures in a number of places in legislation, particularly 7 CFR 319.37 (Foreign Quarantine Notices).

Compliance with regulations or the adoption of good phytosanitary practices to ensure low pest prevalence may both be a condition for import of P4P and a domestic measure to ensure market access. Implementation of phytosanitary regulations is part of the NPPOs tasks as set out in the legislation (Sequeira and Griffin 2014), but application of phytosanitary measures and thus the primary mitigating actions against quarantine is primarily done by producers. The engagement of producers in the implementation of phytosanitary measures through education and guidance from the NPPO is therefore of great importance. How the producer engagement is organised in a country may depend on the phytosanitary design, as well as the organisational complexity and capacity of the plant protection organisation. Thus it may depend on the level of detail in legislation or lower-level legislative texts, as discussed in the previous paragraph, or on the relative importance of sub-national plant protection organisations, which is greater in federal or large states than in unitary states. In cases where there is insufficient capacity within the exporting country, importing countries may provide technical support and capacity building to meet their requirements. For example, the Netherlands and the USA offer training in phytosanitary issues for the benefit of phytosanitary services of poorer trading partners, such as Kenya and Ethiopia. The effectiveness of implementation of regulations is paramount to biosecurity, but there is little evidence for how good implementation, or how effective individual measures are. Inspectors from an NPPO may visit their trading partners to audit the NPPO and producers. These audits provide the importing countries with some information about the quality and reliability of the implementation of measures in the exporting country. For example, the Food and Veterinary Office of the EU periodically audits countries that export to the EU and reports on its findings and recommendations (<http://ec.europa.eu/food/fvo/>).

Countries that do not have the means for such audits have less ability to identify problems with the implementation of phytosanitary practices.

There may also be a discrepancy between regulations and practice in importing countries, due to large numbers of imported P4P and technical capacity limitations. In the EU, for example, all incoming consignments must be inspected at the first POE, but the large differences in the volume of imported plants in member states and the generally limited number of inspectors may result in differences in the way inspections are carried out. The large volume of imported P4P in peak seasons may also affect the ability of inspectors in the USA to carry out inspections as specified (Liebhold et al. 2012).

Any attempt to assess whether the different approaches to phytosanitary safety affect the arrival and establishment rates of new invasive species is difficult, because most countries lack data for use in such an assessment. Beyond information on arrival rates and establishments, import and interception data could also facilitate hazard identification and the assessment of risk (Sequeira and Griffin 2014). In particular, collection and analysis of data on P4P imports, at the genus level and by origin, in conjunction with data on intercepted harmful organisms and clean consignments, could enable analysis of patterns and trends in the import of live plants and the associated risks. However, only a few countries appear to collect data on the pests found during border inspections and negative observations are very rarely reported, which prevents statistically robust analyses of interception data (Work et al. 2005, Kenis et al. 2007). In addition, detailed information on imports of P4P also is rarely collected, as most countries collect trade information primarily for taxing purposes and the level of detail then corresponds to the needs of the customs authority. The customs offices often use the Harmonised Systems codes, but there are far too few categories in live plants to capture the diversity in traded P4P. Yet, these data are critical for comparing countries' regulatory frameworks and the effect of phytosanitary measures, as differences in arrival rates are likely to depend on the intensity, origin and type of trade.

Some of the evidence available to assess the effectiveness of phytosanitary measures includes reduced pest establishment rates in the USA and Canada after the enactment of the plant health legislations in the 20th century (Roques 2010, Hlasny 2012) and low pest interception rates in New Zealand, either at the border or in post-entry quarantine (Tualau and Nair 2008, Tualau et al. 2010), as the result of strict phytosanitary regulations that may have the effect of reducing trade volume. Records of consignments found to be infested while in post-entry quarantine in New Zealand illustrates that post-entry quarantine can be a useful measure. A study for New Zealand's Ministry of Primary Industries revealed that 14% of the consignments were infested (Tualau and Nair 2008), despite earlier clearance during inspections at the point of entry. The vast majority of these infestations were pathogens,

possibly due to the higher likelihood that pathogens go unnoticed during inspections at the point of entry and because pre-export insecticide and acaricide treatments may have removed most arthropod pests. This is a rare example of a measurable effect of phytosanitary measures. More detailed data collection on imports, interceptions, and establishments over time would enable evaluation of phytosanitary measures and more accurate and rapid risk assessment, thus improving phytosanitary safety through implementation of more appropriate, evidence-based measures.

Insights into the range of phytosanitary regulatory frameworks employed by various countries may help countries to identify additional or alternative measures that may be appropriate in their context. Our review of phytosanitary regulations revealed that all countries regulate plant imports differently and most rely on measures targeting specific pests. Given the continuous increase in the number of new pest establishments in many countries and because many of those pests were unknown or not known to be harmful prior to their establishment, such targeted measures appear inadequate for the prevention of new pest introductions. In contrast to measures for wood packaging materials (FAO 2009), there exist few measures that can be generally applied to all trade in P4P. Two exceptions may be fumigation as practiced in Australia and the treatments with pesticides prior to export to New Zealand. However, it may not be possible to apply these on a larger scale, for example in countries that import large numbers of P4P, such as the USA or the EU. Identification of other, particularly effective measures or regulations for reducing pest establishment rates would be very beneficial.

The integrated measures for plants for planting described in ISPM 36 (FAO 2012) have general applicability and are likely to reduce the level of contamination of exported plants with regulated organisms. As such, the adoption and implementation of ISPM 36 could be a good step towards reducing pest approach rates and may lead to some harmonisation of regulatory frameworks. The development of any new system of integrated measures requires, however, knowledge and capacity that depend on research and expert committees to determine likely points of system failures and how to monitor and mitigate such failures. Thus, international collaboration and assistance in capacity building may contribute to the wider implementation of integrated measures. Continued research into generally applicable, single measures nonetheless remains necessary, in particular for the replacement of methylbromide, which is being phased out. We also recommend that detailed data collection to assist with effectiveness evaluations be encouraged.

Electronic Supplement

Summary of the international agreements and national legislations and regulations in the countries that were used for this comparison.

Acknowledgements

We thank Bob Griffin, Brian Double and Bram de Hoop and an anonymous reviewer for comments on earlier versions of the manuscript. Part of this work was developed through working group 'Globalization of the Live Plant Trade: Informing Efficient Strategies for Reducing Non-Native Pest Invasion Risk' supported by the National Socio-Environmental Synthesis Center (SESYNC) under funding received from the National Science Foundation DBI-1052875. RE was supported through a grant from the Swiss Secretariat for Science, Education and Research to join the COST Action PERMIT. The inclusion of Kenya in the study greatly benefited from a CABI Development Bursary, awarded to RE.

References

- Anonymous (1961). Plant Protection Order Section 8 part 10, A subsidiary Legislation to Plant Protection Act (Cap 324) of the Laws of Kenya.
- 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 (2002). Commission Decision of 8 November 2002 authorising derogations from certain provisions of Council Directive 2000/29/EC in respect of naturally or artificially dwarfed plants of *Chamaecyparis* Spach, *Juniperus* L. and *Pinus* L., originating in Japan (2002/887/EC).
- Anonymous (2007). The Directory of Imported Plant Quarantine Pests of the People's Republic of China. The Ministry of Agriculture Bulletin No. 862 of the People's Republic of China. (in Chinese)
- Anonymous (2008). Commission Decision of 7 November 2008 on emergency measures to prevent the introduction into and the spread within the Community of *Anoplophora chinensis* (Forster) (2008/840/EC).
- Anonymous (2011). Psa – Pathway tracing report. Ministry of Agriculture and Forestry, Wellington New Zealand. <http://www.biosecurity.govt.nz/files/pests-and-diseases/psa-tracing-report.pdf> , accessed 5 December 2014
- Anonymous (2012). Import Health Standard 155.02.06 - Importation of Nursery Stock. Ministry of Primary Industries, Wellington, New Zealand.
- Brockerhoff EG, Kimberley M, Liebhold AM, Haack RA, Cavey JF. (2014). Predicting how altering propagule pressure changes establishment rates of biological invaders across species pools. *Ecology* 95: 594–601.

596 Colpetzer KE, Chinchilla GS, Guitierrez WA. (2011). Importation of oversized *Dracaena* for
 597 ornamental purposes from Costa Rica into the United States - A Pathway-Initiated
 598 Pest Risk Assessment. U.S. Dep. Agric. APHIS Pest Risk Assess.
 599 http://www.regulations.gov/#!documentDetail;D_APHIS-2011-0073-0004, accessed 25
 600 June 2014.

601 Devorshak C. (ed.) (2012). Plant Pest Risk Analysis - Concepts and applications. CABI,
 602 Wallingford, UK. 296 pp.

603 Eschen R, Holmes T, Smith D, Roques A, Santini A, Kenis M (2014). Likelihood of
 604 establishment of tree pests and diseases based on their worldwide occurrence as
 605 determined by hierarchical cluster analysis. *Forest Ecology and Management* 315,
 606 103–111.

607 Eschen R, Rigaux L, Sukovata L, Vettraino A-M, Marzano M, Grégoire J-C (2015).
 608 Phytosanitary inspection of woody plants for planting at European Union entry points -
 609 a practical enquiry. *Biological Invasions*. doi 10.1007/s10530-015-0883-6.

610 Evans, HF. (2010). Pest risk analysis - organisms or pathways. *New Zealand Journal of*
 611 *Forestry Science* supplement to volume 40: S35 - S44.

612 FAO (1995). International Standards for Phytosanitary Measures ISPM 4 - Requirements for
 613 the establishment of pest free areas. FAO, Rome.

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

615 FAO (1999). International Standards for Phytosanitary Measures ISPM 10 - Requirements
 616 for the establishment of pest free places of production and pest free production sites.
 617 FAO, Rome.

618 FAO (2002). International Standards for Phytosanitary Measures ISPM 14 - The use of
 619 integrated measures in a systems approach for pest risk management. FAO, Rome.

620 FAO (2004). International Standards for Phytosanitary Measures ISPM 11 - Pest Risk
 621 Analysis for quarantine pests including analysis of environmental risk and living
 622 modified organisms. FAO, Rome.

623 FAO (2004b). International Standards for Phytosanitary Measures ISPM 20 - Guidelines for
 624 a phytosanitary import regulatory system. FAO, Rome.

625 FAO (2007). International Standards for Phytosanitary Measures ISPM 2 - Framework for
 626 Pest Risk Analysis. FAO, Rome.

627 FAO (2007b). International Standards for Phytosanitary Measures ISPM 29 - Recognition of
 628 pest free areas and areas of low pest prevalence. FAO, Rome.

629 FAO (2009). International Standards for Phytosanitary Measures ISPM 15 - Regulation of
630 wood packaging material in international trade. FAO, Rome.

631 FAO (2009b). International Standards for Phytosanitary Measures ISPM 31 - Methodologies
632 for sampling of consignments. FAO, Rome.

633 FAO (2011). International Standards for Phytosanitary Measures ISPM 12 - Phytosanitary
634 certificates. FAO, Rome.

635 FAO (2012). International Standards for Phytosanitary Measures ISPM 36 - Integrated
636 measures for plants for planting. FAO, Rome.

637 Federal Register (2012a). Growing media. Federal Register: Title 7, Part 319, section
638 319.37-8.

639 Federal Register (2012b). Importation of *Dracaena* Plants from Costa Rica. Federal Register
640 77:123 (26 June 2012) pp. 37997-38000.

641 Hidalgo E, Benjamin T, Casanoves F, Sadof C. (2013). Factors influencing the abundance of
642 pests in production fields and rates of interception of *Dracaena marginata* imported
643 from Costa Rica. J. Econ. Entomol. 106: 2027-2034.

644 Hlasny V. (2012). Invasion of non-indigenous insects: the impact of quarantine laws.
645 International. Journal of Agricultural Resources, Governance and Ecology 9, 147-167.

646 Kenis M, Rabitsch W, Auger-Rozenberg M-A, Roques A. (2007). How can alien species
647 inventories and interception data help us prevent insect invasions? Bulletin of
648 Entomological Research 97: 489-502.

649 Liebhold A, Brockerhoff E, Garrett L, Parke J, Britton K (2012). Live plant imports: the major
650 pathway for the forest insect and pathogen invasions of the US. Frontiers in Ecology
651 and Environment 10: 135-143.

652 MacLeod A, Pautasso M, Jeger M, Haines-Young R. (2010). Evolution of the international
653 regulation of plant pests and challenges for future plant health. Food Security, 2, 49-
654 70.

655 NAPPO (2013). RSPM 24 - Integrated Pest Risk Management Measures for the Importation
656 of Plants for Planting into NAPPO Member Countries. NAPPO, Ontario, Canada.

657 Parke J, Grünwald, N. (2012). A systems approach for management of pests and pathogens
658 of nursery crops. Plant Disease 96, 1236-1244.

659 Roques A. (2010). Alien forest insects in a warmer world and a globalised economy: impacts
660 of changes in trade, tourism and climate on forest biosecurity. New Zealand Journal of
661 Forestry Science 40 suppl.: S77-S94.

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

668 Sequeira R, Griffin R. (2014). The biosecurity continuum and trade: pre-border operations.
 669 In: Gordh G, McKirdy S. (eds.). *The handbook of plant biosecurity*. Springer, Berlin: pp.
 670 119-148.

671 Simberloff, D. (2005). The politics of assessing risk for biological invasions: the USA as a
 672 case study. *Trends in Ecology and Evolution* 20: 216–222.

673 Tualau A, Iqram, A, Nair J (2010). Nursery Stock Exiting PEQ Survey, August 2009-May
 674 2010. Data Analysis and Survey Teams, Border Monitoring Report BMR 09-10/03.
 675 Biosecurity New Zealand.

676 Tualau A, Nair J. (2008). Nursery Stock Survey. Data Analysis and Survey Teams, Border
 677 Monitoring Report BMR 08-09/03. Biosecurity New Zealand.

678 Venette R, Moon R, Hutchison W. (2002). Strategies and statistics of sampling for rare
 679 individuals *Annual Review of Entomology*, 47, 143-174.

680 Work T, McCulough D, Cavey J, Komsa R. (2005). Arrival rate of nonindigenous insect
 681 species into the United States through foreign trade. *Biological Invasions* 7, 323-332.

682 WTO (1995). *Agreement on the Application of Sanitary and Phytosanitary Measures*. World
 683 Trade Organization, Rome.

684

685 **Tables**

686 Table 1. Summary of number of regulated pests in different countries. Countries are ordered
 687 alphabetically. Note that Kenya and South Africa have not issued a list of regulated
 688 organisms. Australia regulates Orders, rather than genera or species and in Australia and
 689 New Zealand inspectors must treat unidentified organisms as regulated organisms. Brazil
 690 includes phytoplasmas in prokaryotes.

	Black list						White list	
	Brazil	Canada	China	EU	India	USA	Australia	New Zealand
Arthropods and nematodes	243	82	146	110	517	101	-	9,442
Molluscs	0	12	6	0	4	0	-	34
Prokaryotes	27	10	79	19	104	16	-	296
Fungi	110	46	125	37	281	56	-	4,232
Phytoplasmas	0	10	0	0	19	20	-	126
Viruses and viroids	43	63	40	67	226	83	-	820
Diseases	0	0	0	0	2	0	-	107
Total	423	223	396	233	1153	276	>10,000	15,057

691

Table 2. Summary of the measures stated in regulations, arranged by country. That a measure is required for all live plants imports is indicated with + and measures that are not required at all are indicated with -. Hash signs (#) indicate that additional measures are required for specific genus-origin combinations. In Europe, pathway risk analyses are carried out in exceptional cases, by the European and Mediterranean Plant Protection Organisation.

	New Zealand	Australia	USA	Canada	India	China	Brazil	Kenya	South Africa	EU
Phytosanitary certificate	+	+	+	+	+	+	+	+	+	+
Import permit	+	+	+	+	+	+	+	+	+	-
Import inspections	+	+	+	+	+	+	+	+	+	+
Pathway Risk Analysis	+	+	#	+	+	+	+	#	#	-
No contaminants/soil	#	#	#	+	#	+	+	+	#	#
Pre-export treatments	+	+	#	#	#	#	+	#	#	#
Pest free area	#	#	#	#	#	#	#	#	#	#
Pest free production site	#	#	#	#	#	#	#	#	#	#
Shipping in specific season	#	+	#	#	-	-	-	-	-	#
Post-Entry Quarantine	+	+	#	#	#	#	+	#	#	#