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The Impact of Global Trade and Mobility on Forest Health in Europe

Executive Summary

This document looks at the importance of alien invasive pests and pathogens entering Europe, using a wide range of examples to illustrate the potential these organisms have to damage forest ecosystems. The lack of good phytosanitary management in the global trade in live plants is considered the main reason for the rise in the number of invasive organisms over the last 25-30 years. Although the European and Mediterranean Plant Protection Organisation (EPPO) monitors potentially invasive and established invasive organisms, the mitigation measures available to reduced and prevent incursions and to manage pests and pathogens that have already entered Europe are limited. ISPM 36, published by FAO in 2012, redresses the balance somewhat by emphasizing the roles of the producer and producing nation in making certain that exported live plants are free from potentially harmful organisms. Further techniques are required to enhance the capacity of phytosanitary inspectors to detect alien invasive organisms at ports of entry. In addition, continuous training programmes should be put in place, to maintain the abilities of the phytosanitary staff to apply state-of-the-art protocols to detection and diagnosis.

I. Introduction

1. Over the last 30 years, Europe has witnessed an unprecedented increase in the number of pest and pathogen introductions affecting all sectors of the plant industries (Madden, 2001; Brasier, 2008; Santini et al., 2013). Forestry is no exception: numerous tree pest and disease epidemics are spreading throughout the continent, as a result of changes in the behaviour of organisms already present and, particularly damaging, pests and pathogens introduced into Europe from elsewhere in the world. Certain insect pests are showing large range expansions; many other species have been brought here on plants and plant products (e.g. Aukema et al., 2010).

2. The main distinction between endemic (native) and alien (non-native) organisms is that aliens are introduced to a new region by human activities (Pysek and Richardson, 2006). Over the last five hundred years, increasing international travel and trade have allowed non-native organisms to by-pass geographical barriers that maintained the distribution of organisms for millions of years (Richardson et al., 2000). With the internationalisation of trade, many organisms have been distributed from their

native range into other regions and continents, sometimes leading to substantial disturbance to ecosystems, loss of biodiversity and severe socio-economic impacts (Liebhold et al., 1995).

3. Invasive pests tree diseases cause losses in the varied ecosystems affected, including decreased yields, reduced timber quality, negative impacts on biodiversity, and further impacts on the non-tangible benefits gained from forests, including water catchment and soil protection, non-timber products, recreation and landscape values.

4. In this paper, we review the reasons why alien invasive organisms are spreading at such rapid rates, explain what is responsible for the upsurge in invasions from other continents and give examples of several particularly worrying problems affecting trees.

5. In addition, the measures currently in place that attempt to prevent incursions occurring will be discussed, along with further actions that should be put in place to reduce the impacts of invasions immediately and in the long term. There is, however, no simple 'fix': reducing numbers of invasions requires a concerted effort from all players – state governments and EU legislators, horticulture exporters and importers, forestry companies small and large, academic institutions and research institutes, as well as end-users themselves.

6. Although trade, particularly transporting live plants between continents, may be immediately responsible for the upsurge in alien invasions, in reality, we all carry responsibility for what is happening: we create the demand for imports and importers fulfil those demands in the most cost-effective way they can find.

II. Global trade and mobility projections

7. Until 40-50 years ago, horticulture trading was done mostly at local level. Nurseries raised plants close to where they would be planted. Small forest nurseries raised plants from seeds or cuttings, and finished stock was planted nearby. Horticulture was similarly served: market gardens held mother plants from which cuttings were taken; owners skilled in grafting produced these plants locally too. Many other hardy ornamental plants were produced from seeds.

8. From the 1970s onwards, however, the industry changed rapidly. Transport systems (road, sea and air) improved enormously, and plants could be carried thousands of kilometres from places of production to end users. From that time, seedlings or cuttings were produced by specialized nurseries, transported to other nurseries as "liners" for potting into two or three litre containers, then taken from that stage into larger pots, for planting in the landscape, or to garden centres for sale to the public. Individual nurseries might specialize in producing certain species by cuttings or grafting, reducing the requirement for highly skilled personnel.

9. The development of international trade in plants largely followed the widespread uptake of containerized transport: the availability of space in container ships, some capable of carrying over 18 000 standard-sized containers[1] means that tens of thousands of plants can be shipped by sea, reaching their intended distribution points within days to a few weeks.

10. Inevitably, plant production condensed into regions where the work was done most efficiently and effectively, in terms of both quality and cost. As wages rose in Western Europe, nurseries focused more on producing specialized stock, for example, large ("standard") trees and shrubs, or on particular plant genera. Young plants were often supplied by nurseries in regions where employment costs were lower, initially Central and Eastern Europe, then beyond Europe, as far as Asia, Africa and North and South America.

[1] Shipping containers are a standard length of 20 feet (6.1 metres), width 8 feet (2.44 metres). Although not standardised, the most common height is 8.5 feet (2.59 metres). A container with these dimensions has an internal volume of 39 cubic metres.

11. Between 1995 and 2010, the value of plants imported annually into the EU and EFTA from Asia increased from approximately US$ 8 million to US$ 118 million (Figure 1). In the same period, imports from North America rose from US$ 121 million to US$ 139 million and those from Australasia from US$ 9 million to US$ 21 million. Within Asia, the main exporting countries are now China, Indonesia and Vietnam, which export approximately 58 million, 46 million and 42 million plants per annum, respectively.

12. Most plant imports into Europe are from Africa (Figure 2). The highest numbers of invasive species in Europe with known origins are from North America, although numbers from Asia are high (Figure 3).

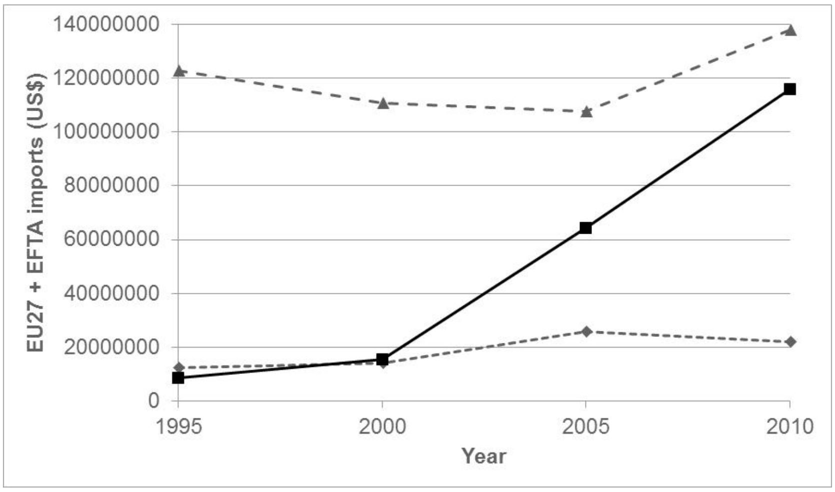

Figure 1. Changes in value of plant imports in the EU27 and EFTA States from North America (▲- -▲), Asia (■-■) and Australia/New Zealand(◆--◆) between 1995 and 2010. (Data from UN Comtrade, courtesy of R. Eschen).

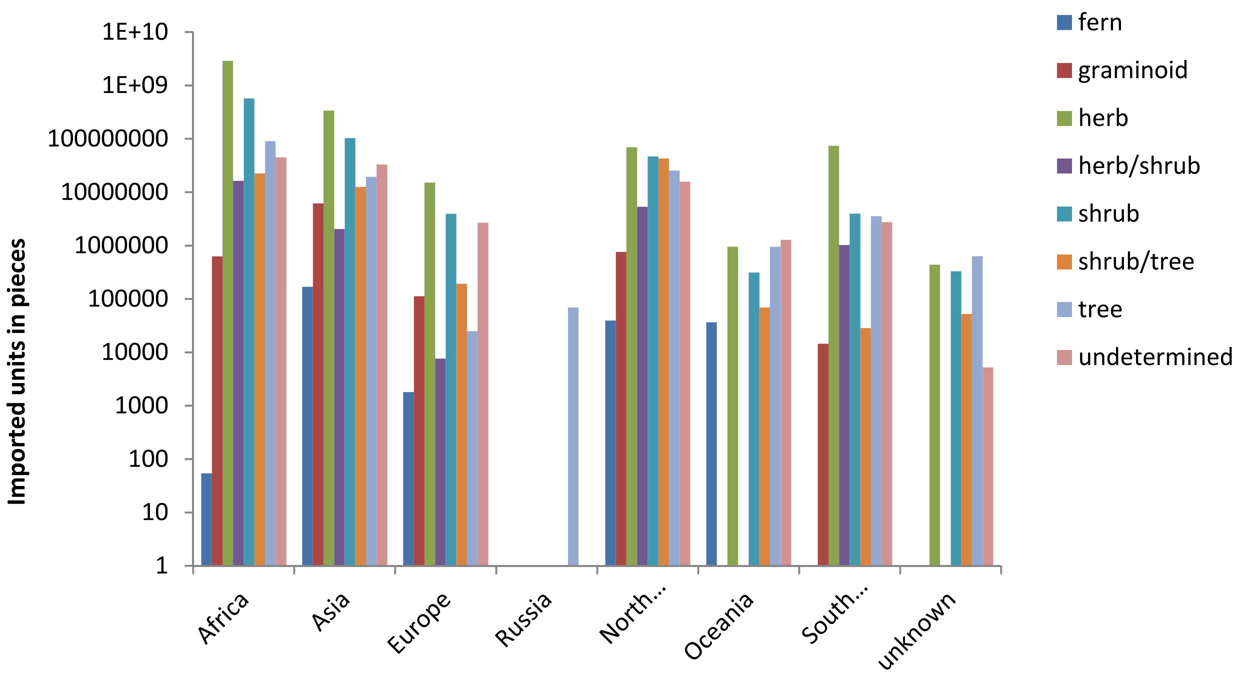

Figure 2. Imports of plants for planting into the EU by producing continent and plant growth type.

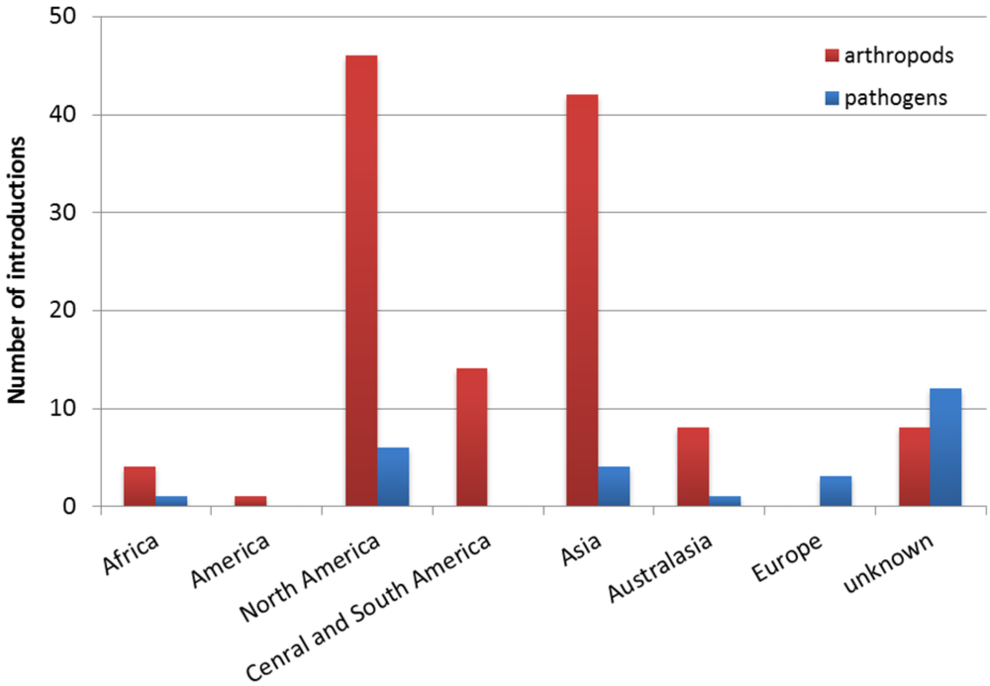

Figure 3. Origins of invasive organisms established in EU countries (Jaworski et al., 2012).

13. Plants and plant products will continue to be imported into Europe from all over the world, bringing in further damaging pests and pathogens. Therefore, it is essential that stringent measures are put in place to minimize the risk of importing alien invasive pests and pathogens in these products.

III. Pathways

14. A pathway, in this sense, is defined as "any means that allows the entry or spread of a pest" (ISPM5) and includes the commodity and mode of transport. Tree pests and pathogens are transported during trade in three major commodities: timber, wood packaging materials and plants for planting, the latter including trees, ornamental nursery stock and seed. Transport is by air, railways, road and sea.

15. Increasing introductions of alien invasive pests and pathogens of plants in the late 20th century coincided with the widespread uptake of containerized shipping (paragraph 9). The number of pests introduced into Europe, compared with the number introduced to North America, by different pathways are illustrated in Figure 4. New EU Plant Health legislation proposes that risk analyses be conducted on such pathways.

16. The plants for planting pathway is now considered by far the most important. The nursery trade is the greatest importer (and exporter) for this pathway, with The Netherlands being the biggest European hub (Table 1). Billions of plants are imported into Europe from different regions of the world, with numbers from Asia increasing most rapidly (Figure 1).

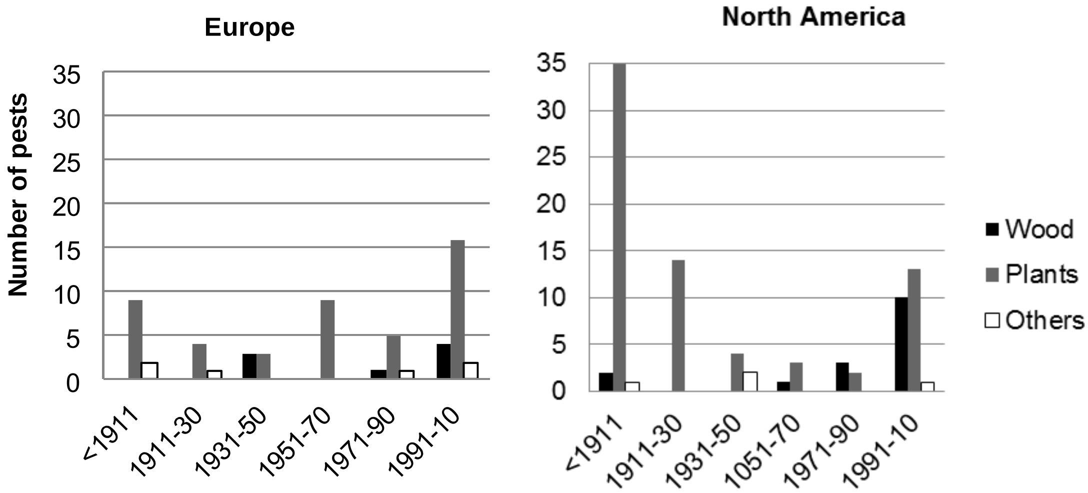

Figure 4. Numbers of major alien insect pests of woody plants arriving in Europe and North America over time and most likely pathways: wood - fresh wood or wood packing material; plants - live plants or cut branches; others - other pathways (e.g. seeds, 'hitchhiking') or pathway not determined (Kenis et al., 2012).

17. Imports of plants for planting have increased year on year in the EU since 2000 (Figure 5). Although most imported plants are not woody, these may also carry pests and pathogens that subsequently affect forest trees.

18. Living plants arrive in the EU through the gross import pathway (large quantities for wholesale nurseries), postal services and via passenger pathways (often tourism).

19. The majority of live plants imported into the EU come from Africa, followed by Asia and North America (Figure 2; Table 2). Moreover, the types of imported plants vary in proportions with exporting continent (Figure 2). Herbaceous plants are the most frequently imported from all continents. Trees commonly come from Oceania, North America and South America, although many woody plants are imported from Asia. The export of shrubs/trees represents 20.8 percent in North America, 2.4 percent in Asia and 1.9 percent in Oceania. Russia exports only trees.

20. Soil arriving in the EU with potted or root-balled plants, carries huge risks of introducing soil-borne pests and pathogens. Soil microbiology is poorly understood and soils are, arguably, the greatest risk factor when importing plants.

21. Once in the EU, the plants are considered "clean", having passed the border inspections, even if not inspected. Further trade within the EU ensues, with huge numbers of plants shipped to countries other than the initial importing state (Figure 5; Table 3).

22. Seeds provide an important pathway for introducing alien pests and pathogens. Numerous introductions have occurred through contaminated seed, including many insect pests, such as cone-feeders (Turgeon et al., 1994; Roques, 1991). Pathogens are also common in seed, both on the surface or within the integument: for example, over 20 Fusarium species have been reported in gymnosperm seed (Axelrood et al., 1995; Ocamb et al., 2002). Under poorly managed nursery conditions, damping-off results from the use of contaminated seed. Amongst Fusarium species, the biggest threat is the pitch canker pathogen, F. circinatum, which is carried in seed of both pine and Douglas fir (paragraph 49).

Country	Tonnes imported (Eurostat)	Rank	Pieces imported (Isefor)	Rank
The Netherlands	7 022.6	1	4 289 992 293	1
Italy	5 996.5	2	86 678 203	2
Belgium	2 188.8	3	23 028 319	4
Cyprus	1 994.1	4	317 221	8
Denmark	862	5	13 642 024	6
France	839.5	6	47 412 115	3
Poland	180.2	7	92 701	9
Czech republic	101.7	8	11 988 647	6
Finland	5	9	2 776 242	7
Estonia	0	10	1 742	10

Table 1 : Imports by countries according to Eurostat and Isefor.

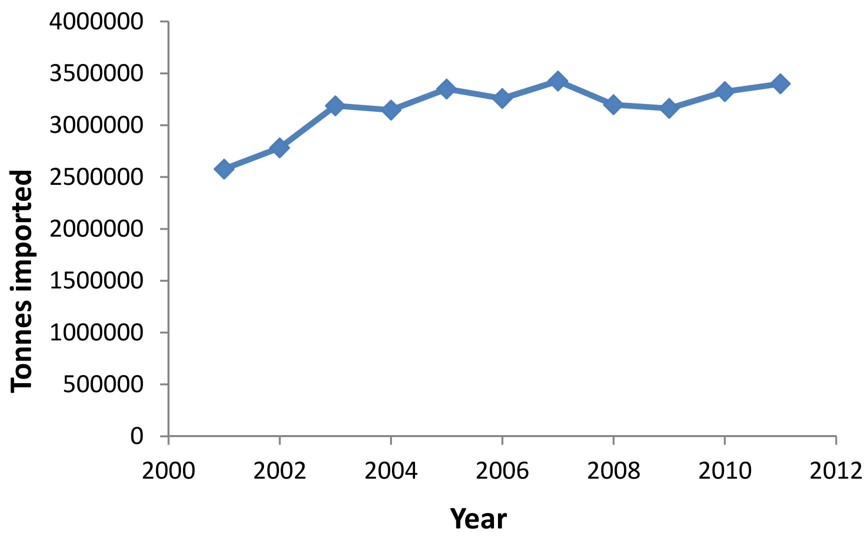

Figure 5. Changes in the quantities by weight of live plants imported in the EU between 2000 and 2011 (Eurostat; Eschen et al., 2011).

Country	Imported plants (%)
Africa	3 628 861 401 (81.3)
Asia	513 855 140 (11.5)
North America	206 907 571 (4.6)
South America	85 443 565 (1.9)
Europe	22 111 367 (0.5)
Oceania	3 603 600 (0.1)
unknown	1 457 638 (0.03)
Russia	68 978 (<0.001)
Total	4 462 309 260

Table 2 : Sources of live plants imported into the EU by continent

23. Seed of angiosperm trees can also be contaminated. For example, the ash dieback pathogen, Hymenoscyphus pseudoalbidus, infects seed of Fraxinus excelsior (Cleary et al., 2013). Oak acorns can be contaminated with numerous pests, including gall wasps, flies and lepidopterans (Gribko and Jones, 1996); a fungal pathogen, Ciboria batschiana, can significantly reduce viability in stored acorns (Delatour and Morelet, 1979).

Country	Tonnes exported
Germany	3 034 688 342.4 (18.2%)
The Netherlands	2 841 908 109.6 (17.1%)
Belgium	1 723 458 568.7 (10.4%)
France	1 569 427 134.1 (9.4%)
United Kingdom	1 399 653 020.8 (8.4%)
Italy	862 325 225.7 (5.2%)
Spain	776 178 480 (4.7%)
Sweden	621 248 911.3 (3.73%)
Czech Republic	497 004 286.8 (2.9%)
Poland	492 472 928 (2.9%)
Others	2 811 773 863.5 (16.9%)

Table 3. Plant exports between the EU 27 states between 2001 and 2011, expressed by weight of goods (source: Eurostat).

24. The seed pathway remains poorly regulated: a recent internet search suggested that seeds can be purchased from up to 22 million sources globally, offering a few seed per species to kilogram quantities. In ordering seed, it is very unlikely that the package(s) will be inspected when in transit.

25. The transport of organisms between regions on timber and woody packaging materials was addressed comprehensively in ISPM15[2], implemented from 2005 onwards (see below). Softwood is rarely imported into the EU in the round: it is likely to be kiln-dried in the country of origin and shipped as finished timber. Within the EU timber may be transported in the round. Hardwoods are subject to similar stringent requirements. Woody packing materials, however, must be treated in accordance with ISPM 15 by any nation signed up to the standard.

IV. Impacts on forest health and composition

26. The outbreak of Dutch elm disease in the southern UK in the late 1960s may be considered the "classic" example of an invading pathogen causing severe disruption to forest ecosystems (Brasier, 1996). Elms, important timber and landscape trees in Europe, play a crucial role for many organisms, some of which are obligate on this genus. Once Ophiostoma novo-ulmi, the pathogen causing the epidemic, established itself, however, elms were killed on a continental scale, leading to severe losses in the multiple roles the tree had. The pathogen is vectored locally by elm bark beetles in the genus Scolytus, which require declining elms for oviposition; because the beetles were efficient vectors of O. novo-ulmi, the disease led to a massive but temporary increase in the beetle population. Some species of elm are not completely killed by O. novo-ulmi, remaining as shrubs or small trees until large enough for the bark to be fed on by Scolytus, when the disease cycle begins again.

27. Dutch elm disease, however, was not the first alien invasive problem affecting trees in Europe. Anecdotal evidence suggests that Phytophthora cambivora and P. cinnamomi were introduced into Europe some 150-200 years ago (Santini et al., 2013).

28. Powdery mildew of oak, caused by Erysiphe alphitoides[3], arrived in Europe from North America in the late 19th or early 20th century, with major impacts on the health of oaks throughout Europe (Mougou et al., 2008).

29. The Italian peninsula has suffered considerably from ingress by invasive pests and pathogens (Santini et al., 2013). Damaging pathogens known to have arrived into Italy from other continents are Cryphonectria parasitica (sweet chestnut canker), Seiridium cardinale (canker of Cupressus spp.) and Ceratocystis platani (wilt of plane; canker stain).

30. The most commonly intercepted genus of pathogens on EPPO lists is Phytophthora, many species of which spread in international trade. Although similar to fungi in ecology, Phytophthora are not related to true fungi; they are Stramenopiles.

31. Recent records indicate that nearly 70 percent of "fungal" interceptions were of P. ramorum, first described in 2001 (Werres et al., 2001), and noted for highly destructive diseases caused on a range of woody plants, including sudden oak death in California and Oregon (Rizzo et al., 2005) and sudden death of Japanese larch in the UK and Ireland (Webber et al., 2010).

32. The spread of P. ramorum in European trade, and the invasion of artificial landscape plantings and forests is a major threat to the integrity of ecosystems dominated by oak and/or Rhododendron family trees and shrubs, particularly in the humid oceanic climate of Western Europe. The wide host range of this pathogen, however, means that it is difficult to predict which plants may succumb to infection in the future.

33. Another Phytophthora species infecting aerial parts of host trees is P. kernoviae. It was found on beech trees showing trunk lesions and dieback in Cornwall, south-west UK, during sampling for P. ramorum (Brasier et al., 2005). Subsequently, old culture collection specimens of an incompletely characterised Phytophthora isolated in New Zealand native forests were shown to be P. kernoviae

[2] http://www.ispm15.com/
[3] Syn. *Microsphaera alphitoides.*

(Ramsfield et al., 2007) ; as P. kernoviae appears to do little damage in the native forests of New Zealand, it is likely that this pathogen is native there.

34. Phytophthora cinnamomi is one of the most destructive pathogens known, with a host range of over 950 plant species, and is arguably the most widespread invasive organism (Hardham, 2005). The potential for invasion and ecological devastation is illustrated by severe Eucalyptus diebacks in forests in Western Australian and Victoria, Australia. P. cinnamomi is widespread in Europe. It is frequent in chestnut forests, sometimes in association with P. cambivora, and in the evergreen oak forests of the southern Iberian peninsula and is spreading throughout the Mediterranean region where Quercus ilex and Q. phellos are common (Camilo-Alves et al., 2013).

35. Phytophthora lateralis emerged in Oregon in the early-mid 20th century, probably imported on infected material from Taiwan (Brasier et al., 2010), and totally altered the Chamaecyparis lawsoniana-dominated forests in the Pacific Northwest. Massive reductions in Lawson cypress timber ensued (Hansen et al., 2000); this pathogen was reported in France in the 1990s (Hansen and Delatour, 1999), and in the UK in 2010 (Green et al., 2013). It is a recognised quarantine pathogen in Europe.

36. An unusual Phytophthora affects alders, leading to dieback and mortality. First isolated from dying Alnus glutinosa in Kent, England in the early 1990s, it has spread through much of Europe where alders grow, probably on trade in alder transplants (Jung & Blaschke, 2004). Phytophthora alni is a hybrid, with P. cambivora as one parent (Brasier et al., 1999), probably originating in Dutch nurseries. Three sub-species of P. alni are recognised, with differing virulence (Brasier et al., 2004).

37. Other Phytophthora affecting European forest trees include P. cambivora, an aggressive and widespread pathogen on a broad range of woody plants, particularly the oak family (Jung et al., 2000), P. quercina, a primary factor in oak decline (Jung et al., 1999), P. citricola, P. cactorum. P. pseudosyringae may be native to northern Europe where populations are genetically diverse (D. Cooke, JHI Dundee, personal communication). P. citricola, P. cactorum, P. cambivora and P. pseudosyringae form a soil-borne complex associated with serious beech decline in Europe (Jung et al., 2005).

38. Phytophthora pinifolia, which causes defoliation of plantation radiata pines growing in Chile (Durán et al., 2008) poses a threat to European pines. Great care is required to avoid importing this species into Europe, where some 50 million ha of pine forests4 may prove vulnerable.

39. Many other important alien invasive pathogens exist. The genus Ceratocystis includes numerous species with similar morphologies (Harrington, 2013), some of which are present in Europe. Tree hosts recorded for Ceratocystis include poplar, oak, plane, cherry and eucalypts, as well as spruce, pine and larch.

40. Ceratocystis platani is a major threat to European plane (Engelbrecht et al., 2004). It has killed hybrid plane in the Italian peninsula since the mid-1930s (Panconesi, 1999), spreading north and westwards into France, where there was a recent decision to remove all hybrid plane along the Canal du Midi, at an estimated cost of EUR 200 million. It is also present in Spain and Switzerland.

41. In Greece in the late 1990s Ceratocystis platani spread into the native range of Oriental plane, Platanus orientalis (Tsopelas and Angelopoulos, 2004), killing all oriental plane trees it infected. As P. orientalis is an important riparian tree, and is relied on for shade in the eastern Mediterranean, these losses are an environmental and ecological disaster.

42. The native range of Platanus orientalis stretches eastwards from Greece into northern Pakistan, and from Hungary southwards to northern Iraq. The pathogen itself arrived in Italy from North America, where it causes relatively little damage to Platanus occidentalis, but has killed many hybrid plane in towns and cities.

43. Ceratocystis fagacearum kills oaks in the eastern states of the USA (Juzwik et al., 2008). Infection leads to rapid death of both red oaks (Erythrobalanus) and white oaks (Leucobalanus; including many

[4] Data from European Forestry Institute

European oaks) dieback, with death taking many years. Measures are in place in Europe to prevent entry of C. fagacearum5, but more stringent regulations are required to maintain the status quo.

44. A further oak wilt threat present in the Far East, Raffaelea quercivorus, is killing oaks in Japan, China and South Korea, and poses a great threat to European oaks if it moves from Asia into Europe (Ito et al., 1998).

45. Dothistroma septosporum (Mycosphaerella pini) and D. pini are highly damaging pathogens that cause Dothistroma (red band) needle blight (DNB) of pine, which have become great problems in Europe over the last 15-20 years (e.g. Brown et al., 2003). Until the mid-1990s, DNB was considered a problem of plantation pines in the southern hemisphere.

46. The presence of DNB on northern hemisphere pines was long recognised, but until the early 1990s, little damage occurred. Since that time DNB incidence has increased exponentially, badly affecting all sub-species of Pinus nigra and causing early defoliation of Scots pine in northern Europe. Lodgepole pine, native to the Pacific Northwest and planted extensively in the UK and western Sweden, has been killed. Recently, defoliation of Pinus brutia was noted in Turkey (Dogmus-Lehtijärvi, 2013, personal communication): one area of over 5 000 ha displays serious symptoms. A similar upsurge in DNB also occurred in the Pacific Northwest; the reasons for this increase in DNB infections is unclear, but may be linked to climate change (Woods et al., 2005).

47. Since 1978, brown needle spot of pines (Mycosphaerella dearnessii), possibly of North American origin, has been recorded in parts of Europe, Asia and Central and South America (EPPO 2008). As with D. septosporum, high humidity in late spring and early summer encourages infection. Infected needles eventually brown and abscise, leading to growth reductions, with particularly damaging effects on young plants. This pathogen is likely to continue spreading in Europe, causing further problems on pines throughout the continent.

48. Further threats to pines in Europe include pitch canker (Fusarium circinatum), pine wood nematode (PWD; Bursaphelenchus xylophilus) and pine processionary moth (Thaumetopoea pityocampa).

49. Fusarium circinatum (teleomorph: Gibberella circinata) is possibly native to the highlands of Mexico (Gordon et al., 1996), but is now present in the USA, Haiti, South Africa, Japan, Korea, Chile and Uruguay (Wingfield et al., 2008). An outbreak has established in radiata pine plantations and native shore pine in northern Spain (Landeras et al., 2005). The disease was reported in France (EPPO, 2005), Italy (Carlucci et al., 2007) and Portugal (Bragança et al., 2009). The host range of F. circinatum includes 57 pines, plus Douglas fir (Wingfield et al., 2008). Most European pine species are susceptible. As the pathogen spreads through infected seed, this particular pathway required close monitoring. Infections on mature trees result in resin bleeding with sunken cankers on branches and main stems; top-dieback results as xylem is blocked by resin. Shoot dieback is frequently seen in the crowns of affected pines. F. circinatum also causes damping-off in forest nurseries, and it is through the planting of asymptomatic infected plants that the disease spreads to forest sites.

50. Bursaphelenchus xylophilus is native to North America, where it is saprotrophic on native pines. It spread into Japan and China in the early 20th century, and is now the worst problem on pines in that region. It was first recorded in Europe when shore pine began dying around Lisbon, Portugal (Mota et al., 1999) in the late 1990s, following which a massive phytosanitary programme was instigated, with extensive felling of pines in affected areas, and in buffer zones around known outbreaks. This process slowed the spread, but dispersal continues and buffer zones are radiating from the initial known outbreak sites.

51. PWD is vectored by long horned beetles, although only Monochamus galloprovincialis is known to carry the nematode so far in Europe. Trees die rapidly after attack in regions where August temperatures average between 20 and 25 ◦C. In cooler regions, B. xylophilus infects pines but lives

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[5] European Union Council Directive 2000/29/EC

saprotrophically, not killing the hosts. Although mortality would not occur in Northern Europe, affected timber would be unsellable, leading to large losses in revenue for forestry.

52. Oak and pine processionary moths are native to Europe, but their range is expanding rapidly (Battisti et al., 2005; Groenen and Meurisse, 2012). Apart from defoliating trees, the caterpillars have irritating hairs which cause skin rashes on humans (Jans and Franssen, 2008). The pine processionary moth (Thaumetopoea pityocampa) is well-known in Mediterranean countries, causing defoliation and serious impacts on growth. This insect has now spread to within a few kilometres of Paris. Oak processionary moth (T. processionea), may be native to southern and central Europe, but has spread widely into Northern Europe (e.g. Jans and Franssen, 2008), causing severe defoliation of oaks; this latter appearance in parts of northern Europe may, however, be a re-colonization after a period of extinction (Groenen and Meurisse, 2012). Climate change is the most likely reason for range expansion of processionary moths, with increasing temperatures enabling northward migrations (Battisti et al., 2005).

53. Ash dieback, caused by Hymenoscyphus pseudoalbidus, is having a large impact on European ash forests. In far eastern Asia, the native range, H. pseudoalbidus is endophytic, infecting foliage of Asian ash during summer, but remaining within the foliage and rachis (petiole). Following abscission, the fungus colonizes the rachis, fruiting in the following summer, when the life cycle begins again (Gross et al., 2013).

54. The pathogen was probably imported into north eastern Poland on ash plants in the early 1990s (Kowalski, 2006), and attacked Fraxinus excelsior. Unfortunately, in both F. excelsior and F. angustifolia, following foliage infection H. pseudoalbidus grows into shoots killing bark tissues and leading to the formation of elongated cankers, severe dieback and, in most trees, death. Seedlings and young trees die rapidly, whereas older trees survive longer, with dieback increasing annually.

55. The rate of spread of H. pseudoalbidus in Europe has been alarming and has led some EU states to ask why greater measures against the spread of the problem were not instigated earlier (Woodward and Boa, 2013).

56. Although individual genotypes of F. excelsior may prove tolerant of H. pseudoalbidus (e.g. McKinney et al., 2012), the additional threat of the emerald ash borer (EAB), Agrilus planipennis must be considered. This beetle, also native to the far east (China, Russia, Japan), arrived in North America approximately 15–20 years ago, probably on untreated pallet boards, and was disseminated into native North American ash populations. Estimates of losses vary, but as many as 100 million ash trees may have died after attack by EAB; the costs of dealing with EAB, in terms of treating trees, felling dead trees and replacements, are estimated to be over US$ 10 billion over a 10 year period (Kovacs et al., 2010).

57. More recently, EAB invaded the Moscow region, killing thousands of Fraxinus pennsylvanica planted as urban trees in the city environs. The insect has spread out of Moscow, to at least 450 km west of the city, near the Ukraine border (Baranchikov, 2013, personal communication). F. excelsior populations stretch continuously from the Ural Mountains in the east, as far west as the Atlantic coast of western Spain: there is nothing standing in the way of EAB spreading throughout the European ash population.

58. European box species, common in some forest shrub layers and important as ornamental plants, are under threat from two recent invasives, blight (Cylindrocladium buxi) and the box pyralid (Cydalima perspectalis). Both organisms are spreading in Europe (Kenis, 2013, personal communication). Anoplophora glabripennis and A. chinensis are commonly intercepted in imports and also outside port areas in Europe (Hérard et al., 2006). Both species were probably brought into Europe from Asia as larvae in wood packaging material (A. glabripennis), or on bonsai and woody nursery stock (A. chinensis). An eradication programme against A. glabripennis was carried out in south-east England in 2012, apparently successfully, with the removal of approximately 1 200 trees around a compound where shipments of slate on wooden pallets from quarries in China were stored.

Eradication programmes are underway in other countries where Anoplophora spp. have been detected, but one population of A. chinensis near Treviso in Italy is now out of control, having already killed thousands of trees and shrubs (Cavagna et al., 2013).

59. The sweet chestnut gall wasp, Dryocosmus kuriphilus, an Asian species, damages sweet chestnut in North America and was found in Italy in 2002 (Brussino et al., 2002); it has spread rapidly to neighbouring countries, despite strict quarantine measures.

60. Several Siberian tree pests have already crossed the Ural Mountains, probably enabled by climate change. The Siberian moth, dendrolimus sibiricus, and the larch gall midge, dasineura rozhkovi, are predicted to expand Westwards where susceptible hosts are present, climatic conditions are favourable and quarantine barriers are limited (Roques, personal communication).

61. Over half the alien plant pathogens reported in the last 30 years were previously unknown to science. Further pests and pathogens have increased in importance due to climate change. Changes in management practices can also favour epidemic development.

V. Mitigation measures

62. Numerous mitigation measures are used in attempts to reduce the probability of introducing alien pests and pathogens via imports of plants and plant products. These vary depending on the pathway and commodity involved.

63. Phytosanitary inspections are mandatory for all consignments of plants and plant products imported into the EU[6]. EPPO publishes lists of regulated pests (Annexes I and II of 2000/29/EC; EPPO A1 and A2 lists). If listed organisms are found, the plants must be treated, returned to the exporter or destroyed. EPPO member states have a mandatory requirement to notify EPPO of any interceptions of A1 or A2 listed pests.

64. The EPPO interception database is a comprehensive list of problems; between 1995 and 2010, approximately 18 000 records were added. One problem identified by EPPO is that not all countries report in promptly; any delays can mean that an invasive organism may be missed in other EPPO states.

65. The authorities intercept many potentially invasive organisms in imports of plants during routine surveys. As only approximately 2 percent are inspected, the discovery rate suggests that extremely high numbers of invasive pests and pathogens are in consignments and some will pass through borders.

66. ISPM15 requires all timber used in woody packaging be pasteurized (56 °C for a minimum of 30 continuous minutes throughout the entire profile of the wood, including the core). When properly implemented, this treatment eliminates most pathogenic microorganisms and all insect pests. Failure to apply the requirements stringently, however, will lead to failures. Compliance is a matter for regulatory authorities.

67. It is difficult to specify a single intervention procedure when dealing with living plants. ISPM36, on “Plants for Planting” published by the IPPC in 2012, specifies a range of measures for reducing the risk of transporting pests and pathogens from the place of production.

68. Particularly notable is the requirement for National Plant Protection Organizations (NPPO) in producing states to approve places of production, plus their management plans and records. Nurseries require access to qualified plant health specialists and have a designated person responsible for all contact with the local NPPO. Plants must be inspected at appropriate times in the production cycle and all pests and diseases, plus any measures taken to manage them, recorded. NPPOs must be notified if

[6] 2000/29/EC

any regulated organism is found. Specifications are provided for regions of high risk for named pests and pathogens.

69. Traceability based on maintaining detailed records at all levels is a key issue in the ISPM. Recommendations are also listed for maintaining plant health, and for any pest management programmes required.

70. Novel initiatives for detecting potential problems on plants imported into Europe include the establishment of sentinel nurseries in exporting countries and collaborations between botanic gardens and arboreta around the world, the latter funded by the EU EUPHRESCO programme. Pests or diseases affecting either sentinel nursery stocks, or plants growing in botanic gardens or arboreta are recorded and passed to central collating authorities. The work will increase understanding of the range of threats to which plants may be exposed in the future, and reduce numbers of unknown pests and pathogens that could be vectored in the plants for planting pathway.

71. Basic treatments are available to reduce risks in the seed pathway, the most common of which is thermotherapy using hot water. Some fungi survive this treatment, however, and methods require more stringent research to determine true efficacy.

VI. Summary

72. In this review, invasive pests and pathogens that pose threats to forestry across Europe were considered. The presence of these problems in Western Europe does not prevent these organisms being rapidly transported to Central and Eastern Europe and causing damage to trees in these regions, as many have already done. Cleary, the overall problem requires a great deal of attention in terms of initially minimizing invasions, reducing the probability of spread, and the development of mitigation methods once a pest or pathogen has been recognized in a "new" region.

73. International laws and treaties7 require each state to provide sufficient phytosanitary capacity at borders to enable inspection of a suitably representative proportion of live plants entering the state territory. For the EU, the current focus lies at international ports, as free trade is maintained between EU states. Legislation, however, does allow certain exemptions from the rules, such as the protected area status which can designate an area or a whole state free of a given pest or pathogen and restrict any trade that may cause incursions of that organism.

74. When a damaging invasive pest or pathogen is confirmed to have entered a given state, measures are adopted to reduce the probability of further spread, including eradication. It is recognized, however, that once an organism has established itself within a territory, eradication is extremely difficult and costly. In fact, very few examples of successful eradication of an invasive pathogen have been reported.

75. The main mitigation methods available to the forest manager once a pest or pathogen has established itself in an area, are alterations to forest management protocols. Monitoring for pest incidence and early felling of affected trees is possible. In extreme situations, it may be necessary to clear fell the affected trees and replant with an unrelated species.

76. Much research and development is required. Improved border security is required, building on data from sentinel nursery plantings and the collaborations between botanic gardens and arboreta will be extremely useful in finding 'new' potential pests and pathogens. Border security must fully exploit state-of-the-art molecular detection techniques, which are extremely sensitive and, when suitably targeted can find many problems. Current chemical detection methods used by military authorities and in anti-drugs trafficking are incredibly sensitive to miniscule concentrations of certain chemicals, and should be adjusted to detect those produced by pests and pathogens.

[7] see: http://www.invasivespeciesinfo.gov/laws/intlglobalconv.shtml

Traceability is another key issue: the origin of a problematic plant must be known, not just within Europe, but to the producing nursery, wherever it is situated.

77. Forest owners, workers and the public in general can be better informed, with educational programmes, and projects such as the Opal Initiative, in which they are trained to look for signs of problems on plants. Forest health days, run by pest and pathogen experts, are useful in this respect, although they are aimed at forestry professionals and there are too few people with this expertise to satisfy current demand.

78. What people want overall is healthy forests. Therefore, it is necessary to focus more on the host plants themselves. Where the origin of a given invasive pest or pathogen is known, the resistance/tolerance of the hosts in that region should be elucidated and then exploited in selection and breeding programmes for European native trees.

79. Training is of the utmost importance in making sure requirements are met. The biosecurity of a region is only as good as the abilities of the phytosanitary inspectors at the weakest ports of entry. Weaknesses could be low levels of inspection due to staffing problems, the huge numbers of plants being imported, lack of appropriate equipment, or poor understanding of phytosanitary issues by the inspectors.

80. Combined training efforts, coordinated by FAO, DG SANCO or EPPO would help to improve standard in these respects. Training can be provided by various agencies, but should be managed and collated by one. FAO would be ideal for this purpose, with unique access to international expertise and a history of supporting the types of multi- and interdisciplinary research and development in forestry required to standardize and disseminate phytosanitary protocols.

81. Responsibility for overseeing these scenarios lies with numerous actors in the field. It is important, however, that the central coordinating roles of EPPO and DG SANCO are supported and maintained. Excellent databases describing known pests and pathogens are available on the world wide web, including the excellent newly developing Plantwise site, run by CABI (www.plantwise.org).

82. If current global trade in plants, with billions of units conveyed between continents is to continue, much greater care must be taken to prevent invasions by damaging pests and pathogens. In the absence of a full commitment to this process, we are likely to see many more ecological and environmental disasters occurring, reducing forest diversity and the biodiversity these important systems support.

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