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LETTER TO THE EDITOR

The biosecurity threat to the UK and global environment from international trade in plants

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Native plant communities, woodlands and landscapes in the UK and across the world are suffering from pathogens introduced by human activities. Many of these pathogens arrive on or with living plants. The potential for damage in the future may be large, but current international regulations aimed at reducing the risks take insufficient account of scientific evidence and, in practice, are often highly inadequate. In this Letter I outline the problems and discuss some possible approaches to reducing the threats.

Keywords: biosecurity, forests, invasive pathogens, natural ecosystems, plant diseases, plant health

Introduction

Over the millennia, complex and often highly specific plant communities, frequently dominated by trees, have evolved on different continents and in different biogeographical zones within each continent. Some of these communities have changed dramatically under human influence, but many pristine areas have survived and, even where the changes have been great, native species may still feature prominently in the local forests or impart a characteristic appearance to the landscape. Both the diversity of the plant communities and individual species within them fascinated early explorer plant collectors such as Joseph Banks, E. H. Wilson and George Forrest, and continue to inspire succeeding generations of scientists, botanists and horticulturalists. Elegant gardens and parks, comprising assemblages of exotic and native plants, have been created and rank highly in the cultural heritage of many countries.

As native, locally adapted plant communities evolved, guilds of unique pathogenic microorganisms, viruses and viroids evolved in association with them. Today these organisms often cause little noticeable damage to their host plants, having developed a natural balance through co-evolution. However, major problems may arise if a pathogen escapes – or is introduced – to another region of the world where the native plants have little resistance and the pathogen has eluded its natural enemies. Such events can trigger damaging disease episodes that may also have long-term negative impacts on the environment, economy and cultural heritage. Movement of plants and plant products between biogeographical zones by human activities is now generally accepted to be the primary mode of introduction of exotic pathogens and pests. There is therefore a tension, in terms of risk to the cultural and natural environment, between the conservation and environmental responsibilities of horticulturalists, foresters, garden designers and landscape architects and their desire for novel material or (these days) cheaper plants and instant trees.

Invasive pathogens have been causing damage to native plant communities, woodlands and landscapes on a global scale for over a century. The root pathogen *Phytophthora cinnamomi*, able to infect more than 3000 plant species (Hardham, 2005), has probably been spreading around the world for over 150 years from its presumed centre of origin within south east Asia (Table 1). It is now a major threat to some of the world's richest plant communities in south west Australia and continues to damage forests and other ecosystems world-wide. Starting around 1910 an introduction of *Cryphonectria parasitica*, the cause of chestnut blight indigenous to China and Japan, resulted in the virtual destruction of American Chestnut forests (*Castanea dentata*) through most of their natural range in the USA within thirty years (Table 1). Subsequently it was introduced to Europe and affected native *C. sativa*. *Ophiostoma ulmi*, the pathogen responsible for the first Dutch elm disease pandemic, was initially observed in Europe around 1911 and caused significant losses (Table 1). Around 1917 it was taken to North America on diseased

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Table 1 Early examples of invasive pathogens causing damage to forests, natural environments and horticulture worldwide

Disease and organism	Hosts and symptoms	Probable mode and date of introduction	Possible geographic origin	Consequences/threat
Cinnamomi root disease or 'Jarrah dieback' *Phytophthora cinnamomi*[a]	> 3000 trees, woody ornamentals, herbs Root and collar necrosis	Imported plants and soil, 1800s–1900s. Multiple onward introductions on infested planting stock.	South-west Pacific area (Celebes, Papua New Guinea)	Enormous and continuing environmental and economic damage to nurseries, trees, shrubs, ecosystems worldwide. Caused heavy mortality of native *Castanea* in forests of southeastern USA and southern Europe, 1940s; mortality and dieback of trees and understory in forest ecosystems in west and east Australia since 1950s. Currently threatens the future of some of the worlds richest plant communities in southwest Australia. Epidemic in UK/European nurseries 1960s–70s (*Chamaecyparis, Rhododendron, Erica*). Associated with current mortality of cork oak (*Quercus suber*) in Spain, Portugal and of oaks in Mexico.
Chestnut blight *Cryphonectria parasitica*[b]	Native European and North American chestnuts Bark canker	Imported chestnut plants, 1908–1940s	Japan, China, Korea	Virtual elimination of native American Chestnut in northeastern USA. Mortality of native chestnuts across southern Europe. Still spreading e.g. via the nursery trade.
Dutch elm disease (first epidemic) *Ophiostoma ulmi*[c]	Native elms Wilt	Imported elm logs *ca.* 1910–1920	Eastern Asia	Death of *ca.* 30% of UK elms between 1920–1940. Similar losses across Europe. Heavier losses in North America. Replaced by *O. novo-ulmi* (Table 2).
Cedar root rot *Phytophthora lateralis*[d]	*Chamaecyparis lawsoniana* Root and collar rot. Rapid death	Imported *Chamaecyparis* plants, 1920s	Taiwan, China, Japan?	Spread from infested nurseries along the US Pacific northwest coast 1920s–50s. Now invading watersheds in southern Oregon and northern California causing 100% mortality of 40 m tall *C. lawsoniana* in its native range. Major threat to ornamental *C. lawsoniana* in UK/Europe. Arrived at least twice in European nurseries: France in the 1990s and the Netherlands in 2004. Presently considered eradicated.

Table 1 *Continued*

Disease and organism	Hosts and symptoms	Probable mode and date of introduction	Possible geographic origin	Consequences/threat
Canker stain of plane *Ceratocystis platani*[e] (Formerly *Ceratocystis fimbriata* var. *platani*)	*Platanus* spp. Bark lesions, dieback and wilt	Imported packing material or planting stock, 1940s	North America	Significant losses of *Platanus* spp. as urban shade and amenity trees in Italy and France where it arrived from the USA in the 1940s. Can be spread in infested soil. Considered a serious threat to UK and many other European countries.
Fireblight *Erwinia amylovora*[f]	Rosaceous trees and fruit trees Foliar necrosis, shoot wilt, stem cankers	Imported planting stock, 1950s. Multiple onward introductions on infected planting stock	USA	Dieback and mortality of susceptible native and exotic trees (e.g. *Crataegus*). Under quarantine regulation in UK and Europe.
Strawberry redcore/raspberry collar rot *Phytophthora fragariae* vars. *fragarie* and *rubi*[g]	Cultivated strawberries and raspberries Root and collar rot	Imported planting stock	North America?	Serious economic losses in strawberry and raspberry plantations in Europe and North America.
Chrysanthemum white rust *Puccinia horiana*[h]	Chrysanthemum Dieback	Imported nursery stock 1960s	China and Japan	Control problem in nursery trade in western Europe including UK; frequently damaging in gardens. Threat to North American horticulture.

Selected references:

[a]Crandall *et al.*, 1945; Zentmyer, 1980; Shearer *et al.*, 1991; Hardham, 2005; Brasier *et al.*, 1993; Brasier & Scott, 1994; Erwin & Ribeiro, 1996; Haltofova *et al.*, 2005; Moreira & Martins, 2005.

[b]Heineger & Rigling, 1994; Anagnostakis, 2000; Wang *et al.*, 2004.

[c]Peace, 1960; Gibbs, 1978a.

[d]Zobel *et al.*, 1985; Hansen *et al.*, 1999; Hansen *et al.*, 2000; Woodhall & Sansford, 2006.

[e]Panconesi, 1999; Http://www.eppo.org/QUARANTINE/fungi/Ceratocystis_fimbriata_platani/; Baker Englebrecht & Harrington, 2005.

[f]Jock *et al.*, 2002.

[g]Erwin & Ribeiro, 1996.

[h]Http://www.eppo.org/QUARANTINE/fungi/Puccinia_horiana/.

elm logs. The current, second Dutch elm disease pandemic has resulted from the introduction of another species of fungus, *Ophiostoma novo-ulmi*, a much more aggressive pathogen than *O. ulmi*. To date it has killed some 30–50 million elms in the UK alone (Table 2).

Since the 1990s a stream of invasive pathogens potentially damaging to trees, natural ecosystems and horticulture has been entering the UK. Notable examples include the alder dieback pathogen *P. alni*; the 'sudden oak death' (SOD) pathogen *P. ramorum*; the similar *P. kernoviae*; horse chestnut bleeding canker (*Pseudomonas syringae* pv. *aesculi*) and box blight (*Cylindrocladium buxicola*) (Table 2). Indeed in a list of 234 pathogens first recorded in the UK between 1970 and 2004 (Jones & Baker, 2007), *ca*. 67% were associated with wild or ornamental plants. Organisms like these represent a significant threat both to the UK natural environment and our horticultural heritage. However this threat, and the effectiveness of international procedures in preventing such invasions, has been scarcely debated in scientific or socio-political circles.

To highlight the issue, at the invitation of the US Department of Agriculture Forest Service, the author presented a critique of current international plant health protocols at the First International Symposium on Sudden Oak Death, Monterey in 2002 (Brasier, 2004, 2005; and see also Ingram, 2005). It emphasised that, to a large extent, the regulations themselves were contributing to, rather than alleviating, the problem. Sudden oak death, caused by *P. ramorum*, was considered to be symptomatic of the issues. In many ways it now appears emblematic (Brasier, 2007). This Letter is an elaboration of these views. I am not qualified to put the case for the plant trade and have not attempted to do so. My intent here is to outline the scientific case, enhance awareness among fellow scientists, challenge the *status quo* and stimulate further debate among plant pathology professionals, plant health regulators and policy makers. This inevitably means crossing the boundary at times between science and what may loosely be termed politics and opinion; not something I am altogether comfortable with, but unavoidable given the nature of the problem. The views expressed are solely my own, based on 40 years investigating the behaviour and impact of forest pathogens.

Although inappropriate importation of timber and dunnage has been of major importance in the introduction of some pathogens (witness the history of Dutch elm disease), and still could be for others, it is my view that commercial movement of living plants, together with unlicenced specialist or amateur plant collecting, is now the pathway of highest risk. Furthermore, while the arguments presented here concentrate mainly on the threat to the UK, the problem is of course a global one. The basic arguments are not only relevant to the situation across Europe, but also apply to most other parts of the world. Indeed they are highly relevant to the future security of relatively unspoiled ecosystems in developing countries. Many of the arguments made here are also highly relevant to pathogens of agricultural crops and to invasive plant pests.

Risk arising from international plant health protocols

In response to expanding world trade and concern over spread of plant diseases, international protocols were set up in the 1950s via the International Plant Protection Convention (IPPC) of the FAO and World Trade Organisation (WTO) rules to regulate the process of trade and to reduce the likelihood of accidental introductions of organisms of phytosanitary concern. Today, protecting a state from invasive plant pathogens is often referred to as plant biosecurity. In most of Europe plant biosecurity protocols are applied via the plant health regulations of the European Union (EU). These broadly follow the Sanitary and Phytosanitary Agreement (SPS) of the World Trade Organisation as consolidated in the 1990s. In the UK, EU regulations are usually regulated and operated to a high standard (plant health teams within the Department for Environment, Food and Rural Affairs (Defra) and the UK Forestry Commission (FC) have many skilled officers and scientists). Equally, many involved in the UK plant trade aim to adhere to the protocols and to minimise the risks involved. However, in the light of recent developments in the plant trade itself and of regular breaches of UK plant biosecurity (*cf*. Table 2; and Jones & Baker, 2007), some tenets underlying the protocols must now be viewed as outdated and seriously flawed.

Problems with identifying the risk

The SPS Agreement of the World Trade Organisation aims to minimise any disruption to trade that plant health regulation might impose. The intention is to ensure that global commercial trade in plants is not unduly hindered by artificial barriers; apparently without question as to whether such international trade is a fundamentally sound or unsound process based on scientific and global environmental grounds.

The protocols principally involve the production of lists of named harmful organisms. These tend to concentrate on organisms likely to affect widely grown agricultural commodities and timber. The case for inclusion of each organism must be founded in 'sound science'. By definition, all 'unlisted' organisms remain unregulated. However, the lists principally comprise pathogens that have *already* escaped from their geographical centres of origin and started to cause overt disease in another part of the globe. Many of these 'newly escaped' organisms were previously unknown to science and were not therefore on any international list before they escaped (Brasier, 2005). Dutch elm disease, sudden oak death, phytophthora disease of alder, and box blight in the UK (Table 2) are all examples of major disease episodes caused by previously unknown pathogens.

Based on these and similar examples, and on estimates that only 7–10% of all fungal species having so far been identified (Hawksworth, 2001; Crous & Groenwald, 2005), some 90% of pathogens may be unknown to science. The number of unknown species of *Phytophthora*, for example,

Table 2 Examples of recently introduced invasive pathogens in forests, natural environments and horticulture in the UK

Disease and organism	Hosts and symptoms in UK	Probable mode and date of introduction to UK	Possible geographic origin	Consequences/threat
Organisms unknown to science before major outbreak				
Dutch elm disease (second epidemic) *Ophiostoma novo-ulmi*[a]	Native elms Wilt	Imported Canadian elm logs *ca.* 1970	Eastern Asia	Massive pandemic across northern hemisphere. Initial death of *ca.* 28 million mature elms in UK 1970–90 and subsequent death of *ca.* 20 million young elms. Comparable major losses across Europe, central Asia, North America.
Dogwood anthracnose *Discula destructiva*[b]	*Cornus* spp. Dieback	Imported American nursery stock, 1995	Asia	Damaging to ornamental *Cornus* cultivation in UK/ Europe. Major losses of native *Cornus* in USA. Threat to Asian *Cornus* spp. unknown.
Box blight *Cylindrocladium buxicola*[c]	Box (*Buxus* spp.) Shoot dieback	Imported nursery stock 1990s	Unknown	Rapid spread. Threatens rare native box. Damages ornamental box hedges in formal gardens.
Phytophthora disease of alder *Phytophthora alni*[d] (including 'PAA', 'PAU' and 'PAM' subspecies)	*Alnus* spp. Bleeding lesions of stem and collar	Imported European nursery stock 1990s	Newly evolved interspecific hybrids, in a European nursery?	The highly aggressive *P. alni* subsp. *alni* (PAA) now spreading and causing mortality of native riparian alders across UK and western Europe. Threat to North American and Asian alders unknown.
Oak root rot *Phytophthora quercina*[e]	Oak (*Quercus robur*) Loss of feeder roots	Imported nursery stock?	Unknown, via Europe?	Widespread and established in UK, Europe. Population structure indicates introduction. Interacts with stress factors-probably contributes to oak declines. Threat to North America and Asian oaks unknown.
Ramorum dieback (sudden oak death) *Phytophthora ramorum*[f]	Rhododendrons, viburnums, beech, other trees and ornamentals Shoot dieback and stem bleeding lesions	Imported European nursery stock 1990s	Eastern Asia? via Europe	Widespread in commercial nurseries. Spreading in woods and public gardens in Cornwall. Uncertain long term threat to UK trees, *Vaccinium* moorlands, gardens, UK nursery trade. Spreading in European nursery trade (currently under regulation). Extensive environmental damage in California.
Kernoviae dieback *Phytophthora kernoviae*[g]	Beech, stem bleeding lesions. Rhododendrons, shoot dieback and mortality. *Magnolia* spp., leaf spots	Imported nursery stock 1990s	Asia, via New Zealand?	In Cornwall, spreading, causing dieback and mortality of *Rhododendron ponticum* and beech. Recently recorded on native bilbury, *Vaccinium myrtillus.* Threat to National Magnolia Collection? Long term threat to UK environment uncertain. Threat to European, American, Asian, Australasian ecosystems unknown.

Organisms previously known to science				
Holly shoot blight *Phytophthora ilicis*[h]	Holly (*Ilex* spp.) Shoot dieback, defoliation, stem bleeding lesions	Imported nursery stock 1980s?	Unknown, Asia?	Has become widespread since 1980s on native and ornamental holly. Very active locally in Cornwall. Threat to Asian *Ilex* unknown but causes severe damage to some Chinese *Ilex* spp. in UK.
Red band needle blight *Dothistroma septosporum*[i]	Corsican pine (*Pinus nigra* ss. *laricio*) Needle death, defoliation, crown dieback	Imported nursery stock 1950s; re-imported, 1990s?	Unknown, via Europe?	Explosive outbreak since *ca*. 1997 with substantial and increasing dieback and mortality. Major threat to future of Corsican pine plantations in UK. Serious damage to other pine species in British Columbia, New Zealand and elsewhere.
Horse chestnut bleeding canker *Pseudomonas syringae* pathovar *aesculi*[j]	Horse Chestnut Stem bleeding canker	Imported European nursery stock or seed, 1990s?	India?	Rapid spread. Mortality and dieback. Increasing threat to specimen plantings and historic avenues across UK. Spreading rapidly across Europe. Threat to North America unknown. Has been found on *Aesculus indica* in India.
Catalpa powdery mildew *Erysiphe elevata*[k]	*Catalpa* sp. Leaf necrosis and defoliation	Imported nursery stock, 1990s?	Unknown, via North America?	Spreading on established ornamentals in parks, gardens.
Impatiens downy mildew *Plasmopara obducens*[l]	*Impatien*s spp. Foliar necrosis	Imported nursery stock or contaminated seed, 2002–3	Central America	Threat to *Impatiens* cultivation in UK and elsewhere.
Heuchera rust *Puccinia heucherae*[m]	*Heuchera* spp. Foliar necrosis	Imported nursery stock, 2004	North America	Damaging to ornamental *Heuchera* cultivation in UK and elsewhere.
Camellia petal blight *Ciborinia camelliae*[n]	*Camellia* spp. Petal necrosis	Imported nursery stock, 1990s?	Japan via New Zealand or USA?	Spreading. Threat to National Camellia Collections.

Selected references:
[a]Brasier & Gibbs, 1973; Gibbs, 1978b; Brasier, 1996; Brasier & Kirk, 2000; Paoletti *et al*., 2006.
[b]Dougherty & Hibben, 1994; Tufts, 1995; Http://www.eppo.org/QUARANTINE/Alert_List/fungi/DISCDE.
[c]Sellar, 1995; Henricot & Culham, 2002.
[d]Brasier *et al*., 1999; Streito *et al*., 2002; Gibbs *et al*., 2003; Jung & Blashke, 2004.
[e]Jung *et al*., 1999; Brasier & Jung, 2003; Jönsson, 2004; Cooke *et al*., 2005.
[f]Brasier *et al*., 2004; Rizzo *et al*., 2005; Sansford *et al*., 2003; Ivors *et al*., 2006; Webber, 2007.
[g]Brasier *et al*., 2005; Sansford *et al*., 2005.
[h]Strouts & Winter, 2000.
[i]Brown *et al*., 2003; Woods *et al*., 2005.
[j]Webber *et al*., 2007; Http://www.forestresearch.gov.uk/bleedingcanker.
[k]Cook *et al*., 2004; Vajna *et al*., 2004.
[l]Lane *et al*., 2005.
[m]Henricot *et al*., 2006.
[n]Cook, 1999; Http://www.defra.gov.uk/planth/pestnote/camellia.htm.

arguably the world's most destructive group of plant pathogens, may be between 100 and 500 (Brasier, 2008). As indicated in the introduction, Darwinian evolution predicts that, being adapted to and co-evolved with their hosts, many of these pathogens are unlikely to do noticeable damage in their native ecosystems, and so are less likely to be detected. Thus a previous survey in the Himalayas led to the discovery of a third species of Dutch elm disease fungus, unknown to science, highly aggressive to European elms, yet apparently benign on Himalayan elm species (Brasier & Mehrotra, 1995).

Both practical experience and predictive science, therefore, dictate that current SPS protocols are flawed. First, because they tend to concentrate on only the most noticeable escapees and so come into effect only after a problem is identified. Second, because they may cover only a minority of the organisms which pose a threat. Moreover, since they largely ignore the risk from benign, co-evolved, unescaped organisms, the protocols may ignore the risk from 90% of potential pathogens. In this sense, therefore, they are non-Darwinian. Rather than focus on already escaped organisms, it is paramount to concentrate on scientific facts and principles which indicate that pathogens need to be contained within their centres of origin; not distributed around the world and subject to regulation only when causing visible damage beyond their natural range.

Under current protocols, once an organism is recognised as a potential threat the scientific case for its regulation or listing is usually based upon a 'Pest Risk Analysis' or PRA. A PRA is typically initiated in response to a severe new disease episode occurring in some part of the world. Usually this will involve a newly escaped or an emerging pathogen. The PRA is developing into an acceptable tool for summarising current risk information on well-characterized pathogens. It is also proving useful for identifying what extra research is needed to better evaluate a newly emerged threat. Indeed it often highlights the fact that insufficient information is available on the potential susceptibility of local hosts to make a meaningful assessment of risk (*cf*. oak wilt, caused by *Ceratocystis fagacearum*; Gibbs, 2003a). In addition, a PRA can be a valuable tool for assessing what action might be undertaken to eradicate or reduce the rate of spread of a new invasive. However, PRAs cannot cover the multiplicity of unknown organisms that may pose a threat. There was no PRA in existence for *O. novo-ulmi*, *P. ramorum*, the alder *Phytophthora*, *P. kernoviae*, or *Cylindrocladium buxicola* (Table 2) prior to their arrival, i.e. until it was too late to prevent them escaping their origin. As with much current international plant biosecurity protocol, the PRA process tends to be reactive, slowing the spread of the fire rather than preventing its ignition.

In addition, many dangerous pathogens identified as a threat in one part of the world still do not have PRAs, or are not on regional quarantine schedules, in countries or areas where they might cause damage. The 'new' Japanese oak wilt pathogen *Raffaelea quercivora*, implicated in heavy oak mortality in Japan since the 1990s (Ito *et al*., 2003; Kubono & Ito, 2004), might be a serious threat to UK and European oaks but is not on European quarantine schedules. Conversely *P. alni* subsp. *alni* (PAA), killing alders across Europe for over a decade (Table 2), could be a major threat to the alders of North America but, although subject to a risk assessment by USDA, it has yet to be scheduled by APHIS. There are many such examples. The process of listing such organisms on schedules is often slow, perhaps too slow to be sufficiently effective given the speed of modern international trade; and, with so many emerging outbreaks of pests and pathogens worldwide, the system may be in danger of being overwhelmed, effectively reduced to dealing with already damaging organisms, frequently too late for effective mediation.

Growing recognition of the complex breeding system of pathogens and improvements in taxonomic tools have made classical concepts of fungal species largely obsolete (*cf*. Brasier, 1997; Harrington & Rizzo, 1998). The fact that current regulations tend to operate at the species level therefore needs to be re-examined. In future, PRAs and regulatory schedules may need to specify genotypes as well as species. Many invasive pathogens enter initially as a single genotype or clone; and sometimes the invasive clones are of only a single sexual mating or compatiblity type. *Phytophthora cinnamomi*, *P. ramorum* and *O. novo-ulmi* (Tables 1 and 2) are all examples of this. Significant additional risk to the host or environment may be posed by the arrival of new genotypes, or of the 'missing' sexual compatibility type (*cf*. Brasier *et al*., 2006; Ivors *et al*., 2006). Therefore, entry of additional genotypes may also need to be prevented.

An additional problem is that international protocols tend to assume that the target host for an organism will be a host taxonomically related to that attacked in the country of source. This assumption usually also defines the 'risk pathway'. However, once arrived in a favourable environment, an invasive pathogen may spread to an entirely new suite of hosts. *Phytophthora ramorum*, for example (Table 2), was most probably introduced into North America, the UK and Europe on ornamental rhododendron (rhododendron may or may not be its host in its centre of origin). Once introduced, in addition to rhododendron, it has already attacked > 100 native and non-native trees and shrubs in the USA and > 30 in the UK and Europe. *Phytophthora cinnamomi* is likely to have a limited host range where it is indigenous, but it now attacks thousands of host species worldwide (Table 1). Perhaps this is also the future for *P. ramorum*? Without extensive host range testing and, where appropriate, investigation of potential new vectors, no safe assumptions can be made about the likely host range or aggressiveness of a pathogen.

Problems with inspection and implementation of regulations

Plants moving in trade are covered by a phytosanitary certificate (or a plant passport within the EU). By using this certificate, the authorities in the exporting country are stating that there is no legal bar to the movement of the material and that it is free from named noxious pests and diseases. However, the second part of the statement is usually based on a simple visual inspection specifically for symptoms of the listed organism(s). Inspections conducted at the port of import or by the recipient nursery are usually also visual, using the same criteria. Moreover, plants are normally containerized and, realistically, with large import volumes, often only a small proportion of plants can actually be inspected. APHIS in the USA claims to inspect only about 2% of imported stock.

Examples of consignments of trees or ornamentals arriving in the UK having a 'pest-free' export certificate but, nonetheless, being visibly infested with pests are becoming all too frequent. There have been many cases from Europe and from elsewhere. 'Passported' *Viburnum* stock has entered the UK from the EU visibly infected with *P. ramorum* (Table 2). Exotic *Acer* spp. and tree ferns with plant health certificates have recently arrived from the far-east and Australasia visibly infested with non-native microfauna and, presumably therefore, many unseen non-native microbes. Moreover, in practice, inspections for viruses, phytoplasmas, bacteria, or for microscopic fungal and oomycetous pathogens such as *Phytophthora* spp. cannot be conducted adequately by visual screening alone, since these organisms may often be present in the form of largely invisible propagules, mycelium or spores.

Given the limitations of visual inspection it is reasonable to assume that in some countries, export procedures, import controls or 'within state' inspection protocols are less than fully effective. Nonetheless in the EU the 27 states are treated as a common regulatory zone. Assuming import inspection protocols across the 27 states will also be variable, then control of plant imports into the Union will inevitably operate at the level of the weakest state (*cf*. Brasier, 2005)[1] and, once EU biosecurity is breached, responses by individual states may also be patchy. Furthermore, EU member states do not always report, or may delay reporting, incursions even of high-risk organisms. In the 1990s, for example, the extremely dangerous conifer root pathogen *Phytophthora lateralis*, invasive in southern Oregon and northern California, USA (Table 1), was discovered at two nursery-associated locations in France. The affected stock was quickly destroyed and the incursion publicized, but to my knowledge the interception was not officially reported to the EU Standing Committee on Plant Health. Pitch canker pathogen of pine, *Fusarium circinatum*, very damaging in the USA, is widely believed to have been invasive, but unconfirmed, in Spain in 1998 but was not formally declared until 2004 when it was confirmed present both in nurseries and forests (Landeras *et al*., 2005).

Other forms of non-compliance can also be a problem. The sudden oak death pathogen *P. ramorum* (Table 2) probably first arrived in Europe as a single introduction around 1990. Subsequently it spread rapidly around Europe via the nursery trade. Following emergency measures in 2000, EU states were instructed in 2004 to survey their nurseries and the natural environment annually for *P. ramorum* and to supply the annual returns. Not all member states have complied, and complying member states have received *P. ramorum*-infected stock from non-compliant states. Such events undermine the EU regulatory process, undermine the resolve of complying countries to adopt EU regulations, and put other countries' ecosystems and nurseries at risk.

Often there is little hard epidemiological data on the local dispersal range of a newly invasive pathogen, resulting in a scramble for scientific information (Brasier, 2007). This inevitably leads to uncertainty over how to regulate nurseries within infected areas. Until recently, nurseries in the UK within the regulated *P. kernoviae* infection zone in south west England continued to be allowed to export susceptible plants as long as they were visibly healthy; in the same way, conifer nurseries in locations with plantation trees infected with red band needle blight (Table 2) continued to produce and distribute susceptible conifer stock to other parts of the UK. Given the epidemiological uncertainties, and given that infections can remain asymptomatic (see below), even such carefully regulated movement must present a risk.

The above inspection-related problems are broadly logistical. Others are broadly biological. For example, it has recently become apparent that foliage and fruits of *Phytophthora*-infected plants can be symptomless due to invisible or systemic infections, yet the pathogen may be actively sporulating on them, as recently demonstrated for *P. ramorum* and *P. kernoviae* (Table 2) on multiple host species (Denman *et al*., 2006, 2007). In 2006, *Grevillea* plants purchased in Italy by the UK Royal Horticultural Society (RHS) as visibly healthy were subsequently found to be infected with *P. niederhauserii*, a newly described *Phytophthora* not previously recorded in the UK (G. Denton & B. Henricot, RHS Garden, Wisley, Surrey, UK, personal communication). Such observations have profound implications for the effectiveness of visual inspection. In addition, exporting nurseries often make extensive use of pesticides and synthetic chemical feeds with the aim of controlling pests and pathogens and providing healthy-looking plants. Widespread use by nurseries of *Phytophthora*-active chemicals, such as phosphonates, that are fungistatic but not fungicidal is a good example.[2] Unfortunately the

[1]In relation to the EU, it should be noted that, in biosecurity terms, a considerable geographical advantage was possessed by the UK and Ireland up to the 1970s by virtue of their island status i.e. in being physically isolated. This geographical advantage was comparable to that of New Zealand and Australia; and both the latter countries have reinforced their geographic isolation by imposing what many would regard as among the world's toughest plant import regimes. It can be argued that much of the comparable advantage for the UK and Ireland was diluted in the interest of wider trade when the two countries joined the EU in the 1970s.

[2]24% of a European-wide sample of 77 *P. ramorum* isolates collected in 2004 were already resistant to the anti-*Phytophthora* chemical Metalaxyl Gold (S. Wagner, BBA Germany, personal communication).

effect can be to suppress but not kill the pest or pathogen. (Unscrupulous nurseries could also use these chemicals to delay symptom development). Again the result may be healthy looking but infected plants, which may then move within the trade, the pathogen breaking out months or years later.

Infestation of potting media or unsterile soil in pots or around roots is a major but even less apparent risk factor. Potting media of nursery grown plants can be contaminated with *Phytophthora* and *Pythium* species and with plant pathogenic nematodes at significant frequences (Davison *et al*., 2006). Resting spores of these oomycetes are commonly present in soil, as are those of many other pathogens (including *Ceratocystis platani*, mentioned below). The many unrecorded *Phytophthora* species that undoubtedly exist in different parts of the world (*cf. P. ramorum* and *P. kernoviae*, Table 2) are as likely to arrive in infested soil as on infected plants. Nurseries in some parts of Europe are already infested with multiple exotic *Phytophthora* spp. not yet recorded in the UK, some of them (e.g. *P. palmivora*) even of tropical origin. The common practice of importing plants 'bare rooted' does not remove the risk entirely: infected roots will usually contain resting spores. Resting spores of *P. ramorum*, for example, have recently been found in symptomless roots of foliage-infected rhododendrons (Riedel, 2008). Whether dealing with unknown or even known pathogens, therefore, importation of bare rooted plants may engender a false sense of biosecurity.

Lack of penalty for biosecurity breaches

At present, neither regulators nor the trade are likely to be held to account for damage to the environment resulting from biosecurity breaches on their watch, i.e. the operation of a shared responsibility principle (a modern, somewhat bureaucratic evocation of the Keynesian 'polluter pays' principle) is largely missing from the market process: there is no cost-feedback on the system (Brasier, 2005). Thus, in the UK/Europe there appears to be a reluctance to prosecute traders or member countries that knowingly or unknowingly breach regulations. A frequently cited reason is the difficulty in obtaining detailed evidence after the event, due to the time-lag prior to detection. A consequence is that there is little financial or other incentive to the trade to make the process more effective, and little career incentive for regulators or politicians to do so. The media do not help. Journalists may readily present headlines on 'doomsday threats' to our forests or gardens, but they do not usually pursue the underlying cause of a plant biosecurity failure. There is a credibility gap regarding regulatory enforcement, and a related gap in public and media awareness.

Equally, there are few documented regulatory analyses of the causes of biosecurity failure. Thus, there are few official investigations into pathways of pathogen arrival; and few if any official investigations into the geographic source of a previously unknown pathogen. For example, by what pathways did *P. lateralis* (Table 1) arrive, at least twice, in Europe? How did box blight and *P. kernoviae* (Table 2) enter the UK and from whence have they originated? Where has *P. ramorum* come from? How did *P. ramorum* (Table 1) get into Europe? How long was it in the UK/Europe before it was detected and why did it take so long before its presence was officially recognized?

Similarly and with hindsight, despite the catastrophic loss of some 30–50 million elms and an investigation by the Parliamentary Ombudsman into its northward spread (Clothier, 1980), there was no official analysis and report by the relevant UK authorities (such as the Forestry Commission, charged with protecting the health of Britain's trees) into the plant health lessons to be learnt from the second Dutch elm disease pandemic (*O. novo-ulmi*, Table 2). The FC, to its credit, did respond by commissioning reviews of some dangerous North American tree pathogens such as oak wilt. Official retrospective analysis of the plant health lessons would be useful for many of the examples listed in Table 2. Without such analyses, information potentially critical to improving and updating plant health policy and legislation is rendered unavailable. Such information would also help raise awareness within the trade, other plant handling professionals, the public and the media. It is surely in everyone's interests that such questions are asked and the lessons publicized.

A requirement for effective implementation of a shared responsibility process is knowledge of the gross cost of security breaches. However, few if any official, authoritative investigations have been conducted into the accumulative environmental, social and trade costs of invasive pathogens damaging to the environment; such as the initial and continuing costs to the nation of the current Dutch elm disease pandemic (see below). Unfortunately, it is the UK environment and the UK taxpayer that will pay for this damage. Some formulae are available for such calculations, though undoubtedly this is an area where further research is needed (Waage *et al*., 2005). Without such information, it is difficult for regulators or scientists to justify the costs of remedial action to politicians, particularly in relation to long-term ecosystem impacts. Therefore, the 'ownership' of the problem may remain vague. The consequences are delay or lack of remedial action by regulators and, again, a public and media that remain uninformed.

Modern plant trade is enhancing the risk

When international protocols were established in the 1950s, the global trade in rooted planting stock was limited, often involving small quantities of plants for local propagation. More recently, international movement of nursery stock and cut flowers has exploded into a high volume industry. Since 1992 the total UK annual plant imports from abroad have more than doubled in commercial value, from about £370 million sterling to about £900 million. Of this, about 31% is comprised of rooted plants: a substantial proportion of the plants sold in UK nurseries and other retail outlets is now directly imported. On present trends, these imports are likely to expand considerably.

A larger volume of movement is likely to bring a larger risk. The trend is also towards globalization. 'Certificated' plants are now increasingly being shipped into the UK and Europe from exotic places such as China, Japan, Australasia, Africa and South America, enhancing the risk of introducing known and unknown pests and pathogens from these areas into the UK.

Other dangerous new trade practices are emerging that are also likely to increase the risk of importing pathogens. One is 'ex-importing', the exporting of young stock from the UK to southern Europe (or even the southern hemisphere) to over-winter or grow-on over several seasons to gain extra growth, followed by their re-importation. Another is 'rebadgeing', the importing of plants from outside Europe, or from another EU country, and their subsequent relabelling by the nursery in the importing EU member state.

Since the 1980s, centres of intensive nursery cultivation have developed in some parts of Europe to supply plants at low cost and high volume to the EU and to other parts of the world. It is often acknowledged by European trade and plant-health specialists in private (but few do so in public) that nurseries in at least two EU countries prominent in plant production (including one defaulting in its survey returns for *P. ramorum*) are infested with many exotic and endemic pathogens (*cf. P. palmivora* cited above). Presumably this is often a result of 'unsafe' importation of plant material from overseas. As a consequence such countries, and the EU as a whole, will act as arrival and distribution centres for pathogens, not only to other parts of the EU but to other parts of the world.

The situation with *Phytophthora* spp. again illustrates the point. A survey in northern Germany in 1995[3] revealed a total of 13 different species in the irrigation water at three nurseries (Themann *et al*., 2002). At a nursery in Bavaria in 2002,[3] five different species were obtained from soil around a single open-planted alder seedling (T. Jung, LWF, D-85354 Freising, Germany, personal communication). Similar infestation levels were found in many alder, oak and beech nurseries in both Germany and Austria (Jung & Blashke, 2004; Jung *et al*., 2008). Clearly use of such material is likely to result in diseased plantings. Since joining the EU, Poland has seen a procession of new *Phytophthora* spp. appearing in its nurseries. Some of these are now being found in its forests and natural ecosystems (Brasier, 2003; Orlikowski *et al*., 2006). A recent survey in Majorca, Spain[3] has revealed 17 different *Phytophthora* spp. across 36 nurseries. Most of them are not recorded from the local 'natural environment' and therefore represent a potential environmental threat (E. Moralejo, IMEDA, 07190 Esporles, Spain, personal communication). Are we therefore planting *Phytophthora* spp. as well as planting trees and shrubs?

Nurseries in Europe and elsewhere infested with multiple species of the same pathogen genus are potential breeding grounds for evolution of new, interspecific hybrids that are more aggressive, or have host ranges unknown in the parent species (Brasier, 1995, 2000, 2001). A prominent example is the swarm of new *Phytophthora* interspecific hybrids (*P. alni*, Table 2) killing native alders across Europe, including the UK, and considered an emerging natural disaster in southern Bavaria and northern France (*cf*. Streito *et al*., 2002; Streito, 2003; Jung & Blashke, 2004). A strong link has now been established between the spread of *P. alni* subsp. *alni* to Bavarian rivers and infested alder nursery stock (Jung & Blashke, 2004). Two other new hybrid Phytophthoras have recently appeared in glasshouses in the Netherlands (Man in't Veld *et al*., 1998, 2007). This risk issue is also nicely exemplified by Dutch elm disease (Table 2). As *O. novo-ulmi* has spread across the northern hemisphere, it has acquired 'useful' major genes by hybridizing with the resident species, *O. ulmi* (Paoletti *et al*., 2006). Critically, this gene-transfer process has probably enabled the survival and epidemic 'success' of *O. novo-ulmi*. The intermixing of resident and invasive pathogens can therefore promote novel and highly dangerous evolutionary risk to the environment.

[3]N.B. These examples reflect the effectiveness of local science: Germany and Spain are not the member states referred to in the paragraph above.

Instant 'woody' landscapes

Further problems are likely to be caused by the current enthusiasm for instant 'woody' landscapes, resulting in the importation of semi-mature or even mature trees and shrubs. Examples include the importation of thousands of tree ferns and 3 m tall *Acer* spp. from Australasia and China already mentioned. They also include importation of specimen trees up to 10 m tall with large root balls attached. Some notable recent examples imported into the UK include mature cork oak trees (imported from the Netherlands but probably originating from Spain) planted in the new Jubilee Gardens at Windsor Castle (featured as part of a British Broadcasting Corporation (BBC) landscaping programme); large fig, olive, cork oak and stone pine trees imported from Italy and planted at Kew Gardens (featured as part of several BBC television series); 6–8 m 'Cypress oak' imported from Italy for planting at Savill Garden (again featuring in a BBC landscaping programme) and elsewhere; and 10 m *Platanus* imported from Italy by a nursery in Bedfordshire. Such specimen trees are readily on offer on UK websites; and the site 'This is London' has highlighted the trade in a news item (www.thisislondon.co.uk/news/article-952642).

Not only may the crowns and stems of such trees be harbouring undetected pathogens or pests, but the soil around the roots represents a non-native microbial ecosystem that could well harbour risk organisms of many types. Clearly such plants cannot be adequately inspected without prolonged quarantine and detailed microbial analysis. Alder saplings imported from other EU countries for landscaping and shelterbelts are the most probable pathway by which the hybrid alder *Phytophthora* (Table 2) came into the UK (Gibbs, 2003b). Plane trees imported from Europe are a likely entry pathway for the dangerous stem pathogen *C. platani* (Table 1).

Indeed the concept of the EU as a single geographical unit for plant importation and plant movement contains within it the implicit assumption that it is reasonably safe to move soil and plant material within it. Patently it is not. Many areas of the EU are highly ecologically and biogeographically distinct, and must have uniquely selected pathogens and other microbes. They must also have undocumented invasives: *P. ramorum* and *P. kernoviae* were probably present in the UK for a decade or more prior to their discovery here. It cannot, therefore, be sound biosecurity practice to transport soil or plants between distinct ecological zones, e.g. from Italy to the UK or from the UK to Spain, without suitably detailed scientific information. The same applies, but perhaps even more so, to importation of soil and plants from countries in more distant continents e.g. from China or Australia.

In practice, information on the microbial status of imported plants and soil, whether from the EU or elsewhere, is usually lacking. It must also be recognized that such information would be difficult to obtain. Considering the apparent scale of the threats and the other system weaknesses outlined above, and in line with the precautionary principle, it could be argued that all plant imports should be considered potential carriers of known or unknown disease organisms, and therefore a potential biosecurity risk, whether or not the plants are in soil or 'bare rooted' and whether or not they have a plant health certificate.

Consequences for the UK environment, culture and horticultural heritage

Many of the examples of recently invasive pathogens listed in Table 2 are organisms previously unknown to science; and most were probably introduced via nursery stock or a similar import pathway. Sometimes their initial impact on the UK 'natural environment' is severe and rapid, as with Dutch elm disease. Often it is more gradual, as with the current mortality and decline of native alder caused by *P. alni* (Table 2). Some incursions may remain undetected or may not be noticed for decades, especially if they are weak pathogens such as the oak rootlet pathogen *P. quercina* (Table 2). Nonetheless weak pathogens can, over time, contribute to chronic disease complexes or declines (such as the current oak decline across Europe) that may become acute if exacerbated by climatic or other environmental stress on the host (*cf*. Jönsson, 2004). This potential for longer term damage is one reason why the arrival of any alien plant pathogen, however initially benign, should be considered a biosecurity risk.

Often, the resulting damage extends well beyond the effect on an individual host species. Invasive pathogens may destabilise entire local ecosystems (e.g. *P. cinnamomi*, Table 1); and affect associated factors such as dependent wildlife, hydrology, fire control, recreation and public amenity (see Waage *et al.* 2005). To this must sometimes be added the costs of attempted eradication, damage to rural economies, loss of tourism and loss of carbon storage value. The present sudden oak death outbreak in California is negatively affecting wildlife food chains, fire control, native tribal traditions and land values. The current death of alders along UK and European rivers is damaging riparian ecosystems, destabilizing river banks and affecting shelter for fish, birds and other wildlife.

The loss of some 28 million elms in the UK between 1970 and 1990 resulted in habitat loss for insects, birds, fungi and microbes. It also involved the loss of a characteristic English lowland landscape (*cf*. the 'elmscapes' in some of the artist John Constable's Dedham-area paintings or his views of Salisbury Cathedral); and the impoverishment of upland woodland communities in Scotland and Wales. Simple economic formulae are sometimes applied to such landscape-scale losses, based mainly on visual and shade impact of the trees. For example in the 1980s, US landscape assessors put the net value of a high value amenity elm at about $2000 per annum; and a modern formula estimates the net value of a small, 6·4 cm diameter disease resistant elm sapling with a potential life of 50 years at *ca.* £23 000 or £460 p.a. (Scott & Betters, 2000; Anon, 2007). However, in many ways such landscape-scale losses are irreplaceable, and the formulae, while providing a guide, also seem redolent of 'knowing the price of everything and value of nothing'. Can we truly put a price on the possible loss of native box (Table 2) from the popular amenity area, Box Hill, Surrey; or the loss of London Plane from the capital's streets and parks to *C. platani* (Table 1)? How does one 'value' evolutionary history or cultural heritage?

Invasive pathogens also damage our horticultural heritage, affecting arboreta, specialist collections and historic gardens. One current example is horse chestnut bleeding canker caused by the bacterium *Pseudomonas syringae* pv. *aesculi* (Table 2). This has all the hallmarks of an introduced organism. Spreading rapidly, it has already infected tens of thousands of individual trees and many heritage avenues. Another is *P. ramorum*. This is not only affecting native woodland beech and understory rhododendron in the south west. It is damaging exotic trees (e.g. *Nothofagus, Magnolia, Drymis*), historic specimen rhododendrons and shrubs in famous gardens such as those of the National Trust. Its arrival represents a potential threat to the National Council for the Conservation of Plants and Gardens (NCCPG) National *Camellia* and *Pieris* collections and to *Vaccinium* moor-land across Britain. Its 'co-arrivee', *P. kernoviae* (Table 2), is now present on, and must therefore be considered a threat to, the NCCPG National Magnolia Collection. It has also been found recently on *Vaccinium* in semi-natural ancient oak woodland. *Phytophthora ilicis* (Table 2), in addition to causing dieback and defoliation of native holly, is killing specimen Chinese holly trees coming from early collections (e.g. those of E.H. Wilson) and damaging ornamental holly in public gardens. Susceptible species in the NCCPG National Collection of *Cornus* have been affected by dogwood anthracnose; while box blight not only threatens native box but causes serious damage to formal box hedges in historic gardens (Table 2).

Evolutionary and epidemiological consequences

Once established outside a nursery, invasive pathogens are usually difficult to eradicate. They are also presented with new potential hosts plants and new microbial and abiotic environments: a novel opportunity for evolutionary exploitation which may be almost indefinite (*cf*. 'episodic selection', Brasier, 1995). Each imported pathogen is therefore an uncontrolled, potentially dangerous, open-ended experiment in evolution. One outcome over time is likely to be adaptation to the new hosts and environments. This might eventually lead to evolutionary divergence from the original population. Another, as already indicated above, can be emergence of new or modified pathogens via interspecific hybridization.

Since invasive pathogens often encounter low levels of host resistance and have escaped their own 'natural enemies', their populations sometimes reach explosive levels. This increases the probability of their spreading to new areas. Judging by its initial distribution, *P. kernoviae* (*cf*. also *P. ramorum*) was probably introduced into western Cornwall in the 1990s, or possibly earlier, most likely by a nursery or plant collector. Recently, infections on *Rhododendron ponticum* have built up intensively in the area. This increases the risk of *P. kernoviae* spreading (via infected plants or infested soil on feet, and machinery) to other parts of the UK, or entering the wider UK nursery trade. The latter in turn would increase the risk of *P. kernoviae* reaching natural ecosystems in other parts of the world. At present, nobody can predict whether or not *P. kernoviae* or *P. ramorum*, if exported from the UK, will cause extensive damage to, for example, the potentially susceptible Gondwanan *Nothofagus* ecosystems of Chile or Tasmania; or the unique, Tertiary *Rhododendron ponticum-Laurus-Quercus* ecosystems of southern Spain. An argument, surely, for maintaining the quarantine status of *P. kernoviae* and *P. ramorum* in the UK and strengthening it elsewhere.

There is usually a time lag between the arrival of an invasive and the appearance of symptoms. This, together with the complexity of natural ecosystems, often makes the tracing of an outbreak to its source impossible or at best difficult. Faced with initially slow rates of disease development, scientists, plant health regulators, nurserymen or land owners may become unduly complacent. For example red band needle blight of pine (Table 2) was first recorded in the UK in the 1950s. It re-emerged in the 1990s, possibly through a further introduction. At first its reappearance was considered of no great consequence and little action was taken by regulators or researchers. Now, ten years on from its reappearance in the 90s, the disease has reached epidemic levels in parts of England and threatens the commercial future of Corsican pine, a major plantation conifer in the UK.

Addressing the issue: initiating system reform and enhancing consumer awareness

The protocol weaknesses outlined above, together with the steady procession of invasives, clearly indicate that the movement of living plants, especially rooted nursery stock, between vegetation zones or continents is a high-risk process. Further major episodes in the UK, such as a loss of Plane trees across London to *C. platani* or a loss of oaks on a scale comparable to Dutch elm disease, may seem unthinkable. Yet, in view of the frequency and character of recent incursions, I would suggest that none of our amenity plantings or native ecosystems, from oak forests to grouse moors, can now be considered sufficiently biologically secure.

Presumably, horticulture trade professionals in the UK and worldwide have a responsibility, as far as they are able, to be cognisant of and to keep abreast of the plant health risks associated with their operations; in much the same way that plant health regulators have a responsibility to keep policy and practice in line with scientific knowledge and trade developments. Currently, however, the retail plant trade appears to be heading strongly in the direction of increasing importation of rooted stock. Principal drivers include the availability of 'cheap' plants from Europe and developing countries; the novelty of exotics; the desire for 'instant trees'; and the limited restrictions placed on the scale and the source of imports. The situation is further exacerbated by plant health protocols which, being primarily list-based, cannot account for the many undescribed pathogens; and take insufficient account of the danger of importing non-native microbial ecosystems via soil and potting media.

Inevitably, in a highly competitive environment, the import and retail trade looks to reduce its costs. But a high cost is being 'paid' by those who care for or have responsibility for the UK natural environment, and also by our heritage of parks and gardens. Remember it is mainly the UK environment and UK taxpayer that is paying for Dutch elm disease, box blight, alder dieback or horse chestnut bleeding canker. Were they alive today and armed with modern rather than eighteenth or nineteenth century knowledge, it seems reasonable to conclude that pioneering scientists of the stature of Darwin and Hooker and early plant collectors of the calibre of Banks, Wilson and Forrest would be deeply concerned at the current threat to the UK's, and to the world's, plant heritage. Indeed it is ironic to note that striking and beautiful *Banksia* species, such as *B. laricina* and *B. grandis*, are now seriously threatened, along with much of the local flora, by the invasive *P. cinnamomi* in western Australia (e.g. Shearer & Hill, 1989; Shearer *et al*., 1991). And that the unique Wollemi Pine, discovered only recently in a remote ecosystem in eastern Australia, is already under threat from the arrival of *P. cinnamomi* (www.environment.gov.au/biodiversity/threatened/publications/wollemia-nobilis.html). It may only be a matter of time before other classic plant collecting areas, such as Yunnan visited by Forrest and Wilson, are themselves threatened by invasive pathogens as a result of inappropriate importations of exotic plants.

If the unsatisfactory level of breaches in international plant biosecurity is to be reversed, the risks associated with trade in imported plants needs to be substantially reduced. Past experience shows that eradication of invasive pathogens once they are in the nursery is often very difficult, if not impossible, to achieve. The emphasis therefore needs to remain on preventing their introduction, but with processes that are far more effective and devoid of the current weaknesses and loopholes. Semi-mature and mature trees and shrubs are something of a special case. For reasons already outlined, it is difficult to envisage how these can be imported without being a biosecurity risk, unless (i) a detailed analysis of the soil and plant microbes and pests is conducted on each individual tree; (ii) extended quarantine is used (to allow for seasonal pathogen activity), and (iii) the trees are maintained in isolation throughout. Consequently, prohibition would seem the wisest approach.

For more regular plant consignments, attempting to tighten existing inspection protocols by radically improving *in situ* diagnosis, including molecular diagnosis, is one option. While this would give the satisfaction of something 'being seen to be done', I suggest it would be unlikely to achieve the consistently high levels of stringency required. First, because of the large volumes of plant material and soil that would need to be screened to provide a sufficiently comprehensive test, especially for latent or low level infestation. Second, because of the diversity of the organisms involved, especially the many unknowns. Third, because of the many international system failures already exposed. Developing and applying *in situ* molecular diagnostics for a large and almost indefinite array of organisms would also involve considerable expense and would be probably be beyond the reach of many countries.

The obvious and effective way to reduce the risks would be to limit the level of plant imports to the minimum necessary for subsequent propagation. This could best be achieved by importing small parcels of juvenile plant material under licence and subjecting them to rigorous quarantine testing before release, i.e. a system closer to the licenced importation procedures already required of professional plant collectors. Licenced material could be brought in as surface treated seed, as meristematic tissue (tissue culture), unrooted cuttings, or as small numbers of rooted plants. Tissue culture and seed are already widely accepted as offering greatly reduced plant health risk. Indeed tissue culture is often a preferred transfer method among plant breeders or genetic conservation groups concerned at the risk of disease movement. Even so, some fungal pathogens are seed borne and cocoa breeders have discovered that even tissue cultures may harbour deleterious plant viruses (e.g. Frison *et al*., 1999) which can become symptomatic only when plants have been grown from them.

Such methods would constitute a much safer distribution process for desirable new varieties of known plants, or of new species of exotics amenable to propagation. In parallel, established plant varieties could, when practicable, be propagated from material already in the UK. As a result local commercial propagation of forest trees, shrubs and herbaceous plants would be stimulated. Adoption of such an approach could therefore lead to a stronger 'home grown' nursery industry; and hopefully to one also imbued with the need to produce pathogen-free stock. It could also encourage a return to standards of mass propagation and plant husbandry more in keeping with the objective of the RHS to promote 'best practice' in horticulture and gardening; and of organisations such as Defra, FC and Kew to protect plant resources and promote sustainable use and development. Use of planting stock that carries a risk, knowingly or unknowingly, of being pre-infested with pathogens is surely inconsistent with, for example, a policy of sustainable forestry or of ethical sourcing.

Any future implementation of plant biosecurity reforms will probably meet with resistance from some parts of the horticulture trade and some plant health professionals. As with other environmental issues, such as climate change and fisheries, there are likely to be individuals with entrenched views, or with vested interests in the *status quo*.[4] One means of counteracting this would be to ensure that the details of plant biosecurity breaches are more widely publicized by the responsible authorities (EU, Defra, FC). For reasons of protecting trade, details of plant disease outbreaks under statutory control on retail premises are often not disclosed to the public. This also has the unfortunate effect, albeit indirectly, of reducing public scrutiny of the regulatory process and of the public responsibilities of the trade. Greater openness would seem to be more in keeping with the relative transparency and freedom of information on day-to-day developments in recent animal disease outbreaks, such as foot and mouth, blue tongue and avian flu.

Another way to counteract resistance to reform could be to ensure that the 'real' or hidden cost to the environment and to the taxpayer engendered by plant biosecurity breaches, including costs of research, surveys, and possible long term social impacts, is also better publicized. Indeed, when there is a security breach, the horticultural trade, its professional organisations and others may have a collective obligation to make reparation. With regard to the latter, a shared responsibility (cost-sharing) framework could be developed (see Waage *et al*., 2007). One way to accomplish this could be an industry-wide levy or green tax (similar to that imposed recently on fruit and vegetable growers in New Zealand). A formula could be adopted that fairly reflects the overall potential negative environmental impacts. Revenue from such a levy could be used to fund both research activity and restitution. Proactive research could include host susceptibility testing

[4]A vested interest in the *status quo* would not necessarily be confined to individuals within the plant trade. Internationally, plant health has an array of well meaning, highly professional inspectors, administrators, research scientists, risk analysts, and officers of plant protection organisations (EPPO, NAPPO) and of governmental and intergovernmental committees. I count myself among them. In essence, plant health has become an industry in itself. As in all professions, some may seek to stay within the comfort zone, becoming institutionalized and resistant to initiating change even when system failure is apparent.

in support of PRAs; and surveys for ‘unknown risk organisms’ in ecosystems of exporting countries (many countries remain a ‘closed book’ in this regard). Research on amelioration could include breeding affected host species for disease resistance, and environmental restoration projects. A levy could also have the effect of slowing import levels, altering the pattern of trade and, by raising the public and political profile on the issue, focus the retail trade and the public on the risks.

Surprisingly, there is a general lack of awareness about the extent of the invasive pathogen problem among trade professionals such as horticulturalists and foresters, conservationists and environmental scientists and even among some plant pathologists. Furthermore, international regulatory protocols appear to be conducted in much of the world as if there were no fundamental flaws, the application of the protocols sometimes giving the impression of being institutionalized and ‘box ticking’. There is also little serious international debate on the issue either at a scientific[5] or at a political level. Equally, there is little awareness of the issues among the buying public. Rather, there is a serious gap in public education regarding disease risk from imported plants, the geographic origins of the plants they purchase and the chemical treatments that have been applied to them. In this regard, there has been virtually no public debate in the UK[5] and little serious attempt by government agencies, horticultural journalists, nature conservation bodies or the trade to heighten public awareness. In contrast to the level of public debate on other risk issues such as climate change, genetically modified organisms or ‘bird flu’, the question of plant biosecurity has tended to be overlooked.

To enhance public awareness, professional organisations such as the Horticultural Trades Association or the RHS could consider introducing a certification scheme to guarantee that a plant or tree has been produced according to environmental best practice (a range of cultural conditions) and that it is, to the best of reasonable knowledge, disease free. In addition, plants in retail outlets could be clearly labelled, following strict label guidelines to ensure proper documentation and consumer information in circumstances such as ‘re-badgeing’. Labels could highlight features such as the country of initial propagation, the country of any subsequent propagation including any re-potting or growth enhancement, any associated disease risk, potential invasiveness, its associated carbon footprint, climatic suitability, and a list of chemicals that have been applied. A suitable voluntary plant labelling scheme could be promoted under the stewardship of an appropriate non-governmental organisation, such as the HTA or RHS, in much the same way that fish labelling is promoted by the Marine Stewardship Council (www.msc.org). It was recently suggested to the author that the labelling might take the form of a ‘traffic light system’ (red, amber, green spots), in line with other current thinking on food labelling (DA Slawson, PHSI, York YO1 7PX, UK, personal communication). Perhaps the trade and the EU also have a natural obligation to provide such information, and the consumer has a natural right to be provided with it?

As indicated above, the *Phytophthora*-nursery situation developing in the EU is perhaps best described as one of bio-insecurity, rather than biosecurity. In terms of the consumer’s right to be informed, therefore, there must also be a strong case for the EU and the trade to thoroughly investigate, and to publicize, the quarantine and non-quarantine *Phytophthora* species (and other pathogens?) infesting nursery stock within the Community, and the frequency of their movement between EU states.

Concluding comments

The main thesis of this Letter is that international plant biosecurity protocols have been overtaken by events – primarily global shifts in market structure and practice and by developments in scientific knowledge – and are now outmoded, flawed, institutionalized, and too ineffectual. In my view they now need to be fully scientifically reviewed and appropriately overhauled, taking full account of the underlying scientific weaknesses and of the many other causes of security failure. Clearly, global initiatives and agreements, involving regulators and trade representatives from organisations such as the WTO, IPPC and EU, would be needed to service any such changes, The problem therefore has a marked political as well as scientific dimension.

Recently, there has been the beginning of an official awareness of the problem. In the USA, in the context of sudden oak death (*P. ramorum*) and other issues, a fundamental review of ‘Plants for Planting’ has been initiated by APHIS within the Department of Homeland Security (www.aphis.usda.gov/import_export/plants/plant_imports/downloads/q37_whitepaper.pdf). The IPPC has also recently set up a working group on ‘Plants for Planting,’ to consider the development of new standards; and the International Union of Forest Research Organisations has initiated a working group on ‘Invasives’ which has also identified this pathway as one needing scientific and regulatory attention. Hopefully the recognition process will accelerate, with the EU and UK playing a prominent role.

One concern must be that the IPPC and other relevant organisations will take greater account of the growing scale of the international trade, which is quantifiable, and the significance of the trade lobby, which is large and influential, rather than the scale of the international threat and the environmental costs, which are difficult to define and quantify with any precision and lack a coherent institutional ‘voice’. Another concern must be that, in consequence, any eventual proposals will amount to various prescriptions to enforce the *status quo* by tightening or improving existing inspection regimes (more certificates, more inspectors, improved on-site diagnostics – essentially ‘more of the same’), rather than an aim to significantly reduce the scale of the risk by cutting and

[5]An exception being a Science Exchange hosted by the RHS at Reading University in November 2005 (http://www.rhs.org.uk/Learning/Research/scienceexchange/speakers.htm).

reversing import volumes. Since the main loopholes in current regulations are the access points for the large numbers of unknown threat organisms, an approach involving tightening of existing inspection and diagnosis alone will probably only delay the inevitable. The regulatory equivalent of trying to tighten a worn and leaking tap rather than replacing it.

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