Revised Summary Pest Risk Analysis For *Phytophthora Kernoviae*

STAGE 1: PRA INITIATION

1. What is the name of the pathogen?

Phytophthora kernoviae sp. nov. (Brasier *et al*., 2005). The pathogen was previously known informally as *Phytophthora taxon* C (Sansford, Brasier & Inman, 2004) and as *Phytophthora kernovii* (Anon., 2005b). *Phytophthora kernovii* is the name that is used in the emergency legislation (Anon., 2004a) (see 7).

Synonyms: None.

Taxonomic position:
Kingdom-*Chromista;* Phylum-*Oomycota;* Order-*Pythiales;* Family-*Pythiaceae;* Genus-*Phytophthora*.

Common names of the disease:
No formal names have been assigned to the disease that this pathogen causes and symptoms vary according to the host that is affected. See Table 1. Pathologists could consider using the terminology of Hansen *et al.* (2002) that was used to describe the three main disease types caused by *Phytophthora ramorum*, another recently-described pathogen of trees and shrubs (Werres *et al*., 2001). These were: ramorum bleeding canker (e.g. 'sudden oak death'), ramorum dieback and ramorum leaf blight. Thus, for *P. kernoviae* tree stem diseases could be termed 'kernoviae bleeding canker', shoot and bud diseases could be termed 'kernoviae dieback' and foliar diseases as 'kernoviae leaf blight'.

Special notes on nomenclature or taxonomy:
The nearest known relative of *P. kernoviae* based on molecular data (ITS (internal transcribed spacer) DNA sequences) is *P. boehmeriae* (Brasier *et al*., 2005); these species belong to a clade that lies outside of the main *Phytophthora* clades (Cooke *et al*., 2000). *P. boehemeriae* has been recorded on several species of tree in China and Australia, as well as cotton in China and Greece (Erwin and Ribeiro, 1996; CABI, 2002).

The relatively low ITS sequence matches (92-95%) obtained through molecular analysis of the DNA shows that *P. kernoviae* appears only distantly related to *P. boehmeriae*, but probably shares an ancient ancestor (Sansford, Brasier & Inman, 2004).

P. kernoviae falls into the traditional *Phytophthora* morphological Group II of Waterhouse (1963) (and see Stamps *et al*., 1990; Erwin and Ribeiro, 1996), along with *P. boehmeriae,* on the basis of its papillate sporangia and amphigynous antheridia. However, this morphological group is artificial and polyphyletic: neither *P. kernoviae* nor *P. boehmeriae* is phylogenetically closely related to the other species in Waterhouse Group II (cf. Cooke *et al*., 2000). *P. kernoviae* is also not closely related to *Phytophthora ramorum*, another new, exotic *Phytophthora* formally described in 2001 (Werres *et al*., 2001) which was recently introduced to the UK and is subject to official control (see 4.).

P. kernoviae differs morphologically from *P. boehmeriae* in its larger sporangial pedicels (those of *P. boehmeriae* are short at < 5 μm) and its tendency to produce tapered oogonia.

2. What is the reason for the PRA?

This is a full revision of the PRA conducted in September 2004 (Sansford, Brasier & Inman, 2004). It is required to help inform a review of the current policy for this pathogen in the UK including a review of the legislation (Anon., 2004a). It takes into account all of the available publications as well as the findings from completed UK-funded† research projects as well as available data from those that are yet to be completed. It also accounts for new information that relates to the presence of *P. kernoviae* in New Zealand.

3. What is the PRA area?

The PRA area is the United Kingdom.

STAGE 2: PEST RISK ASSESSMENT

4. Is the pest established in the PRA area?

Yes. It is present in the UK, mainly on established plants or trees in the natural or semi-managed environment (woodlands; parks and gardens); there have been only three findings in nurseries. However, it has a limited distribution and is the subject of official control.

Since the discovery of this new pathogen in 2003 (described below) surveys have been carried out by the Forestry Commission (FC), Defra and the Scottish Government Rural Payments and Inspections Directorate (SGRPID) in woodlands, gardens and nurseries in England, Scotland and Wales with intensive surveillance in Cornwall/Devon (Slawson, 2006). This has been done to help determine the distribution of the pathogen in the PRA area.

Summary of current situation

Between October 2003 and February 2008, *P. kernoviae* was found at 52 non-nursery sites sites in England and Wales, mainly affecting rhododendron in small areas of woodland in Cornwall as well as a number of trees of a range of species (D. Slawson, Plant Health and Seeds Inspectorate (PHSI), *personal communication*, 2007). One finding has been made in Devon (Beales *et al*., 2006). Outside of the south-west of England the pathogen has been found in 6 locations in south Wales and one in north-west England (single mature rhododendron plant – eradicated). Three findings have been made on nurseries, two in Cornwall and one in Cheshire: the latter has been eradicated; the former remain under official notice/control. All

† Defra, Forestry Commission and the Horticultural Development Council

the remaining outbreaks are still the subject of an eradication/containment programme. The latest findings in England and Wales are mapped at: http://www.defra.gov.uk/planth/pkernovii2.htm

Until recently there were no findings in Scotland. However, in January 2008 two established rhododendron plants in a private garden in Argyll in the west of Scotland were found to be infected with *P. kernoviae*. (V. Smith, SGRPID, *personal communication*, 2008).
http://www.scotland.gov.uk/News/Releases/2008/01/10144052

In February 2008 two rhododendrons and one *Drimys* plant in a managed garden were found affected by *P. kernoviae* on the Isle of Arran, an island off the west coast of Scotland (V. Smith, SGRPID, *personal communication*, 2008).
http://www.nts.org.uk/Property/13/News/171/
http://www.theherald.co.uk/news/news/display.var.2054133.0.Warning_as_shrub_disease_found_in_Arran.php

There are no findings of *P. kernoviae* in Northern Ireland (D. Slawson, PHSI, *personal communication*, 2007).

A brief history of the detection in the UK is given below (more detail was given for 2003 and 2004 in the previous version of this PRA; Sansford, Brasier & Inman, 2004).

A climate-matching model using the CLIMEX programme (Sutherst and Maywald, 1985) was run by CSL in March 2003 (R. Baker, CSL, UK, *personal communication*, 2003) to identify which areas of the UK were most at risk from *P. ramorum*. This work was based upon identifying climatic similarities between the UK and Oregon/California where *P. ramorum* occurs. The outcome, was that based upon a more similar match with Oregon alone (compared to California), the south and west of the UK were identified as potentially at high risk of *P. ramorum* establishing there. (See Appendix 1). This information was used to inform the PHSI surveys for *P. ramorum* required under emergency EC (and UK) legislation since 2002 (Anon., 2002, 2004, 2007). As a result of intensive surveillance in Cornwall for *P. ramorum* by the PHSI and investigations by Forest Research (FR), a new and unknown *Phytophthora* species was isolated by CSL from symptomatic rhododendron (*Rhododendron ponticum* and *Rhododendron* spp.) from an established woodland area adjoining a commercial nursery in Cornwall in late October 2003. Concurrently, FR isolated a similar *Phytophthora* from a large bleeding canker on a mature beech tree (*Fagus sylvatica*) and from an adjacent rhododendron with foliar symptoms adjacent to the tree at a second woodland site located 23km from the first site. The pathogen was causing widespread foliar necrosis and shoot dieback of the rhododendrons. By December 2003 the isolates were considered to be the same organism and all samples submitted to CSL by the PHSI since that date for testing for *P. ramorum* were also tested for this new organism.

Since these early findings, between May and July 2004 the pathogen was found on a wider range of hosts at these sites and at a number of other sites in Cornwall. Two of the south-west sites are small woodlands with a mixture of mature beech (*F. sylvatica*), sycamore (*Acer pseudoplatanus*), holly (*Ilex* spp.) and oak (*Quercus* *robur*) trees with a dense rhododendron understorey, a high level of infected rhododendron, and, some severely affected trees. These woods have been monitored pre and post-clearance of rhododendron (to help control the disease) by CSL and FR since 2004 as part of two Defra Projects PH0318 and PH0414 (Anon., 2006c; Turner *et al*., 2006). A summary of this work is given under section 13.

In July 2004 the pathogen was found affecting established rhododendron at three sites in south Wales. It has now been confirmed there at six sites. Most of the findings have been on rhododendron. Eradication action has been taken at all sites and major clearance of *R. ponticum* was continuing at a woodland site. (Slawson, 2006).

The first finding of the pathogen on a nursery was made on ornamental rhododendron in the retail sales area of a nursery in Cheshire in August/September 2004 from which it has since been eradicated. This nursery had suffered several outbreaks of *P. ramorum* between July 2002 and October 2003 (and several since with the last being in August 2007). The affected plants had been brought onto the site since the spring of 2004 but the origin of the source of infection could not be determined. (S. Matthews-Berry and C. Lane, CSL, *personal communication*, 2004). The pathogen was not found on any other part of the site and no symptoms of disease were found on plants in an area surrounding the site (Slawson, 2006). The small area on which the plants were standing has been replaced with concrete (D. Slawson, PHSI, *personal communication*, 2007).

A second nursery, located in Cornwall, was reported to have rhododendron infected with *P. kernoviae* in January 2006. This h is surrounded by a 30ha ornamental garden and woodland where the first infected rhododendron in the UK were reported in October 2003. Further findings have been made on the nursery on *Magnolia brooklynensis* (June, 2006), *Michelia doltsopa* (December 2006), rhododendron (January 2007) and *Drimys* (June 2007). Water-baiting of an open channel at the nursery detected *P. kernoviae* in January 2007. The woodland and garden has been cleared of *Rhododendron ponticum*. Other susceptible host species, including other species of rhododendron are present in the garden. This site continues to be subject to official control (D. Slawson, PHSI, *personal communication*, 2007). *P. ramorum* has been found here both on the nursery (first found in September 2003) and in the managed garden (first found in October 2004). All plants for export to third countries from this nursery have been tested by CSL; all prior recipients of host material in third countries have been notified to the National Plant Protection Organisation (NPPO) for the relevant countries (Slawson, 2006).

A third nursery, also located in Cornwall, was reported to have three mature container-grown magnolia plants infected with *P. kernoviae* in September 2007. This nursery has also been found to have *P. ramorum* infected plants (first found in June 2003) with outbreaks continuing up to January 2008 to date. This site continues to be subject to official control.

In May 2006, as part of the PHSI survey work, a single, large 150-year old rhododendron in the grounds of a managed garden in north-west England was sampled and found to be infected with the pathogen. The plant was destroyed immediately. (Slawson, 2006). This site continued to be subject to official control in

2007 but no further findings of *P. kernoviae* have been made and the outbreak is now considered to be eradicated. *P. ramorum* has also been found here and infected plants have been destroyed although findings occurred in 2007 and so this outbreak is still not considered to be eradicated.

In December 2007 and January 2008 two significant events occurred. Firstly the first record of *P. kernoviae* affecting the environmentally important species *Vaccinium myrtillus* was made. http://www.defra.gov.uk/news/2008/080114b.htm. Mildly symptomatic plants were sampled from a mixed broad-leaved woodland in a valley in Cornwall by the PHSI (I. Sanders, PHSI, *personal communication*, 2007) and were confirmed infected with *P. kernoviae*; Kochs postulates were completed for *V. myrtillus* (P. Beales, CSL, *personal communication*, 2008). The area has been subject to survey since 2004; *P. ramorum* was first found there affecting *R. ponticum* in March 2005 and *P. kernoviae* in April 2006 with subsequent findings in October 2007 (B. Jones, FC, *personal communication*, 2007). The site is subject to surveillance and eradication activities. The second significant event was the first finding of *P. kernoviae* on two established rhododendron plants in a private garden in the west of Scotland in January 2008. The plants are 10 to 15 years old. The garden is open to the public. Prior to this the most northerly find was in north-west England in May 2006. The affected site is subject to surveillance, eradication and containment activities. (V. Smith, SGRPID, *personal communication*, 2008).

In February 2008 two rhododendrons and one *Drimys* plant in a managed garden were found affected by *P. kernoviae* on the Isle of Arran, an island of the west coast of Scotland. (V. Smith, SGRPID, *personal communication*, 2008).

5. Is there any other reason to suspect that the pest is already established in the PRA area?

The pest is established in the PRA area with a limited distribution and is still subject to official control. As part of the PHSI surveys for *P. ramorum*, all samples submitted by the PHSI to CSL are routinely tested for *P. kernoviae*. Samples submitted for the FC Woodland Survey for *P. ramorum* are also checked for *P. kernoviae*. The number of confirmed findings compared to the number of samples tested appears to be relatively low. Four years after the first finding the organism is mainly confined to south-west England and south Wales, with one isolated managed garden finding in the north-west of England (eradicated), one north-west nursery (eradicated) and recently, one Scottish mainland and one island garden. Between 1 December 2003 and 22 March 2007, CSL tested 22,991 samples for *P. kernoviae* and 1,556 were positive. Since 2006 the PHSI have used a lateral flow device (LFD) to test suspect symptoms onsite for *Phytophthora* species. As a result, the number of samples tested by CSL has fallen-off dramatically and the percentage of samples that are recorded as positive for *P. kernoviae* by CSL no longer includes all of the negatives, since those tested and found negative on site are not forwarded to the laboratory (C. Lane, CSL, 2007 *personal communication*).

The finding on a retail nursery in September 2004 in north-west England and two in south-west England may mean that the pathogen could also have been distributed to other, as yet unknown, locations which if this has occurred are likely to be private gardens. The first affected nursery in Cornwall (January 2006) is still subject to official control. This nursery sells plants to the public and given the findings of *P.*

kernoviae in the adjoining woodlands in October 2003 it is possible that potentially infected plants had been despatched within the UK and overseas prior to 2006. However, although the NPPOs in receiving countries have been notified, no data have been generated that would support this assumption. The second affected nursery in Cornwall has been subject to official inspection for some time as *P. ramorum* was found there in June 2003. There are currently no further details on the September 2007 report of *P. kernoviae* on magnolias at this site but it is assumed to be only recently introduced as it would have been detected earlier because of the ongoing inspection and testing for *P. ramorum*. Investigations are ongoing at this site.

6. What is the pest's EPPO status?

Phytophthora kernoviae is on the EPPO Alert List; it was added in October 2005 (EPPO, 2005) subsequent to it being formally named as a new species (Brasier *et al*., 2005).

7. What is the pest's EC Plant Health Directive status?

None.

However, in the UK, statutory action to eradicate and contain *P. kernoviae* is taken under the Plant Health (England) Order 2005, the Plant Health (Scotland) Order 2005, the Plant Health (Wales) Order 2006, the Plant Health (Northern Ireland) Order 2006 and the Plant Health (Forestry) Order 2005.

The Plant Health (*Phytophthora kernovii* [sic] Management Zone) (England) Order 2004 (Anon., 2004a) introduced in December 2004 gave Defra and the FC specific powers of action within a defined region of Cornwall where *P. kernoviae* was first identified.

8. What are its host plants?

8.1 Natural hosts.

Natural hosts recorded to date are listed in Table 1.

Natural hosts fall into the families Aquifoliaceae, Araliaceae, Ericaceae, Fagaceae, Magnoliaceae, Podocarpaceae, Proteaceae, Rosaceae and Winteraceae. Symptoms include bleeding cankers on trees of beech, oak and the tulip tree (*F. sylvatica*, *Q. robur* and *Liriodendron tulipifera*), foliar blights and shoot dieback on trees and ornamentals as well as bud blast on *Magnolia*. See Anon., 2005b for a fuller description with images of symptoms on shrubs and trees known to be affected at the time. Stem symptoms on ivy (*Hedera helix*) and foliar symptoms on winter's bark (*Drimys winteri*), Chilean hazelnut (*Gevuina avellana*), variegated holly (*Ilex aquifolium*), *Podocarpus salignus*, as well as foliar (leaf spotting) and stem symptoms (top-down dieback with no stem cankers) on cherry laurel (*Prunus laurocerasus*) and leaf/stem symptoms on *V. myrtillus* are not shown in this 2005 publication.

The number of ornamental shrubs affected is not available. The number of trees affected up until mid-October 2007 counted by FR plus those counted by the PHSI up to April 2007 is as follows (J. Webber, FR, *personal communication*, 2007):

Trees with bleeding cankers: beech (*F. sylvativa*) – 56 (includes one tree with *P. ramorum* infection too); oak (*Q. robur*) – 2; tulip tree (*L. tulipifera*) – 1. Total = 59 trees at 9 sites

Trees with foliar symptoms: magnolia (*Magnolia* spp.) 19; holm oak (*Quercus ilex*) 5; *Drimys winteri* 16; *M. doltsopa* 2; Chilean hazelnut (*G. avellana*) 1; tulip tree (*L. tulipifera*) 1; *Podocarpus* sp. (podocarpus) 1, plus one unidentified tree. Total = 46 trees at 8 sites.

Table 1. Plants reported as natural hosts of *Phytophthora kernoviae* in the UK

Host[1]	**Common name**	**Family**	**Type of infection***	**Reference**
Ornamental plants				
Hedera helix	Ivy	Araliaceae	Stem infection	FR records
Magnolia amoena[2]	-	Magnoliaceae	Leaf infection	FR records
Magnolia brooklynensis	Evamaria Cucumber Tree	Magnoliaceae	Leaf infection	CSL records
Magnolia cylindrica[2]	Yellow mountain magnolia	Magnoliaceae	Leaf spot and bud blast	FR records
Magnolia delavayi[2]	Chinese evergreen magnolia	Magnoliaceae	Leaf blight	CSL/FR records
Magnolia Gresham hybrid 'Joe McDaniel'[2]	-	Magnoliaceae	Leaf infection	FR records
Magnolia Gresham hybrid 'Sayonara'[2]	-	Magnoliaceae	Leaf infection	FR records
Magnolia kobus [2]	Kobus magnolia	Magnoliaceae	Bud base death	FR records
Magnolia Leonard Messel[2] = *Magnolia kobus* x *Magnolia stellata*[2]	-	Magnoliaceae	Leaf spot and bud blast	FR records
Magnolia liliiflora[2]	Lily magnolia	Magnoliaceae	Leaf spot	FR records
Magnolia mollicomata 'Lanarth' = *M .campbelli* var. *mollicomata* 'Lanarth'x *M. liliiflora*	Vulcan Campbell's Magnolia	Magnoliaceae	Leaf spot and necrosis plus stem tip dieback	FR records
Magnolia salicifolia	Anise magnolia	Magnoliaceae	Leaf spot and necrosis	CSL/FR records
Magnolia sargentiana[2]	-	Magnoliaceae	Leaf infection	CSL records
Magnolia sprengeri[2]	-	Magnoliaceae	Leaf infection	CSL records
Magnolia stellata[2]	Star magnolia	Magnoliaceae	Leaf infection	FR records
Magnolia	Wilson's Magnolia	Magnoliaceae	Foliage necrosis	FR records

wilsonii[2]			and blossom blight	
Magnolia x *soulangeana*[2]	-	Magnoliaceae	Leaf spot	FR records
Pieris formosa[2]	-	Ericaceae	Leaf infection	Brasier *et al*. (2005)
Pieris japonica[2]	-	Ericaceae	Leaf infection	Beales *et al*. (2006)
Rhododendron spp.[2]	Rhododendron	Ericaceae	Shoot dieback and leaf infection	Brasier *et al*. (2005)
Vaccinium myrtillus[2]	Bilberry	Ericaceae	Leaf infection and stem lesions	CSL records
Trees[1]				
Annona cherimola	Cherimoya/custard apple	Annonaceae	Shoot and fruit necrosis	New Zealand MAF
Drimys winteri[2]	Winter's bark	Winteraceae	Foliage necrosis	CSL records
Fagus sylvatica[2]	Beech	Fagaceae	Bleeding canker	Brasier *et al*. (2005)
Gevuina avellana[2]	Chilean hazelnut	Proteaceae	Leaf infection	FR records
Ilex aquifolium 'Variegata'	Variegated holly	Aquifoliaceae	Leaf infection	CSL records
Liriodendron tulipifera[3]	Tulip tree	Magnoliaceae	Bleeding canker and leaf infection	Brasier *et al*. (2005)
Michelia doltsopa[2]	-	Magnoliaceae	Leaf infection	Beales *et al*. (2006)
Podocarpus salignus	-	Podocarpaceae	Shoot tip wilt, foliar blight	FR records
Prunus laurocerasus	Cherry laurel	Rosaceae	Leaf spots, leaf blight with top-down dieback	CSL records
Quercus ilex[2]	Holm oak	Fagaceae	Leaf necrosis	Brasier *et al*. (2005)
Quercus robur	English oak	Fagaceae	Bleeding canker	Brasier *et al*. (2005)

*Symptoms are as described by the diagnostician hence the inconsistent reporting of foliar infections

Please also note the finding in **New Zealand** under symptomless stands of ***Pinus radiata*** in the 1950s (Ramsfield *et al.* 2007)

[1]Note that the division between trees and ornamentals/shrubs is somewhat artificial; plant species can be one or other, or both, depending on climate, maturity or end use. [2]Koch's postulates successfully completed for this host. [3]Koch's postulates for *Liriodendron tulipifera* are completed for leaf infection only.

Because *Liriodendron*, *Michelia* and *Magnolia* all belong to the Magnoliaceae, Brasier *et al*. (2005a) have suggested that *P. kernoviae* might be more of a 'magnolia specialist' in its natural habitat. Its host range in the UK is, however, more extensive affecting plants and trees in 9 families, although the number of host species affected is far less than *P. ramorum*. Denman *et al*. (2005) have commented that some of the affected magnolias are very rare or even threatened species and have cultural and horticultural significance in the UK.

Camellia was reported associated with *P. kernoviae* in March 2007 (CSL records) but no symptoms were observed; the pathogen was isolated by baiting with rhododendron leaves from asymptomatic *Camellia* leaves which had not been surface-sterilised. This was for pre-export consignment testing and is likely to have arisen from surface contamination as the sample was from a known outbreak site.

8.2 Experimental hosts

The experimental host lists in Tables 2 and 3 are compiled from three pieces of work. Table 2 represents two years of testing tree species (FR). Table 3 shows the results of testing heathland species at CSL (Anon., 2006a). Where two ratings for one species are given this is where results differ between experiments. Note that some species can be grown as ornamentals and trees.

Table 2. Experimental susceptibility of trees to *P. kernoviae* in laboratory tests. * natural hosts; high susceptibility in bold, where 'more' means 'more susceptible' and 'less' means 'less susceptible' based on laboratory tests.

Host	Common name	Family	Plant part - tested by wounding	Susceptibility
Abies grandis	Grand fir	Pinaceae	Logs from mature trees	Resistant
Abies procera	Noble fir	Pinaceae	Logs from mature trees	**More**
Acer pseudoplatanus	Sycamore	Aceraceae	Logs from mature trees	Less
Aesculus hippocastanum	Horse chestnut	Hippocastanaceae	Logs from mature trees	Less
Betula pendula	Silver birch	Betulaceae	Logs from mature trees	Less
Castanea sativa	Sweet chestnut	Fagaceae	Logs from mature trees	Less
Chamaecyparis lawsoniana	Lawsons cypress	Cupressaceae	Logs from mature trees	Resistant
***Eucalyptus* sp.**	-	Myrtaceae	Logs from mature trees	**More**
Fagus sylvatica*	Beech	Fagaceae	Logs from mature trees	**More**
*Ilex aquifolium**	Holly	Aquifoliaceae	Logs from mature trees	Resistant
*Liriodendron tulipifera**	Tulip tree	Magnoliaceae	Logs from mature trees	Resistant and less
Nothofagus dombeyi	False beech	Nothofagaceae	Logs from mature trees	**More**
Nothofagus obliqua	Roble beech	Nothofagaceae	Logs from mature trees	Resistant and less
Nothofagus procera	Rauli	Nothofagaceae	Logs from mature trees	Less and **more**
Pinus contorta	Lodgepole pine	Pinaceae	Logs from mature trees	Resistant
Pseudotsuga menziesii	Douglas-fir	Pinaceae	Logs from mature trees	Less
Quercus cerris	Turkey oak	Fagaceae	Logs from mature trees	Resistant and less
Quercus coccinea	Scarlet oak	Fagaceae	Logs from mature trees	Less
*Quercus ilex**	Holm oak	Fagaceae	Logs from mature trees	Resistant
Quercus palustris	Pin oak	Fagaceae	Logs from mature trees	Resistant
Quercus petraea	Sessile oak	Fagaceae	Logs from mature trees	Resistant and less

*Quercus robur**	English oak	Fagaceae	Logs from mature trees	Resistant and less
Quercus rubra	Northern red oak	Fagaceae	Logs from mature trees	Less and more
Sequoia sempervirens	Coast redwood	Cupressaceae	Logs from mature trees	Resistant
Tilia cordata	Small-leaved Lime	Tiliaceae	Logs from mature trees	Less
Tsuga heterophylla	Western hemlock	Pinaceae	Logs from mature trees	Less
Ulmus procera	English elm	Ulmaceae	Logs from mature trees	Resistant
Acer pseudoplatanus	Sycamore	Aceraceae	Stems from sapling trees	Low
Aesculus hippocastanum	Horse chestnut	Hippocastanaceae	Stems from sapling trees	Moderate
Betula pendula	Birch	Betulaceae	Stems from sapling trees	**High**
Castanea sativa	Sweet chestnut	Fagaceae	Stems from sapling trees	**High**
Chamaecyparis lawsoniana	Lawson cypress	Cupressaceae	Stems from sapling trees	Low
Fagus sylvatica*	Beech	Fagaceae	Stems from sapling trees	**High**
Fraxinus excelsior	Ash	Oleaceae	Stems from sapling trees	Low
*Ilex aquifolium**	Holly	Aquifoliaceae	Stems from sapling trees	Low
*Liriodendron tulipifera**	Tulip tree	Magnoliaceae	Stems from sapling trees	Moderate
Magnolia sp.*	Magnolia	Magnoliaceae	Stems from sapling trees	Low
Picea abies	Norway spruce	Pinaceae	Stems from sapling trees	Low
Picea sitchensis	Sitka spruce	Pinaceae	Stems from sapling trees	Moderate
Pinus contorta	Lodgepole pine	Pinaceae	Stems from sapling trees	**High**
Pinus nigra* var *maritima	Corsican pine	Pinaceae	Stems from sapling trees	**High**
Pinus sylvestris	Scots pine	Pinaceae	Stems from sapling trees	Moderate
Chamaecyparis lawsoniana	Lawson cypress	Cupressaceae	Stems from sapling trees	Low
Pseudotsuga menziesii	Douglas fir	Pinaceae	Stems from sapling trees	Moderate
Quercus cerris	Turkey oak	Fagaceae	Stems from sapling trees	Moderate

*Quercus ilex**	Holm oak	Fagaceae	Stems from sapling trees	Low
Quercus petraea	Sessile oak	Fagaceae	Stems from sapling trees	Moderate
*Quercus robur**	Common oak	Fagaceae	Stems from sapling trees	Low
Quercus rubra	Red oak	Fagaceae	Stems from sapling trees	Low
*Rhododendron**	Rhododen dron	Ericaceae	Stems from sapling trees	Moderate
Taxus baccata	Yew	Taxaceae	Stems from sapling trees	Low
Tsuga heterophylla	Western hemlock	Pinaceae	Stems from sapling trees	**High**

In comparing the foliar susceptibility of twenty-six broad-leaved species and eleven conifer species to *P. kernoviae* or *P. ramorum* (albeit the tests were not conducted at the same time), Denman *et al*., 2006 considered that fewer plant species were susceptible to *P. kernoviae*, and, that the only species (of those tested at the time) that were highly susceptible to *P. kernoviae* were *Magnolia* spp., *Rhododendron* spp. and *L. tulipifera*, with *Aesculus hippocastanum* (horse chestnut) being moderately susceptible.

Subsequently, a number of the species that were tested for susceptibility by FR have been found to be natural hosts. The experimental susceptibility of these natural hosts has been shown to range from resistant to highly susceptible as shown in Table 2. Tissue was wounded before inoculation. Beech (*F. sylvatica*) was the only known natural host tested to show high ('more') susceptibility in tests on wounded logs from mature trees; wounded stems of saplings were also highly susceptible. Webber (2006) states that log inoculation studies have shown that the bark lesions caused by *P. kernoviae* following inoculation indicate it is less aggressive than *P. ramorum* except when inoculated onto beech. Interestingly, the experimental susceptibility of the other hosts that have been found with stem cankers naturally has not been found to be high. Oak (*Q. robur*) demonstrated low susceptibility in wounded stem sapling tests and was found to be resistant and 'less susceptible' in tests on wounded logs from mature trees. The tulip tree (*L. tulipifera*) was found to have moderate susceptibility in wounded stem sapling tests and like oak (*Q. robur*), was found to be resistant and 'less susceptible' in tests on wounded logs from mature trees.

Those natural hosts that exhibit foliar symptoms and which have been tested for susceptibility experimentally are *Q. ilex* (holm oak) and *I. aquifolium* (holly) both of which exhibit low stem sapling susceptibility and were resistant when logs from mature trees were inoculated; also *Magnolia* sp. which exhibits low stem sapling susceptibility and *Rhododendron* sp. which had moderate susceptibility when stems of saplings were tested. Webber (2006) has clarified that whilst the stems of saplings of *Magnolia* sp. have low susceptibility, foliage susceptibility (unwounded leaves, zoospore dip) is high. Similarly holm oak and holly were only tested for wounded stem susceptibility so the results of the tests do not reflect the natural susceptibility of the foliage.

Those species which were found to have ‘more susceptibility’ in wounded log tests and/or high susceptibility in wounded stems of sapling tests and which have not yet been found as natural hosts were noble fir (*Abies procera*), *Eucalyptus* sp., false beech (*Nothofagus dombeyi*), rauli (*Nothofagus procera*), birch (*Betula pendula*), sweet chestnut (*Castanea sativa*), lodgepole and corsican pine (*Pinus contorta* and *Pinus nigra* var. *maritima*) and western hemlock (*Tsuga heterophylla*). Despite a number of conifer species being highly susceptible, until recently none have been found affected to date in the UK. It is not known if this reflects the distribution of available host species in the areas of Cornwall and south Wales where *P. kernoviae* has mainly been found to date, i.e. whether coniferous species have been exposed to the pathogen by association with sporulating foliar hosts such as rhododendron. The first record of a conifer becoming affected in the UK was in 2007 on *P. salignus* which had been underplanted in a woodland in Cornwall which was known to contain high levels of infected *R. ponticum*. The earliest record of *P. kernoviae* in New Zealand is now known to be from soil under symptomless *Pinus radiata* (radiata pine) (Ramsfield *et al*., 2007); this conifer is not reported as a host but the presence of the pathogen in the vicinity is not explained.

Table 3. Heathland plants found to be susceptible to *P. kernoviae* in laboratory tests (*natural host)

Host	Common name	Family	Plant part tested	Test method	Susceptibility
Arctostaphylos uva-ursi	Bearberry	Ericaceae	Detached leaves	Zoospore dip; both wounded and unwounded	**High**
Calluna vulgaris	Heath	Ericaceae	Detached leaves	Zoospore dip; both wounded and unwounded	Slightly
Empertrum nigrum	Crowberry	Empetraceae	Detached leaves	Zoospore dip; both wounded and unwounded	Slightly
Erica cinerea	Scotch heath	Ericaceae	Detached leaves	Zoospore dip; both wounded and unwounded	Tolerant
Erica tetralix	Crossleaf heath	Ericaceae	Detached leaves	Zoospore dip; both wounded and unwounded	Tolerant
Vaccinium macrocarpon	American cranberry	Ericaceae	Detached leaves	Zoospore dip; both wounded and unwounded	Resistant
Vaccinium myrtillus*	Bilberry	Ericaceae	Detached leaves	Zoospore dip; both wounded and unwounded	**High**
Vaccinium vitis-idaea	Cowberry	Ericaceae	Detached leaves	Zoospore dip; both wounded and unwounded	**High**

Incubation of test material was at 19°C at high humidity for 7 days

Resistant = no evidence of necrosis on either wounded or unwounded tissue for all five isolates tested

Tolerant = necrosis only observed on wounded tissue (any isolate)

Slightly susceptible = necrosis observed on all wounded tissue (all isolates) and one isolate for unwounded tissue
Highly susceptible = necrosis observed on all wounded tissue (all isolates) and more than one isolate of unwounded tissue

Of the heathland species that were tested for foliar susceptibility by CSL, three were found to have highly susceptible foliage: bearberry (*Arctostaphylos uva-ursi*), *V. myrtillus* (bilberry) and *Vaccinium vitis-ideae* (cowberry). *P. kernoviae* killed both leaves and stems of these large-leaved species. Smaller-leaved species such as heathers and heaths (*Erica cinerea*, *Erica tetralix* and *Calluna vulgaris*) were less susceptible. Anon. (2006a). In December 2007, *V. myrtillus* was found to be infected with *P. kernoviae* in a woodland in Cornwall (see http://www.defra.gov.uk/news/2008/080114b.htm). This was the first record of this species being a natural host albeit not in a heathland environment.

9. What hosts are of economic and/or environmental importance in the PRA area?

Of the natural tree hosts, beech (*F. sylvatica*) (a native tree) and oak (*Q. robur*) are economically and environmentally important hosts. Of the tree species affected by bleeding cankers, the highest number affected are beech trees with 56 symptomatic trees (J. Webber, FR, *personal communication*, 2007). Only two oak (*Q. robur*) trees and one tulip tree (*L. tulipiferae*) have been found to date exhibiting bleeding cankers. Rhododendron is probably the most commonly affected ornamental host. Most of the other hosts are grown as ornamentals in the UK. Of these *Magnolia* and *Drimys* are currently the most severely affected. Bilberry (*V. myrtillus*), a recent new host, is an important species in heathland, moorland, acid woodland and grasslands in the UK.

Several of the ornamental hosts are grown as important features in historic gardens in the UK. More detail of the importance of the hosts of *P. kernoviae* is given below. Details are also given of estimates of tree values both from a commercial perspective as well as in terms of amenity value and biodiversity.

Beech

Beech (*F. sylvatica*) grows commonly in the UK in pure or mixed woodlands or occasionally as standard trees or pollards in wood pasture. It is widely planted in avenues and as hedges. Beech is widely used for furniture especially since the demise of elms to Dutch elm disease. (Preston *et al*., 2002).

In Great Britain, there are 76,551 hectares of beech in '*high forest*' (woodlands greater than 2ha) and 6,430 hectares in woodlands 0.1 to <2ha, with the majority located in England. There are a further 3.4 million individual trees located outside woodlands. (Smith and Gilbert, 2003).

Lee (S. Lee, FC, *personal communication*, 2003) estimated the timber value of standing trees of beech in woodlands and small woods in Great Britain to be *ca.* £87 million. (Table 5).

Oak

Oak (*Q. robur*) is a tree found in the UK in high forest, coppice woodland and ancient wood-pasture. It is very widely planted in hedges and woodland. The dominance of *Q. robur* in many woods is the result of many centuries of selective woodland management, followed by deliberate planting in recent centuries. (Preston *et al*., 2002).

In Great Britain, there are 206,154 hectares of oak (assumed to be *Q. robur*) in '*high forest*' (woodlands greater than 2ha) and 16, 543 hectares in woodlands 0.1 to <2ha, with the majority located in England. There are a further 8.8 million individual trees located outside woodlands. (Smith and Gilbert, 2003).

Lee (S. Lee, FC, *personal communication*, 2003) estimated the timber value of standing trees of oak in woodlands and small woods in Great Britain to be *ca.* £196 million (Table 5). He also calculated the value of amenity trees based upon the Helliwell method (Helliwell, 2000). This is a respected method of valuing individual trees in terms of amenity as well as timber which is used by the FC when trying to value trees that have been illegally felled. Values vary with location. Excluding timber and biodiversity values examples include a medium-sized oak adjacent to a nursery valued at £1,440 and a large oak in Hyde Park, London valued at £34, 500. Values have also been calculated for small woodlands; for example £50 for 'a few scrubby trees' of mixed species not having an impact on the area compared to £10,800 for a small woodland of mature oak with a high local landscape value.

Timber values – all trees in Great Britain

Lee (S. Lee, FC, *personal communication*, 2003) has made estimates of the volume and value of timber in Great Britain. He has estimated that the volume of standing timber is *ca.* 316 million cubic metres (Table 4). Of this, 25 million is oak (mainly white oaks in England). European beech (*F. sylvatica*) is relatively unimportant outside of England but the total volume of timber is 9 million cubic metres.

Table 4. Estimated volume (m^3) (millions) of timber in standing trees in woodlands and small woods in Great Britain (2003)

Species	England	Scotland	Wales	Great Britain
Total conifers	63.5	155.0	32.0	250.5
Oak (mainly white oak)	18.0	1.5	5.5	25.0
European beech	7.5	0.5	1.0	9.0
Other broadleaves	28.5	9.5	4.5	42.5
Total broadleaves	44.0	11.5	10.5	66.0
Total – all species	107.5	166.5	42.5	316.5

The estimated values of the volume of timber for standing trees in Great Britain‡ (S. Lee, FC, *personal communication*, 2003) detailed in Table 4 is shown in Table 5. These values are derived from estimated values of £6 /m^3 for conifers and £10 /m^3 for broadleaf species giving a derived total value of the timber standing in British forests of £2 billion.

‡ Other than 122.5 million individual trees in the landscape and excluding private gardens - S. Lee, FC, *personal communication*, 2003.

Table 5. Estimated timber value (£ million) of standing trees in woodlands and small woods in Great Britain (2003)

Species	England	Scotland	Wales	Great Britain
Total conifers	378.5	926.0	185.0	1490.0
Oak (mainly white oak)	159.0	13.5	23.0	196.0
European beech	73.0	5.5	8.5	87.0
Other broadleaves	221.5	83.0	17.5	322.5
Total broadleaves	453.0	102.0	48.5	603.5
Total – all species	831.5	1028	233.5	2093.5

Whilst the value of conifer timber is fairly stable, the value of broadleaf species can vary from negative (more expensive to fell than the value of the firewood) to very high in the case of veneer oak (for example).

Assuming a 50-year rotation for conifers and 100-year rotation for broadleaf species these derived figures approximate to an annual value for all species of *ca.* £35 million (19.5, 11.5 and 4 million pounds for Scotland, England and Wales respectively).

In addition to the values given in Table 5 there is a value associated with the individual standing trees which in terms of purely timber value could be between £30m and £80m in total but at roughly £1 to £2 million per year this is a relatively small contribution. (S. Lee, FC, *personal communication*, 2003).

In addition to the estimated value of the timber of standing trees in Great Britain estimates have also been made of the social and environmental value of forests (Willis *et al*., 2003) as summarised below (S. Lee, FC, *personal communication*, 2003). These include values for open access free recreation, landscape amenity, biodiversity and carbon sequestration. Other benefits not presented here include water supply and quality, pollution absorption, health effects and the preservation of archaeological artefacts

Table 6. Annual value (£ million) of some of the social and environmental benefits of forestry in Great Britain

Location	**Recreation**	**Landscape**	**Biodiversity**	**Carbon sequestration**	**Total**
England	354	124	363	43	885
Scotland	25	19	19	41	104
Wales	13	7	4	9	34
Total GB	393	150	386	94	**1022**

The social and environmental benefits of British forests are therefore estimated to be *ca*. £1022 million per year. This is made up principally of recreational and biodiversity benefits followed by landscape value and carbon sequestration.

Whilst the estimated annual value of timber is small by comparison (*ca*. £36m) there are obvious benefits in employment related to this raw material as well as the products produced from it.

In crude terms combining the raw timber value and the social and environmental benefits British forests could be valued at *ca.* £1058 million per year (2003 figures).

Lee (S. Lee, FC, *personal communication*, 2003) has attempted to give more detailed illustrations of the social and environmental benefits of three forests in regions of England based upon Willis *et al*., 2003. The values (Table 7) were derived by estimating the % of the total value of forests in each region from the estimated % area which each of the three forests represents in that region. Timber values for each region were estimated at £2m.

The forests selected were:

1. The New Forest, Hampshire. An area rich in broadleaf species with a high amenity and biodiversity value close to highly populated areas. Represents 35% of the south-east region.

2. Grizedale Forest, Cumbria. A forest with a higher proportion of conifers but also with high values for recreation. Represents 40% of the north-west region.

3. Kielder Forest in Northumberland. A large post-war man-made forest, predominately comprised of exotic conifers. Represents 70% of the north-east region.

Table 7. Estimated annual value (£ million) of some of the social and environmental benefits of three forests in England

Forest	Recreation	Landscape	Biodiversity	Carbon sequestration	Total
New Forest	32	12	49	4	**97**
Grizedale	14	5	11	2	**32**
Kielder	3	4	13	2	**22**

Rhododendron

Although rhododendrons are grown as ornamental garden plants, species such as *R. ponticum* have become naturalised and are considered to be invasive alien species in managed woodlands, where they are subject to grant-aided control (R. Burgess, FC, *personal communication*, 2004) as well as in unmanaged woodlands. No figures are available for the value of ornamental rhododendron in the UK but it is an economically important plant for the ornamental nursery trade and is very popular as an outdoor plant in managed gardens involved in the tourist industry.

Holm oak

Holm oak (*Q. ilex*) is an evergreen tree, native to the Mediterranean region. It is planted in the UK in parks, large gardens, churchyards and cemeteries, and is described as becoming well-established in copses, woodland and on sand dunes (Preston *et al*., 2002).

Variegated holly

Variegated holly (*I. aquifolium*) is a native evergreen shrub of deciduous woodlands, especially those on acidic soils in which *Fagus* and *Quercus* predominate. It is described as a frequent or locally dominant undershrub but rarely dominating the canopy. It is also found in wood-pasture, scrub and hedgerows, and on ledges of acidic cliffs. It is often planted in amenity areas and parkland. Widespread planting has completely obscured the native distribution of this species. (Preston *et al*., 2002).

Cherry laurel

Cherry laurel (*P. laurocerasus*), a native of the Balkan peninsula, is a glossy-leaved evergreen shrub or small tree, naturalised in woods and scrub, and sometimes self-sown. This was being cultivated in Britain by 1629 and was known from the wild by 1886. It is now commonly planted for amenity. (Preston *et al*., 2002).

Ivy

Ivy (*H. helix*) is a native evergreen perennial woody climber most characteristic of woodland, scrub and hedgerows, but also common on walls, rock outcrops and cliffs. It may carpet the ground in secondary woodland. It generally favours basic to moderately acidic soils. It is highly palatable to deer and stock. (Preston *et al*., 2002). It is also sold as an ornamental plant (RHS, 2007).

The remaining hosts (except *V. myrtillus*) are all grown as ornamentals in the UK and so are not listed in Preston et *al*., 2002. Further detail on the popularity of these hosts in the UK has been gleaned from RHS 2007.

Magnolia

Magnolia spp. is a genus with a scattered natural range which includes eastern North America, Central America and the West Indies and east and south-east Asia. Some species are found in South America. Many species of *Magnolia* and an ever-increasing number of hybrids can be found planted as ornamental trees in large parts of North America, Europe, Australia and New Zealand. *Magnolia* spp. are extremely popular in the UK and the RHS (2007) lists 340 records with numerous suppliers. The genus features as specimen plants in managed gardens involved in tourism. Denman *et al.* (2005) have commented that some of the magnolias that are affected by *P. kernoviae* are very rare or even threatened species and have cultural and horticultural significance in the UK. Cicuzza *et al*. (2007) has found that over half the world's magnolia species are facing extinction in their forest habitats.

Pieris

Pieris japonica and *Pieris formosa* belong to a genus of seven species of evergreen shrubs native to mountain regions of eastern and southern Asia, eastern North America and Cuba. In RHS 2007 there are many entries for suppliers of varieties of both species in the UK.

Chilean hazelnut

Chilean hazelnut (*G. avellana*) is an ornamental tree that is native to South America (Mabberley, 1997). It is listed in RHS 2007 as having 4 suppliers in the UK.

Michelia

M. doltsopa is an ornamental tree native to Asia (Mabberley, 1997) and is listed in RHS 2007 as having 10 suppliers plus 2 suppliers of named varieties in the UK.

Podocarpus

Podocarpus salignus is a coniferous tree native to southern Chile and it is listed in RHS 2007 as having more than 20 suppliers in the UK.

Tulip tree

The tulip tree (*L. tulipifera*) is a tall deciduous tree native to eastern North America. RHS 2007 list 49 suppliers plus a high number of suppliers of named varieties in the UK.

Winters bark

Winters bark (*D. winteri*) is an evergreen tree native to temperate forests in Chile and Argentina, where it forms a dominant tree in the coastal evergreen forests. It is listed in RHS 2007 as having 30 suppliers in the UK with a further 16 suppliers of two named varieties in the UK.

Bilberry

Bilberry (*V. myrtillus*) is a low-growing shrub which grows in acid soils. In the UK it is commonly found in lowland and upland heathland, moorland (which differs from typical heathland in being much colder and wetter often with extensive bogs), some grasslands and as an understorey plant in acid woodland of *Betula* (birch), *Pinus* (pine) and *Quercus* (oak). (Preston *et al*., 2002). Although it has been found affected in a woodland valley in Cornwall it has not been found affected in the other habitats.

Alonso (2008) has reviewed the importance of bilberry in Great Britain. The following paragraphs are taken from her report:

Ritchie (1956) lists 30 species of insects associated with bilberry but it is unclear whether these are monophagous (feed exclusively) on *V. myrtillus*, oligophagous (feed on this species and just a few other) on *Vaccinium* species or polyphagous on a range of host plants, of which bilberry is one. Crafer (2005) lists 56 species of macrolepidoptera (moths and butterflies) which are known to feed on bilberry. Some of these are monophagous on bilberry; some are monophagous in the UK but known to feed on other species (e.g. *Calluna*) in other countries; some may be locally monophagous but associated with a suite of low-growing woody shrubs, e.g. *Calluna*, *Betula* and *Vaccinium* spp. in other parts of their ranges. Emmet (1988), lists 3 species of microlepidoptera as monophagous on *V. myrtillus* with a further 37 species known to feed on *Vaccinium* species as part of their diet. Three of the moths are species of notable importance in national conservation terms. Heie (1995) lists 10 species of aphid associated with

Vaccinium species of which only one species is listed as monophagous on *V. myrtillus*. Southwood & Leston (1959) list only one species of heteropteran associated with *V. myrtillus*, and one other polyphagous species. UK BAP (Biodiversity Action Plan) also lists two hymenopterans (bumblebee and bee). Some of them require bilberry for part of their lifecycle, not only for feeding. *Vaccinium*, therefore, cannot be considered in isolation from other factors in the environment.

As a fruit, bilberry is sold in small amounts (not well-documented) but a value of £10K per annum was achieved in the Stiperstones area of Shropshire and lesser amounts in Wales (Sanderson and Prendergast, 2002). The berry is also collected from the wild by individuals.

Cherimoya

The New Zealand host cherimoya, also known as custard apple (*Annona cherimola*) is a shrub or small tree which is native to the Andean-highland valleys of Peru, Ecuador, Colombia, Argentina, Chile and Bolivia. It is widely-cultivated in Chile for its fruit. It is listed in RHS 2007 as having 3 suppliers in the UK.

10. If the pest needs a vector, is the vector present in the PRA area?

There is no evidence of direct vector involvement but most *Phytophthora* species do not require a vector to facilitate dispersal and spread. The mode by which this organism spreads is discussed under question 14, below.

11. What is the pests present geographical distribution?

United Kingdom

P. kernoviae is present in England, Wales and Scotland in the UK where it is currently limited to a number of locations in Cornwall, one location in Devon, six locations in south Wales, one location in western Scotland as well as on the Isle of Arran off the west coast of Scotland. It has been found on one 150-year old rhododendron in north-west England which has been destroyed and no further findings of *P. kernoviae* have been made at this site for more than a year. All of the known affected trees are currently in Cornwall (Webber, 2006).

The nursery finding in north-west England in September 2004 was eradicated but as this was a retail nursery it is possible, but not confirmed, that infected plants have been sold to the public. The likely distribution of any potentially-infected plants that may have been sold has not been discovered. Trace-back activity did not identify any sources of infected plant material. Trace-forward is not possible for retail premises where details of purchasers are not normally kept. The first affected nursery in Cornwall is still under official control but may have despatched potentially- infected plant material within the UK and to third countries. Recipient countries NPPOs have been notified. The second affected nursery in Cornwall is also a retail nursery (currently no information on exports to other countries) and is also subject to official control. The recent finding in western Scotland (confirmed in January 2008) was on two established rhododendron plants in a private garden. This site is subject to investigation and official control. The finding on the Isle of Arran, an island off the west coast of

Scotland on two rhododendrons and one *Drimys* was confirmed in February 2008. (V. Smith, SGRPID, *personal communication*, 2008).

New Zealand (NZ)

P. kernoviae is also present in New Zealand where it was first officially reported to be present in March 2006. (Anon., 2006d; NAPPO, 2006; EPPO, 2006). According to EPPO (2006) the pathogen was found during studies aimed at determining which species of *Phytophthora* were present in New Zealand. *P. kernoviae* was found at 2 sites in Northland (North Island). It was isolated from a cherimoya (*Annona cherimola*) sample in one orchard, and from a soil sample collected from Trounson Kauri Park.

Subsequent personal communication (J. Webber, FR, 2006) following a visit to Australia informed by discussions with Dr M. Dick (Ensis - Scion, NZ) and later on with Dr M. Ormsby (Biosecurity-NZ) and Dr Buchanan, Landcare Research, NZ suggests that *P. kernoviae* has in fact been found associated with two orchards of cherimoya (*Annona cherimola*) in Kohukohu (a historic settlement on the Hokianga Harbour in the far north of New Zealand), and that in both cases the orchards had become non-productive because of the extent of shoot and fruit blight apparently caused by *P. kernoviae*. The pathogen had been isolated from the infected shoots/fruits of plants from one orchard sampled in September 2002 and from soil/litter of the other sampled in December 2005. Gill (2006) states that the first sample had been submitted for testing by a cherimoya grower and that plants had been displaying symptoms there since the early 1990s. The orchard was surrounded by native bush; it is no longer being managed as an orchard and has reverted to bush. Phytosanitary controls there include prevention of movement of plants and soil off-site and restricted access.

A third isolate came from soil under a dead *Agathis australis* (a coniferous tree native to the northern districts of North Island known as a kauri) in Trouson Kauri Park sampled in May 2003 (J. Webber, FR, *personal communication*, 2006). According to Gill (2006) samples were collected as part of an investigation of kauri dieback; the tree was described as ‘long-dead’ and *P. kernoviae* was not isolated from kauri tissue. Phytosanitary controls at this site include prevention of movement of plants and soil off-site and restricted access. Trounson Kauri Park comprises 450ha of primary forest surrounded by pastoral land (Gill, 2006).

There are no links between the cherimoya site(s) and this third site in Trounson Kauri Park. (Gill, 2006).

By July 2006, trace-forward activity of budwood of cherimoya detected *P. kernoviae* in soil at Whangarei, the northern-most city of New Zealand. No further details of the site situation were given. Other sites were negative but many trees had been destroyed by growers who had reported problems with ‘fungi’. Trace-back activity was negative at Kaitaia which is approximately 160km northwest of Whangarei. (Gill, 2006).

Gill (2006) also refers to a ‘Tokoroa *Phytophthora*' being considered a new species in 1970 and having been collected in 1953, 1956 and 1968/69. This organism was described as having low temperature requirements like *P. kernoviae*.

Most recently, Ramsfield *et al*., (2007) have reported[§] that the Tokoroa *Phytophthora* is in fact *P. kernoviae* and that it was first found in the 1950s under stands of symptomless *P. radiata* (radiata pine). It has been isolated from both indigenous and exotic forests in several regions of the North Island. Although no hosts other than *A. cherimola* are reported in New Zealand, the lead author has acknowledged that there are currently no plans to conduct surveys of nursery stock so the status of *P. kernoviae* in plants in the New Zealand nursery trade is unknown.

Details of New Zealand isolates can be found at:
http://nzfungi.landcareresearch.co.nz/html/data.asp?ID=81-XJD-43&NAMEPKey=38942

AFLP (Amplified Fragment Length Polymorphism) analysis of a number of UK isolates and one New Zealand isolate of *P. kernoviae* showed that there was no significant difference between isolates from the different countries but some variation between isolates from the same site and from different sites. (K. Hughes, CSL, *personal communication*, 2007). Sequencing of the ITS region showed that the one NZ isolated sequenced had a single base pair difference compared to UK isolates (K. Hughes, CSL, *personal communication*, 2007); this was confirmed by New Zealand studies (Ramsfield *et al*., 2007).

For the UK, *P. kernoviae* is considered to be a recent exotic introduction (Brasier, 2007). AFLP profiles of over 90 UK isolates showed there was little or no genetic variation between the isolates from discrete outbreak sites or hosts, suggesting their introduction from a single source, rather than from multiple introductions from genetically variable populations (Anon, 2005a).

Prior to the reports of the presence of the pathogen in New Zealand, speculation as to the area of origin of *P. kernoviae* was made by Brasier *et al*., 2005, 2005a. Because of its temperature optima (*ca*. 18°C) and upper limit (26°C) for growth *in vitro*, the authors considered that *P. kernoviae* may be adapted to a temperate climate. Its main host range at the time of writing (2005) (Ericaceae, Fagaceae and Magnoliaceae) and its closest relative being *P. boehmeriae* (which has affinities with China and the western Pacific) led the authors to believe the origin of the pathogen may be in temperate forests of the eastern Himalayas, China or Taiwan. The 'favoured origin' was Yunnan in south-west China and the Himalayas because these areas were frequented by plant collectors. Patagonia was another option because of the association with *G. avellana*, the Chilean hazelnut. There is currently insufficient evidence to judge whether the findings of *P. kernoviae* in New Zealand are evidence of an introduction or whether this is a region where the pathogen is endemic or even native (J. Webber, FR, *personal communication*, 2007; Brasier, 2007).

12. Could the pest enter the PRA area?

[§] Not reported in the abstract; reported in the platform presentation

Yes. *P. kernoviae* has already entered the PRA area from an unknown origin or origins. The status of the pathogen on commercial nurseries in New Zealand is not known but it has the potential to be present on host plants there and could enter the UK on plants originating there (or may have already done so). Brasier *et al*. (2005a) suggest that *P. kernoviae* was introduced into the UK by the plant trade in the past 10 to 15 years and possibly prior to *P. ramorum.*

Until information is available on its full distribution outside of the UK and New Zealand, especially its area of origin including whether the initial speculation of an Asian origin is correct (suggested prior to the reports from New Zealand), it is not possible to say whether, or when, further introductions of *P. kernoviae* would occur.

With New Zealand currently being the only other country where the pathogen is known to occur an examination of exports of known host plants shows that there is a long history of potential pathways of entry for *P. kernoviae* from New Zealand to the UK. Exports from the UK to New Zealand seem less likely but have not been investigated to date.

<u>Imports of ornamentals from New Zealand</u>
Between January 1995 and November 2006 the value of imports of rhododendron from New Zealand amounted to £4,000 (1996), £5,000 (1999) and £7,000 in 2001 (Source: H M Revenue and Customs; Data prepared by Trade Statistics, Agricultural Statistics and Analysis Division, DEFRA; M. O'Donnell, Defra, 2007, *personal communication*). No detailed data are available from this source for the other known hosts of *P. kernoviae*.

CSL internal records document imports of many of the hosts of *P. kernoviae* over the past 20 to 30 years from a large (140ha) New Zealand ornamental plant specialist (specialising in several of the host species of *P. kernoviae*) based on North Island as well as from several others in New Zealand. The large company has been involved in tree/plant exports for more than 100 years.

Examples of the numbers of imported host species into the UK (from more than one New Zealand source) include:

i 1977 – first 3 months – *ca.* 10,000 'ornamentals'
ii 1981 – *ca.* 9,000 *Magnolia*, 1300 *Rhododendron*
iii 1982 – 1,950 *Magnolia*, 3, 800 *Pieris*, 390 *Rhododendron* with a total of 204,294 plants
iv 1983 – imports into the south-west of England – 250 *Magnolia*, 600 *Pieris*, 240 *Rhododendron* with a total of 15,000 plants
v 1984 - imports into the south-west of England – 2,675 *Pieris*, 519 *Rhododendron* with a total of 32,000 plants
vi June 1985 – a reference to 20,000 *Pieris* entering the UK

Many of these plants came into the UK under a derogation from a prohibition on such imports since prior to the Plant Health (Great Britain) Order 1987, Part IA of Schedule 2 of the Import and Export (Plant Health) (Great Britain) Order 1980 set out the conditions under which rooted plants and unrooted vegetative propagating material could be imported. Item 5 prohibited the import of all plants of trees and shrubs (except a few genera of conifers, *Castanea*, *Quercus* etc.) from a long list of countries, including New Zealand. The Plant Health (Great Britain) Order 1987 was far more liberal in that, under Schedule 3, Part II item 8, most plants of trees and shrubs from New Zealand were permitted entry with a phytosanitary certificate. No further detailed records of imports were made as a result. (P. Bartlett, CSL, UK, *personal communication*, 2007; I. Johnstone, PHSI, UK, *personal communication* 2007). It is known that the first nursery to become affected in Cornwall, which is adjacent to the first known affected woodland, has imported many *Magnolia* plants from New Zealand over at least the last ten years.

The CSL records also document interceptions of pests and pathogens on imported ornamentals but with only one record of an unknown *Phytophthora* sp. on roots of *Camellia* in November 1989. There is also a report from the Lincoln Plant Health Service (South Island, New Zealand) in November 1980 of a *Phytophthora* sp. causing the demise of a gooseberry bush in Timaru (wet conditions implicated so it is assumed to be a root infection) and a *Phytophthora* sp. causing the death of walnut seedlings in Nelson with no further details. To date *P. kernoviae* has not been recorded on any of these hosts and has also not been directly implicated in root disease. Brown *et al*. (2006) reported that lesions on tree stems of beech (*F. sylvatica*) caused by *P. kernoviae* have also extended below ground level but root infection has not yet been reported. The same has been found for rhododendron (Anon., 2006c).

<u>Imports of timber from New Zealand</u>

Now that it has been shown that *P. kernoviae* can survive in the xylem of beech (*F. sylvatica*) (12mm maximum depth for 24 months after bark removal) (Brown and Brasier, 2007), timber of this species and possibly other tree host species which become infected in the stem such as oak (*Q. robur)* represents a possible pathway of entry into the UK if these hosts become infected in exporting countries, such as New Zealand. The first isolates of *P. kernoviae* in New Zealand arose from soil underneath stands of symptomless *P. radiata* (radiata pine) and it is possible that untreated timber of this species may harbour the pathogen.

According to MAF (2007) the New Zealand forest industry is comprised mainly of planted forests, covering 1.8 million hectares (*ca.* 7% of New Zealand's land area). Forests have been planted there for production purposes for *ca*. 100 years. They are mainly composed of coniferous softwood species with 90% of the area planted with radiata pine (*P. radiata*). Experimental testing by FR has shown that *Pinus contorta* and *Pinus nigra* var. *maritima* are highly susceptible in log/sapling tests and that *Pinus sylvestris* has moderate susceptibility (see Table 2). Sixty-seven percent of the planted forest in New Zealand has been pruned to produce high quality timber. In the year up the end of June 2002 the New Zealand forestry industry harvested 21.6 million cubic metres of logs and exported the roundwood equivalent (from logs and residues) of 15.6 million cubic metres in raw and processed form.

The biggest concentrations of plantation forests are in the central North Island with other major growing areas in Northland, Hawkes Bay, East Cape, Nelson, Marlborough, Otago and Southland. (MAF, 2007). *P. kernoviae* has been detected in Northland and it is presumed that the findings of the pathogen in the 1950s under stands of *P. radiata* was in a plantation forest.

New Zealand also has 6.4 million hectares of indigenous forest (24% of the total land area) located mainly in the mountains and hill country, and on the west coast of the South Island. The major indigenous tree species in these complex forests are beech (presumed to be *Nothofagus* spp. according to FITEC, 2007 rather than *F. sylvatica*), kauri (*A. australis*), rimu (*Dacrydium cupressinum*), taraire (*Beilschmiedia tarairi*) and tawa (*Beilschmiedia tawa*). Approximately 77% of the indigenous forest is in national parks and reserves, covering 18.2 percent of the total land area. (MAF, 2007). FITEC (2007) states that New Zealand government policy requires that extraction of native forests must be 20% less than the forests can grow each year. Less than 1% of New Zealand's timber harvest comes from natural forests. Natural beech forests on South Island have survived well because their timber was 'less desirable' and the land they occupied was not so useful for farming purposes. Exports of indigenous timber are restricted to sawn beech (presumed to be *Nothofagus* spp.) and rimu (*Dacrydium cupressinum*) (although FITEC, 2007 ascribes rimu to *Podocarpus spicatus*). *Nothofagus dombeyi* and *Nothofagus procera* were 'more susceptible' to *P. kernoviae* in log inoculation/sapling tests conducted by FR and *Nothofagus obliqua* 'less susceptible' (Table 2). No antipodean species of *Nothofagus* have so far been tested for susceptibility to *P. kernoviae*.

FAOSTAT (2007) shows that in 2004 New Zealand exported the following forestry products to the UK:

- i Industrial roundwood (wood in the rough - non-coniferous) – 15, 000 m^3. This commodity aggregate includes all industrial wood 'in the rough' of non-coniferous species of origin other than tropical (the UK exported only 4 m^3 to New Zealand)
- ii Sawnwood (coniferous) - 2, 364 m^3
- iii Sawnwood (non-coniferous) – 20 m^3

The tree species that are harvested for export from New Zealand are not specified by FAOSTAT (2007) but the volume of the exports shows that both coniferous and non-coniferous species are exported from there to the UK. There are currently no specific phytosanitary requirements for *P. radiata, Nothofagus* spp. or rimu imported from New Zealand into the UK with respect to *P. kernoviae.*

In the last 12 months (R. Burgess, FC, 2007 *personal communication*) the FC have inspected 4 consignments of timber totalling 183m^3 of *P. radiata*, all declared as kiln-dried. Two of the accompanying phytosanitary certificates showed treatment of 40 hours at 85°C. No details of the thickness of the timber were given but if this was less than the normal thickness of 5.1cm (R. Burgess, FC, 2007 *personal communication*) it is assumed (but not scientifically proven) that such a treatment would render *P. kernoviae* non-viable.

MAF New Zealand has implemented requirements for Pest-Area Freedom Declarations for *P. kernoviae* and *P. ramorum* for exports of timber to Australia. See http://www.biosecurity.govt.nz/exports/forests/standards/australia-pest-area-freedom.htm.

A requirement for measures for timber imports to the UK may need to be considered with respect to freedom from *P. kernoviae* in New Zealand timber.

13. Could the pest establish outdoors in the PRA area?

Yes. The organism has been found to be established in woodlands and managed gardens with a limited distribution in the PRA area since the autumn of 2003 and it is subject to official control. Most of the currently affected woodland and garden sites are close to the coast and located in the south-west and west of the UK. The finding of a single mature rhododendron in a managed garden in north-west England was also close to the coast. The finding in mainland Scotland was on the western coast. The finding on the Isle of Arran was coastal. Because of the distribution of the known findings, there may be some significant influence of humidity and rainfall, coupled with mild winters, on the biology of the organism, which may help determine the extent to which *P. kernoviae* could establish if official control was lifted. Of the three nursery findings, the first-affected nursery in Cornwall is adjacent to the woodland site where the first infected rhododendrons were located and the pathogen may have moved onto the nursery from there or vice-versa. This nursery is known to have received imports of *Magnolia* spp. from New Zealand over a number of years.

In vitro investigations (Brasier *et al*., 2005) revealed that the optimum temperature for growth of *P. kernoviae* on carrot agar is *ca*. 18°C with an upper temperature for growth 26°C. This suggests it is adapted to a temperate climate.

Baker (CSL, *personal communication*, 2006) compared the climate of one of the affected woods in Cornwall with that of Trounson Kauri Park, New Zealand where *P. kernoviae* is present. Patterns of rainfall and temperature were the same when comparing the same seasons, with New Zealand being warmer and wetter. However, maximum temperatures were less than 25°C in Trounson Kauri Park compared to less than 20°C at the Cornish site. This fits in with the temperature optima and maxima described by Brasier *et al*., 2005. The cooler temperatures at the affected wood in Cornwall may be more favourable to the pathogen than those of North Island, New Zealand; nevertheless the temperatures there are not restrictive to the establishment of the pathogen.

The host range of this pathogen is currently narrower than that of *P. ramorum* but still relatively wide. Nevertheless, there are sufficient host plants present in the natural environment of the UK as well as planted in public and private gardens to support establishment. Denman *et al*. (2006) suggested that *P. kernoviae* has a higher degree of '*field fitness'* than *P. ramorum* and that it is very aggressive to rhododendron in Cornwall. At the time of writing (October 2005) the authors considered that there were probably more plants infected with *P. kernoviae* in the UK (this must refer to non-nursery sites) and that it was a more competitive pathogen than *P. ramorum* and more aggressive to its hosts.

With the recent finding of *P. kernoviae* on *V. myrtillus* in a mixed broad-leaved woodland located in a valley in Cornwall there is potential for the pathogen to establish in environments where this host occurs i.e. heathland, moorland, acid woodland and some grasslands. The affected woodland contains *R. ponticum* and this has been surveyed since 2004. *P. ramorum* was found on *R. ponticum* in a wood to the north of the site in March 2005 and *P. kernoviae* in the same area in April 2006. There are watercourses in the area as well as access by walkers both of which could contribute to further spread and establishment. The first affected *V. myrtillus* plants were adjacent to an infected *R. ponticum* but later finds have been *ca.* 10m away. It is possible that the pathogen could have initiated infections from *R. ponticum* and then spread amongst the vaccinium plants. The outbreak continues to be investigated but it is subject to eradication activity. (B. Jones, FC, 2007/8 *personal communication*).

Prior to this natural finding, experimental work showed that both wounded and unwounded detached plant material of *V. myrtillus* (and *V. vitis-idaea*) was highly susceptible to infection by *P. kernoviae* (see Table 3). As part of the same investigation, the sporulation potential of a range of heathland species, including *V. myrtillus*, compared to California bay laurel (*Umbellularia californica*; a key sporulating host of *P. ramorum* in California) and *Rhododendron catawabiense* was done to further determine the potential risk to heathlands posed by *P. kernoviae*. Both wounded and unwounded leaves/sprigs were inoculated and incubated using the same method as the host susceptibility tests (zoospore dips, incubation at 19°C at high humidity for 7 days). The number of sporangia that were observed per cm^2 at the end of the experiment is shown in Table 8.

Table 8. Sporulation potential of heathland species inoculated with *P. kernoviae* (Anon., 2006a)

Test plant	Species	Sporangia/cm^2	
		Wounded leaves	Unwounded leaves
Control species	*Umbellularia californica*	1200	900
	Rhododendron catawabiense	1100	800
Heathland species	*Empertrum nigrum*	7300	0
	Erica tetralix	5400	0
	Erica cinerea	1500	0
	Vaccinium vitis-idaea	400	0
	Vaccinium myrtillus	400	5
	Calluna vulgaris	500	0

Whilst similar levels of sporulation occurred in the wounded and unwounded control plants (not heathland species), few if any sporangia were produced on unwounded plant parts of the heathland species, but wounded material of all species tested did sporulate. However, *V. myrtillus* and *Vaccinium vitis-ideae* produced the least sporangia under these conditions despite being highly susceptible to infection.

Although heathland species have yet to be found to be naturally infected in heathland environments or the other environments where they occur, those that have been found to be less susceptible to infection by *P. kernoviae* are smaller-leaved but have a greater sporulation potential than the larger leaved, highly susceptible species (see Tables 3 and 8; Anon., 2006a). Compared to the favourable conditions of these experiments, heathland and other environments where these species grow vary somewhat and not all locations may be favourable to the pathogen. Further work is needed to determine the ability of heathland species to sporulate in their natural environments as well as an indication of the incidence of known sporulating hosts in these environments, since without sufficient sporangia the pathogen may not be able to perpetuate itself there. Woodlands containing these environmentally-important species, such as the location where the *V. myrtillus* was found infected recently are more likely to be favourable but it is not known if the pathogen can perpetuate itself on this species alone. Because heathland is found adjacent to woodlands where trees and rhododendrons are known to be naturally infected with *P. kernoviae* in Cornwall there remains a risk that the pathogen could spread to heathland environments. Heathland species could also become a source of inoculum for trees and shrubs.

The pathogen is homothallic (i.e. does not have a requirement for an opposite mating type to be able to reproduce sexually). It has been observed to produce oospores in the laboratory in culture (Anon., 2005b) and in rhododendron leaves following inoculation (Anon., 2006c). If these form naturally then they could facilitate survival in the UK. The sporangia which contain the motile infective zoospores are caducous (deciduous and detached primarily by water); this aids dispersal from the aerial parts of infected plants. Release and dispersal of sporangia is primarily considered to involve water, such as rain or mist events, which may also involve some wind assistance e.g. wind-blown mists or wind-driven rain-splash that may then also result in the formation of aerosols. This might enable dispersal over longer distances than by rain-splash alone. Although dispersal of sporangia from plant surfaces by 'dry' wind alone cannot be ruled out, there is currently no evidence for this. No chlamydospores (survival structures) have been observed. The potential for the pathogen to adapt further to its putative new environment intrinsically or via hybridisation is not known; work investigating species hybridisation between *P. kernoviae* and other *Phytophthora* species is on-going under a Defra-funded fellowship (Defra Project PH0312).

<u>A summary of research findings related to the risk of establishment is given below</u>.

All of the research work undertaken to date seems to support the view that rhododendron foliage is acting as the primary inoculum source for infection of tree stems in the UK leading to bleeding cankers (Anon., 2006c, Brown *et al*., 2006a). It is not known whether other foliar hosts are major sources of inoculum for tree and shrub hosts but there is no reason why this should not be the case, though the quantity of inoculum produced will vary significantly depending on the host. Studies in two woodlands in Cornwall where both *P. ramorum* and *P. kernoviae* were present affecting a naturalised understorey of *R. ponticum* as well as a number of trees including beech (*F. sylvatica*) showed that 9 out of 12 trees with lesions caused by *P. kernoviae* were within 2m of an infected rhododendron, in many cases being in direct contact with the foliage. It was assumed that zoospores or sporangia were splash-dispersed from the rhododendron foliage onto the tree stems and that the spores penetrated the bark leading to infection and symptom development. Where affected trees were not in close proximity to the rhododendrons it was suggested that wind-driven inoculum in mist and/or rain had led to tree stem infection. (Brown *et al*., 2006). Webber (2006) considers that foliar colonisation and sporulation is vital in driving the disease epidemic and suggests that sufficient inoculum may have to build up in the canopy of susceptible foliar species before stem infection of tree hosts can occur. Webber (2006) and Denman (2006) reported that when trap plants of *Q. ilex*, *Rhododendron* and *Magnolia* were placed in the field near to infected rhododendrons for 14 day periods from June 2005 the highest levels of infection in the trap plants occurred from the end of June to the end of July and then again in September to mid-October. However, some level of infection occurred in most months and the activity of *P. kernoviae* extended longer than that of *P. ramorum.*
Studies on the vertical movement of *P. kernoviae* in infected woodlands shows that it can infect foliage up to 3m (the height of the rhododendron canopy) but does not appear to escape from infected woodlands through the margins (Webber, 2007). Long distance dispersal of spores has been detected at very

low levels at a maximum of 50m from the nearest inoculum source; this is the maximum distance tested to date and not necessarily the maximum dispersal distance for the pathogen (J. Turner, CSL *personal communication*, 2007).

Sporulation potential

The sporulation potential of leaves of tree hosts was investigated by inoculation of the leaves of whole plants with zoospores (Anon., 2006c). Hosts tested were selected on the basis of being the most common tree hosts found with foliar symptoms in nature (*Magnolia* sp., *M. doltsopa* and *Q. ilex*) and these were compared to *Rhododendron catawbiense*. Following inoculation and incubation, sporulating lesions developed. There was no significant difference in the mean number of sporangia produced per cm^2 between *Magnolia* and *R. catawbiense* with significantly fewer sporangia produced by *Q. ilex* and the least number being produced on leaves of *M. doltsopa*. More details of this work (Denman and Orton, 2007) and the interpretation by the authors suggest that *P. kernoviae* sporulates more on rhododendron than the other hosts and causes larger lesions. Earlier preliminary work using detached leaves and leaf dipping in a zoospore suspension (Denman *et al*., 2006) showed that following inoculation larger lesions developed on magnolia compared to rhododendron and that sporulation was abundant on magnolia on both sides of the leaves and less abundant on the lower surface of rhododendron leaves. However, these were visual observations and were not quantified. Sporulation is supported by symptomatic foliar hosts such as rhododendron and magnolia. From experimental work it appears that naturally-infected asymptomatic leaves of rhododendron and holm oak may also support the sporulation of *P. kernoviae* (Denman *et al*., 2007; Webber 2007), though the significance and frequency of this asymptomatic sporulation in natural situations is as yet unknown.

By taking swabs from bleeding lesions on infected trees it was concluded that few if any spores are produced on infected bark. The low level that was only very rarely detected may reflect contamination. However, it has been shown that *P. kernoviae* commonly occupies the xylem beneath phloem lesions and that it can spread in xylem and may initiate new phloem lesions via this route. (Anon., 2006c; Brown and Brasier, 2007). This is described in more detail under '*Infection process*' below.

The sporulation potential of heathland species is shown in Table 8 and described above.

Infection process

In vitro studies showed that zoospores of *P. kernoviae* were able to penetrate the unwounded bark of logs of beech (*F. sylvatica)* leading to phloem lesions. In field experiments, no lesions developed on logs of beech (*F. sylvatica*), oak (*Q. robur*) and sycamore (*Acer pseudoplatanus*) when placed under rhododendron infected with *P. kernoviae* in early July 2006 through to mid-August when conditions were hot and dry. In a repeat experiment, fresh logs were placed out in early August and rain started falling from late August onwards. Lesions developed only on the beech logs and after 6 weeks. Results demonstrate that rain is required for dispersal and infection to occur. The experiment also included *P. ramorum* and by comparison, the lesions which developed were larger but less numerous for *P. kernoviae*. (Brasier *et al*., 2007).

Specific studies of the behaviour of *P. kernoviae* in individual trees were described in detail in Brown and Brasier (2007) (earlier reported in Brown *et al*., 2006) who described observations of spread of *P. kernoviae* from heavily infected *R. ponticum* onto stems of *Fagus*, *Quercus* and other tree hosts leading to aerial stem bleeding lesions. Coniferous species (an important component of the UK timber industry) have been shown to be susceptible to infection in laboratory tests and only recently became reported as natural hosts (*P. salignus*; foliar and shoot infection). Surveys in Cornwall gave rise to observations that suggested *P. kernoviae* was active in the xylem tissue underlying phloem lesions on *F. sylvatica* and had the potential to move from infected xylem into previously healthy bark. Further experimental work showed that this was the case for *P. kernoviae* as well as other *Phytophthora* spp. including *P. ramorum*. The commonly held view prior to this publication was that *Phytophthora* stem lesions tend to be confined to the phloem and cambium layers. It now seems that *P. kernoviae* and other *Phytophthora* species can colonise the underlying xylem up to a depth of 25mm.

Brown *et al*. (2006) describe fresh lesions on beech (*F. sylvatica*) tree stems as having a high level of moisture and suggest that mycelium may actively transport water from the xylem into the phloem. They surmise that this would provide a favourable environment for *Phytophthora* species and an unfavourable environment for other competing fungi (ascomycete and basidiomycetes). *P. kernoviae* lesions under the bark of beech are described as '*pumping*' water from the xylem (Brasier and Jung, 2006); these authors suggest that bark-invading ascomycetes and basidiomycetes may replace the primary pathogen.

Brown and Brasier (2007) suggest that various features of the symptoms and results of isolation suggest that the '*linear pattern of phloem lesions*' might result from vertical movement of *Phytophthora* spp. including *P. kernoviae* within the xylem followed by bark colonisation. It is surmised that the pathogen may move as spores or mycelium on an '*embolism*' inside xylem vessels. However, inoculum may also spread by runoff of water on the surface of the bark, leading to multiple sites of infection and symptoms on the stem of the tree. The findings of this work show that xylem AND phloem function can be affected by infection by *P. kernoviae*. The result is disruption of water and nutrient supplies within the tree arising from callus formation associated with lagoon formation (local breakdown of xylem and phloem tissue produces '*lagoon cavities*'). Pressure may build up within the internal vascular system leading to bark rupture and external bleeding.

Brown and Brasier (2007) describe attempted experimental eradication of *P. kernoviae* from trees of *F. sylvatica* in Cornwall by excision of infected phloem. Their study showed that *P. kernoviae* had survived in the xylem for at least two years after excision of the overlying phloem. This has implications for risk management. (See Stage 3, below).

Effects of eradication

Studies conducted in two small (<1 ha) woods in Cornwall which were found to contain high levels of disease on rhododendron and a number of affected beech (*F. sylvatica*) trees were undertaken by CSL and FR in 2005 and 2006 (Anon., 2006c). All of the affected trees in the woods were in direct contact with heavily infected shoots and foliage of rhododendron. The woods also contained sycamore (*A. pseudoplatanus*), holly (*Ilex* spp.) and oak (*Q. robur*) trees with dense rhododendron understorey. The studies aimed to: (a) quantify disease levels and environmental contamination at infected sites prior to eradication and monitor inoculum levels during and after eradication and to (b) determine whether removing infected rhododendron and leaf litter reduced inoculum levels sufficiently to protect susceptible trees from further infection. Eradication began in November 2004 and was completed in January 2005. Disease monitoring undertaken in October 2004 was used to inform the eradication strategy which involved removing all rhododendron in the woodlands, which, along with the surface leaf litter, was burnt on the edges of the woods. Rhododendron stumps were treated with herbicide to try to prevent regrowth. Hygiene precautions to try to prevent spread outside of the woods were targeted at footwear, machinery and tools. The final report for this work (Anon., 2006c) is completed but further monitoring was ongoing until the end of March 2007 (Turner *et al*., 2006). The work has so far shown the following:

Mapping of the distribution of infected trees and rhododendrons in the woods showed there to be two large foci of infection in the centre of one wood and distinguishable foci in the second wood; interconnections between foci in the second wood followed pathways of easiest access, which may indicate movement via vectors or via wind/air movement within the wood during rainfall or mist events. However, there was no evidence for any disease gradient across the woods that would normally suggest that dispersal was purely via wind-blown inoculum, although secondary spread and microclimate conditions within the woods may subsequently have influenced any initial dispersal pattern. Rather, it was suggested the pathogen was being splash-dispersed but also being moved by wind-driven rain. Rotorod spore traps failed to detect airborne spores in October 2004 pre-eradication (November 2004) but rain traps detected inoculum during rain. Following eradication, rain traps sited 1m above ground (high level rain traps) failed to detect *P. kernoviae* between December 2004 and March 2006. Regrowth of rhododendron in September 2005 was found to be infected and the symptoms may have arisen through rain splash, but stem-base infections may have occurred through another route. (Residual inoculum was detected in the stump and the surrounding soil). As a result of the finding of infected rhododendron regrowth in September 2005, ground level rain traps were set-up in November 2005 in areas of the woods where high levels of disease had been present prior to eradication. Splash-borne inoculum was subsequently detected every month up to the end of monitoring in April 2006. Levels were at their highest in November and December and then declined in January and February rising again in March/April. (Anon., 2006c). Further monitoring undertaken between May and October 2006 did not detect *P. kernoviae* between May and August but the pathogen was detected again in September and October. (Turner *et al*., 2006).

Prior to eradication of infected rhododendron, *P. kernoviae* was found to be present in the litter layer (using rhododendron leaf baiting methods) and in the soil in the root zone around infected trees of beech (*F. sylvatica*) in both woods. The root zones of infected trees were the primary areas where inoculum could be detected below the surface soil/litter layer. It was not present in litter (soil data were not presented) around healthy trees which is where levels of infected rhododendron were lower. Testing of soil and leaf litter across the whole area of the woods showed that *P. kernoviae* was found in the leaf litter but not in the soil. Post-eradication and one year after the first samples were taken *P. kernoviae* was not detected in the surface soil/litter at any of the main sampling points across the wood. However, the pathogen was detected in soil samples taken at a number of additional sampling points which were located in areas where infected plant material had been stacked prior to burning or areas where infected regrowth had been found. Results indicate that eradication action was very successful in lowering the inoculum at the sites but that additional contamination occurred as the result of movement of infected plant material or from infection of regrowth from a residual inoculum source. (Anon., 2006c).

A method of detecting *P. kernoviae* in soil through detection of DNA showed that the normal bait test (baiting using rhododendron leaves) is less sensitive and may not detect the presence of *P. kernoviae* below a certain level. Data from monitoring of rain traps shows a clear seasonal pattern of inoculum detection with levels highest during the winter and lowest during the summer. This seasonal pattern is most likely due to dry warm summer conditions suppressing sporulation on foliar hosts. In 2006, soil samples taken from the two woodlands showed higher levels of inoculum (based upon DNA detection) where disease levels were highest pre-eradication and where regrowth of rhododendrons had become infected (Turner *et al*., 2006). The results indicate that inoculum is still present within the woodland but at levels below the threshold of detection of the traditional baiting method. Levels of contamination are still being analysed.

Monitoring the foliage of holm oaks (*Q. ilex*) in the two woods post-eradication of infected rhododendrons revealed no detectable *Phytophthora* infections in February, May, July and September 2005 and none in October 2006. In February 2005 a sprouting rhododendron stump adjacent to one of the holm oaks in one wood was symptomatic and *P. kernoviae* was isolated from the leaves of the sprouts. Trap plants of *R. catawabiense* and *Q. ilex* were placed in the wood in November 2005 and although suspect symptoms appeared on one rhododendron trap plant in May 2006 no *Phytophthora* spp. were isolated. The conclusion was that the holm oak foliage in both woods remained free of *P. kernoviae* over a 2-year period and that following removal of infected rhododendron there was little sign of aerially-dispersed inoculum in either wood. (Anon., 2006c).

Following eradication of the infected rhododendron the lesions on the infected beech trees continued to develop. No additional trees were found to have become symptomatic after rhododendron removal. (Anon., 2006c). Reducing the level of inoculum in the woods by removing infected rhododendron was therefore shown to have a significant impact on protecting trees from new infection by *P. kernoviae*.

Related studies

In 2006, studies commenced at a large managed garden in Cornwall focussing on five diseased plants as 'sites' for monitoring contamination of soil/leaf litter and movement of inoculum either by low-level rain splash or larger scale dispersal in the air during rainfall (Turner *et al*., 2006). Results to date show that *P. kernoviae* was detected in high-level (1m above ground) rain traps in May and June 2006, was absent between July and early September and then detected again between October and December. Low-level traps detected the pathogen in each of these months but not at all locations and less so in July and August. A rain trap located in open ground did not detect *P. kernoviae* at any time between May and December 2006 suggesting no detectable long-distance spread at this site. However, quantitative analysis of the water samples collected from rain traps between October 2006 and February 2007 has shown that inoculum was detectable in samples collected during January. The number of spores present was estimated to be approximately 40 spores/L. Monitoring close to the diseased plants has indicated peaks in dispersal occurring in November 2006 and January 2007. *P. kernoviae* was detected in leaf debris near two of the 'sites' (diseased plants).

Studies of the effect of removal of a large, heavily-infected rhododendron in July 2004 at an estate in Cornwall showed that *P. kernoviae* was readily isolated from soil (baiting with rhododendron leaves) for several months prior to removal and that a rapid decline in the level of the pathogen in the soil occurred subsequently with sporadic but lower levels of isolation up to the end of the study in April 2006. These data provide evidence that *P. kernoviae* declines rapidly in soil following removal of the inoculum source but can persist for at least two years. (Lockley *et al*., 2007).

At another outbreak site, disease development on a single infected rhododendron bush surrounded by more plants with severe symptoms was monitored between November 2005 and October 2006. Leaf washes showed no sporulation at the first assessments. (Anon., 2006c). When assessed in June 2006 there appeared to be little spread of disease but significant disease development occurred between June and the next assessment in October. This spread of disease coincided with the flush of new leaves on the plant during September and new infections were most prevalent where the plant was closest to another heavily infected rhododendron. (Turner *et al.,* 2006). Therefore, there is evidence that disease development on rhododendron is dependent both on the seasonality of inoculum production and seasonality of growth and the age of leaves.

14. Could the pest establish under protected environments in the PRA area?

Yes. There have been three nursery findings to date, that in the north-west of England was in a semi-protected shade house (with a covered roof, net sides and an open door). However, the first finding on a nursery in Cornwall was not under protection. (D. Slawson, PHSI, *personal communication*, 2007). At the second nursery to become affected in Cornwall, the three mature magnolia plants that were found to be infected were located outside a polytunnel in an area where public access occurs (the polytunnel is used for retail sales). The pathogen could establish and spread under protected environments (e.g. glasshouses or polytunnels) if environmental conditions and cultivation practices favour disease development (i.e. cool temperatures; overhead irrigation); high temperatures and a lack of overhead irrigation would be less favourable for the pathogen.

15. How quickly could the pest spread within the PRA area?

Subsequent to the first record of *P. kernoviae* in October 2003, the pathogen appears to have spread relatively slowly but significant action has been taken to eradicate/contain the pathogen in infected areas. It is not known whether the organism was introduced separately to the affected locations or has spread between them. The rate of spread may increase if controls are lifted. If the pathogen enters the nursery trade more frequently (only three findings to date) the potential for spread will increase significantly. Future investigation of data collected over the last 4 years of surveillance and testing and dates of first findings might help show the course of events at the affected sites.

Brown *et al*. (2006a) support the view that plant collectors or the horticultural nursery trade were likely to have been responsible for the introduction of *P. kernoviae* to the UK. Brasier and Jung (2006) suggest that there is a link between *Phytophthora*-infested nursery stock (referring to the genus *Phytophthora*) and damage to forests with circumstantial evidence of the apparent spread of *P. kernoviae* from out-planted rhododendrons or other nursery stock onto *R. ponticum* and then onto trees in Cornwall. Infected rhododendron has been found at all of the affected outdoor sites and it is surmised that plants of this genus (and maybe other genera of foliar hosts that support sporulation) are acting as a source of inoculum, at least for beech (*F. sylvatica*) if not other tree and shrub hosts. Infected *R. ponticum* is present in the area where *V. myrtillus* was found infected in late 2007. Although some of the infected vaccinium plants are some distance from infected rhododendron this may still be the original source of the inoculum which could have been liberated from the rhododendron and spread aerially, in the local water courses, or by walkers in the area. The finding in north-west England in May 2006 was on a mature rhododendron in a large managed garden open to visitors where *P. ramorum* had been found previously and since. The first finding in Scotland, in late 2007, was also on rhododendron plants that had been planted there for 10 to 15 years. These plants had been sourced from a local rhododendron nursery that sources its plants from outwith Scotland. The garden is open to visitors. Inspection in 2003 for *P. ramorum* did not find any infected material. The pathogen was most recently found in February 2008 in a managed garden on rhododendron and *Drimys* on the Isle of Arran. The garden is open to the public. It is not known how the pathogen has spread to the island but it may have come in on infected plant material.

The first finding on a nursery in Cornwall (January 2006) is adjacent to the first known affected woodland (October 2003) and lies within the *P. kernoviae* Management Zone (see 20.). This nursery has also been in receipt of magnolias from New Zealand. It is not known whether *P. kernoviae* spread from the nursery to the woodland or from the woodland to the nursery, nor whether this site was the original or only point of introduction into the UK. There is known to have been movement of plants between several of the sites in Cornwall and from Cornwall to south Wales. The finding on a nursery in Cheshire may have facilitated further spread to private gardens (not proven) but it does not appear to have spread to the immediate area around the nursery. The circumstances related to the second nursery to become affected in Cornwall are still subject to investigation.

Amplified Fragment Length Polymorphism (AFLP) analysis of the relationship of isolates of *P. kernoviae* from a selection of locations and hosts, showed that there were no distinct groups or clusters based on host, geographical location or place of origin in the UK (Anon, 2005a; K. Hughes, CSL, *personal communication* in Beales *et al*., 2006). Subsequent AFLP analysis of UK isolates and one New Zealand isolate showed that there was no significant difference between isolates from the different countries but some variation between isolates from the same UK site and from different UK sites (K. Hughes, CSL, *personal communication*, 2007). Isolates from the garden in north-west England, the gardens in Scotland and the Isle of Arran and the vaccinium in Cornwall were not included in this study as they were detected later.

The biology of the organism is becoming better-understood. This is a caducous species (i.e. with deciduous sporangia) and a pathogen principally affecting the aerial parts of its hosts; local aerial spread over short distances is considered to be primarily by rain splash and by wind-driven rain or even mists. In culture, *P. kernoviae* produces deciduous sporangia but it does not produce chlamydospores. Longer distance dispersal of spores has been detected 50m from an inoculum source, but at very low levels (J. Turner, CSL *personal communication*, 2007). However, long distance spread over many kilometres could easily occur through the movement of infected stock of all of the known host plants as well as others that are as yet undiscovered. This may explain the recent findings in Scotland. Early findings of *P. kernoviae* did not appear to be linked to water or footpaths (D. Slawson, PHSI, *personal communication*, 2004). The organism has been isolated from soil in the UK and New Zealand, although the form in which it exists in soil is unknown. It has also been isolated from soil/debris attached to boots (Webber and Rose, 2005). It is possible therefore that soil and leaf litter/debris movement could facilitate long and short-distance spread including through contamination of invertebrates or vertebrates, or human agents (e.g. through contaminated soil/debris attached to footwear, machinery, etc). As part of the investigation of the effect of eradication of rhododendron in two small woods in Cornwall, rabbit and badger burrows and badger tracks have been sampled but no *P. kernoviae* has been detected. However, samples taken from boots of people walking through the woods has yielded some positive samples for *P. kernoviae*. (Anon., 2006c; Webber, 2006). By sampling scrapings of shoes of people walking mainly within the *P. kernoviae* Management Zone in Cornwall (see 20.) between July 2004 and December 2005, 10% of samples yielded *P. kernoviae.* The peak period for positive samples was in June and July.

No large-scale detailed studies of the presence of *P. kernoviae* in water courses has been undertaken. Limited monitoring between October 2006 and March 2007 of a stream at an outbreak in a managed garden indicated consistent presence of inoculum in the water during the period (J. Turner, CSL, *personal communication*). Water-baiting of an open channel at the first affected nursery in Cornwall where the *P. kernoviae* outbreak is subject to eradication detected *P. kernoviae* in January 2007. The potential for water-borne inoculum to lead to new plant infections and further spread of the pathogen is not known.

The observed rate of spread could be related to inoculum levels being below a threshold for infection and disease development to occur in areas where obvious symptoms have not so far been detected. Clearance of rhododendron in some areas has slowed the observed rate of spread. Evidence from monitoring shows that where inoculum sources (foliar hosts) have been left *in situ* the frequency of new infections in susceptible plants is increasing.

16. What is the pest's potential to cause economic, environmental or social impacts in the PRA area?

P. kernoviae currently poses most threat to beech (*F. sylvatica*), oak (*Q. robur*) rhododendron (*Rhododendron* spp.), holm oak (*Q. ilex*), *Magnolia* spp. and bilberry (*V. myrtillus*) as well as a number of other susceptible trees, shrubs and other environmental or ornamental plants based on recorded natural hosts and experimental hosts.

Evidence suggests that *P. kernoviae* has killed some established *R. ponticum* plants and at least one beech tree (*F. sylvatica*); these are the main species affected to date. Fifty-six beech trees have developed bleeding cankers to date. Beech exhibits (sometimes) large or multiple bleeding cankers (Brown and Brasier, 2007). The first beech tree to be completely girdled as result of *P. kernoviae* infection was found in 2006 (Anon., 2006c). *P. kernoviae* has also caused bleeding stem cankers on two oak trees (*Q. robur*) and on one tulip tree (*L. tulipiferae*). Of the foliar hosts, those most at risk at present based upon the number of infected individuals are *Drimys*, *Magnolia* spp. and *Rhododendron* spp. The recent first finding of *P. kernoviae* in western Scotland and on the Isle of Arran are considerably out of its previous range although the climate in western Scotland is favourable to the pathogen. This shows its potential to cause damage in the range predicted by earlier climatic matching work undertaken to direct the surveillance for *P. ramorum* (see Appendix I). Should the pathogen start to move around in the nursery trade or spread further in the outdoor environment then there is potential for more host species to become affected.

P. kernoviae has the potential to cause significant economic damage by directly affecting:

i Trees grown for timber – these may be killed or physically damaged. Also, it now seems that *P. kernoviae* and other *Phytophthora* species can colonise the underlying xylem of beech trees (*F. sylvatica*) up to a depth of 25mm (12mm for *P. kernoviae*) and that the pathogen can survive in the xylem for at least two years after excision of the overlying phloem. (Brown and Brasier, 2007). This has implications for risk management. (See Stage 3, below)

ii Other economically important hosts including ornamental species, both trees and shrubs which may also be killed or physically damaged iii The natural and semi-natural environment. This would occur through death or non-lethal damage to key tree and understorey species in woodlands, forests, parkland, heathland, moorland and possibly grassland. There is a risk to *Vaccinium* species and other heathland species growing in woodland. *V. myrtillus* was recently found infected in a woodland valley in Cornwall and this species, as well as *V. vitis-idaea* (and *A. uva*-ursi) have been shown by experiment to be highly susceptible to infection by *P. kernoviae*. However, limited surveys by the PHSI have not revealed any natural infection of these hosts in heathland , moorland or grassland to date. It is not known whether this type of (more open) environment would favour disease or whether the pathogen can sustain itself on heathland species if there is no significant source of sporulation such as rhododendron in the vicinity. This requires further investigation.

Indirect damage would occur through impacts on:

iv Local economies which are associated with tourism. It is known that some historic gardens involved in tourism have been negatively affected because of the damage to ornamental plants, as well as the removal of some of these, which has affected the landscape
v Employment in the forestry industry (this has not been a problem to date)
vi Exports of plants and domestic plant sales in the UK nursery industry. If controls are not maintained that prevent the pathogen from being distributed by the nursery industry the implications for these sectors will increase. This is discussed further below:

Currently, in the PRA area, *P. kernoviae* is only known to occur in a limited number of locations in England and Wales, as well as one mainland and one island location in Scotland. Depending upon its phytosanitary status in other countries there may be trade implications for exports of host plants from the UK. *P. kernoviae* has only been found on three nurseries to date despite extensive testing and this needs to be kept in check if the export trade is to be maintained (the value of which has not been accounted for to date). The UK domestic nursery trade is also very important and would be affected if *P. kernoviae* was to be more widely distributed in UK nurseries. With regard to UK exports, limited investigation of information held in the International Phytosanitary Portal (IPP, 2007) done to determine which countries have specific requirements for *P. kernoviae* showed that only one Regional Plant Protection Organisation (EPPO) named the organism (EPPO, 2005). This may be because the organism has only been recently described. A general search of IPP (2007) yielded a list of 62 countries which either include *P. kernoviae* in their regulated pest lists or mention it in their legislation but this may not be valid. For example, in the summary of the Australian regulations *P. kernoviae* is not listed specifically. However import condition C9599 for *Rhododendron* spp. nursery stock from European Countries, New Zealand and the USA states: 'This genus/species is a host of *Phytophthora ramorum* (Sudden Oak Death) and/or other *Phytophthora* complex species. The importation of plants and plant parts (other than tissue cultures) of this genus/species is prohibited entry into Australia.' MAF New Zealand has implemented requirements for Pest-Area Freedom Declarations for *P. kernoviae* and *P. ramorum* for exports of timber to Australia. (See http://www.biosecurity.govt.nz/exports/forests/standards/australia-pest-area-freedom.htm). For Canada *Phytophthora ramorum* and *Phytophthora* spp. are both included on the Canadian regulated pest list but not *Phytophthora kernoviae*. For the USA only *Phytophthora fragariae* is listed on the APHIS regulated pest list. (S. Bishop, CSL, 2007 *personal communication*).

Potential impacts
The potential impact of *P. kernoviae* in the UK will depend upon the geographic areas to which it might spread, especially if controls are relaxed. The recent findings in Scotland may be related to infected plant material being brought to the sites. Whilst the pathogen is subject to phytosanitary control its full impact has not been realised. It should be assumed that in the absence of control it has the potential to spread more freely to existing and new hosts, particularly in the nursery trade. The full potential extent of spread of *P. kernoviae* is directly related to the local environmental conditions, the availability of natural hosts and the presence of sporulating hosts.

Based upon current observations, the pathogen's range in the PRA area may be restricted to mild, humid areas in the south and west of the UK. Clearly it has the potential to affect gardens and woodlands in the south-west of England, south Wales and western Scotland based upon the outbreaks that have occurred to date. Four years after the first findings it seems less likely (but not impossible) that much of rest of the UK might be suitable for establishment of the pathogen. However, damage to tree stems and subsequent death of susceptible tree species might occur only if they are subjected to high inoculum pressure from spores produced on nearby infected rhododendrons or other foliar hosts, since tree hosts which do not support foliar infections and sporulation but only have susceptible bark are unlikely to provide their own inoculum. If that is the case then vulnerable woodland could be protected by accelerating efforts to remove potential sources of inoculum such as invasive *R. ponticum,* the commonest rhododendron in the UK in woodlands and wild spaces, and a key factor in the epidemiology of this disease. In addition to ongoing clearance work targeted at controlling *P. ramorum* and *P. kernoviae*, *R. ponticum* is already being controlled at some affected sites because it is an invasive non-native weed which reduces biodiversity by smothering out native species. The recent finding of *P. kernoviae* on *V. myrtillus* in a woodland in Cornwall supports the view that there is a potential for damage to heathlands, moorlands and possibly grasslands if the pathogen spreads into these environments and if it can sustain itself there. This will affect the ecology of these habitats as vaccinium (and other heathland species that may become infected) is a primary food source for a number of species and supports the lifecycles of others directly or indirectly (see 'Bilberry' in section 9).

Britain and Ireland together support *ca.* 20% of the worlds lowland heath and the UK supports 2-3 million hectares of upland heath, which represents *ca.* 75% of the total resource. All upland and lowland heathland types are classified ad Annex 1 habitats under the European habitats Directive (Council Directive 92/43/EEC; UK regulations Statutory Instrument SI 2007/1842). (J. Perry, Countryside Commission for Wales, *personal communication*, 2008). The potential impact that *P. kernoviae* may have if it establishes in these habitats is not known as it is not known how damaging it could become there. *Vaccinium* is clearly environmentally important and even if it is not killed by *P. kernoviae*, removal or wide-scale cutting of *Vaccinium* to reduce the risk of pathogen spread will impact on a range of species, even if they spend part of their life-cycles elsewhere, with consequent repercussions through the food chain over a wide area.

In terms of costing the potential impact of the pathogen then the effect it might have if left uncontrolled needs to be weighed against the cost of maintaining official controls. The risk management scenarios are to:

i Do nothing
ii Attempt full eradication
iii Continue with containment action (some elements of which will involve eradication activities such as removal of *R .ponticum* and possibly other foliar host species that would otherwise generate inoculum).

Cost-benefit analysis has not been performed for the different management options for *P. kernoviae*. This requires a comparison of the costs of risk management and the value (benefit) of the hosts, environments and businesses that may be affected.

Costs involved in eradication and/or containment include:

i Continued surveillance and testing of plants, natural and artificial substrates and possibly waterways in wild areas, managed gardens and nurseries
ii Eradication of known infected and non-infected hosts with the potential to sporulate
iii Restrictions on movements of plants, people and potentially contaminated substrates etc.

The value (benefit) of individual hosts, woodlands, forests and timber is described under 9. Relative to the extremely large social, environmental and economic benefits of woodlands, the value of the timber industry, the value of the ornamental industry, and, the national heritage in historic gardens, the value of environmentally important areas such as heathland and moorland (which are not yet affected but may be at risk), the costs of eradication and/or containment in the currently affected areas are likely to be small, but still very substantial and requiring long-term commitment. Cost of removal of trees and rhododendron is described under 19.

17. What is the pest's potential as a vector of plant pathogens?

Phytophthora kernoviae is a plant pathogen which like other *Phytophthora* species has no capacity to vector other plant pathogens.

STAGE 3: PEST RISK MANAGEMENT

18. What are the prospects for continued exclusion from the PRA area?

Until the distribution of the organism outside of the PRA area is known, it is not possible to determine from which countries it could be excluded. Monitoring of imports is in place in the UK but as yet *P. kernoviae* has not been detected on imported plants. Prior to the reports from New Zealand it was speculated (but not proven) that the pathogen may be Asian in origin. Controls on host plants originating in New Zealand where the pathogen is known to occur would reduce the risk of further entry to the UK. Controls on imports of wood may need to be considered given the recent confirmation that *P. kernoviae* was first isolated in New Zealand in the 1950s from soil under stands of the timber species *P. radiata*, as well as the evidence that *P. kernoviae* can survive in the xylem of *F. sylvatica* for up to 2 years (see 19.). MAF New Zealand already export timber to Australia on the basis of 'pest-free areas' to fulfil Australian import requirements. See http://www.biosecurity.govt.nz/exports/forests/standards/australia-pest-area-freedom.htm. Lateral flow devices (LFDs) that can detect the presence of the genus *Phytophthora* are available for official inspectors to test material that may enter the PRA area or move within it; research in on-going as to whether a species-specific LFD can be developed for *P. kernoviae* (Defra Project PH0412). Any suspect material can be tested in the laboratory and identified to species by traditional isolation and culturing methods as well as molecular methods including real-time PCR (Schena *et al*., 2006).

19. If the pest enters or has entered the PRA area what are the prospects of eradication?

Eradication in outdoor (non-nursery) sites is dependent upon clearance of infected and uninfected foliar host plants that are or can become sources of inoculum, principally (but not exclusively) rhododendron in woodlands and managed gardens. *P. kernoviae*, like *P. ramorum* uses rhododendron as its primary foliar host in the UK as it is very susceptible and infection results in higher levels of inoculum being produced compared to other tested hosts (Denman and Orton, 2007). Where infected rhododendrons (mainly *R. ponticum*) have been removed from affected woodlands as part of experimental investigations of management approaches this has (to date) been successful in reducing inoculum levels in the woods and no additional trees have become symptomatic with stem cankers (Anon., 2006c). Prevention of regrowth from the stumps of large rhododendrons which have been left *in situ* has to be undertaken to avoid further sporulation. Destruction and safe disposal of infected plants and associated debris will aid eradication. Clearance of vaccinium and *R. ponticum* at the affected woodland valley site in Cornwall (plants within a 2 metre radius of an infected plant) is underway. Site monitoring will be needed to determine the efficacy of the eradication campaign.

Eradication has so far been achieved outdoors at one of the 52 non-nursery outbreak sites where *P. kernoviae* has not been detected for at least 1 year. (D. Slawson, PHSI, *personal communication*, 2007).

In Cornwall, a small-scale exercise funded by Defra and the FC is underway to clear rhododendrons, particularly invasive *R. ponticum* from woods which pose a high risk of spread of the pathogen (Ward, 2006). By November 2006 approximately 40ha had been/was being cleared of *R. ponticum* (Slawson, 2006). Priority for clearance in Cornwall has been based upon a risk matrix in which all infected woodlands in Cornwall have been given a score based upon the % rhododendron cover, the level of infection of both *P. kernoviae* and *P. ramorum* in the woods, access and value. In south Wales, 40 ha of rhododendron was due to be cleared by the local council with assistance from the FC. Further clearance work depends upon the costs, practicalities and effectiveness of this action. Continued surveillance in the affected areas is planned until at least 2009. (Anon., 2007a).

With respect to costs, according to Lee (S. Lee, FC, *personal communication*, 2003) the estimated cost of felling and burning an area of *ca*. 1 hectare of trees according to draft protocol, was estimated then at around £7,000. This does not include an additional £4,000 required for surveying the surrounding area and possible subsequent monitoring. The cost of destroying rhododendrons varies with the size and density of the 'crop'. £3,000 per hectare was a typical contractor figure at the time. More recent figures based upon work in Cornwall give the costs of clearance for *R. ponticum* as £7,000 per ha for woodland and £10,000 per ha for public gardens (I. Sanders, PHSI, *personal communication*, 2007).

With regard to efficacy, clearly there has been a highly significant reduction in inoculum in the two Cornish woods studied post-clearance of rhododendron, but it is not 100%. Webber (2007) considered that *P. kernoviae* could persist for at least a year in leaf litter. Monitoring at a site in the south-west of England has shown residual inoculum in the soil/litter persisted for at least two years after the removal of rhododendron plants. This was detected using sensitive DNA-based methods but this may be below epidemiologically significant levels. Long term monitoring shows that inoculum levels decline rapidly in soil following removal of infected plants. Low levels of inoculum have been detected in hot spots especially near to the stumps of previously infected plants. *P. kernoviae* does not produce chlamydospores which would normally facilitate longer-term survival. However, as it is homothallic it has the potential to produce oospores in host tissue without the need for an opposite mating type. This could facilitate survival in the absence of live hosts. Oospore production has not been observed naturally to date but the pathogen has been observed to produce these potentially long-lived, sexually-produced spores in culture and in inoculated rhododendron leaves. Long-term persistence in the natural environment may depend on the propensity for oospore production; although, the longevity of these spores is not known, it is likely to be at least several years based on comparisons with other *Phytophthora* species. Whether these spores could lead to new infections is not known. Findings of *P. kernoviae* in soil or water may be difficult to eradicate if the pathogen is surviving in this form.

Eradication will be made more difficult if long-distance aerial dispersal over kilometres is possible by wind. Many of the trees with stem lesions have been within 2m of an infected rhododendron. There is recent evidence of aerial dispersal associated with rain events up to 50m from an inoculum source. This is the maximum distance tested to date, but not necessarily the maximum distance that spores could travel in favourable conditions such as wind-driven rain.

When considering work aimed at eradication other management options that could be considered are to:

i Decrease the frequency of potential hosts within vulnerable ecosystems and managed gardens by removing all potential sources of sporulating foliar hosts, not just *R. ponticum*

ii Link eradication activities to the epidemiology of the pathogen. Inoculum levels seem lower in hot dry summers and highest between November and February. Plants are susceptible to infection during leaf flush and flowering. Thus, clearance work may be best scheduled for hot dry summer periods

Regarding survival of the pathogen in wood, Brown and Brasier (2007) showed that *P. kernoviae* had survived in the xylem of *F. sylvatica* for at least two years after excision of the overlying phloem (this had been undertaken as an experimental control measure). In some cases fresh phloem lesions appeared to have arisen from a source of inoculum in the xylem. It is not known in what form the organism was present in the xylem. If it had formed oospores these have the potential to facilitate long-term survival in host tissue, making eradication potentially difficult.

Brown and Brasier (2007) state that '*total removal of phloem and outer bark from tree stems is a recommended protocol for preventing national and international spread of quarantine organisms such as* P. ramorum *and* P. kernoviae *on transported wood products'*.

They recommend that where excision is used for control this should also include removal of affected xylem.

Currently according to FAO (2006) '*bark-free wood'* is '*wood from which all bark excluding the vascular cambium, ingrown bark around knots, and bark pockets between rings of annual growth has been removed'*. This therefore does not include removal of the xylem.

Brown and Brasier (2007) suggest that as *Phytophthora* spp. can remain viable up to 25mm into the xylem a minimum removal of 3cm of outer sapwood would be needed which may not be practicable. They suggest it may be preferable to destroy the infected tree stems when dealing with a quarantine issue such as *P. kernoviae*.

Findings on beech (*F. sylvatica*) or other tree hosts will need to be managed on a case-by-case basis based upon the risk posed to other hosts with foliar hosts probably posing the greatest risk of spreading the pathogen to uninfected host plants and trees.

All of the actions that are currently being undertaken (see 20.) should assist eradication at non-nursery sites in the longer term if they are given full support.
Two of the three nursery outbreaks are ongoing but could be declared eradicated if the actions described under 20 are strictly applied and natural re-introduction

from any local sources prevented. (D. Slawson, PHSI, *personal communication*, 2007). It is possible that the recent findings in Scotland were related to infected planting material. Keeping *P. kernoviae* out of the nursery trade is essential in preventing further spread within the UK and perhaps overseas.

20. What management options are available if eradication is not possible?

Since the first findings of *P. kernoviae* in the UK in October 2003 new legislation (the Plant Health (*Phytophthora kernovii* [sic] Management Zone) (England) Order 2004) (Anon., 2004a) has been introduced aimed at <u>containing</u> the pathogen within a specified area of the south-west of England known as a ‘Management Zone’, but with a view to eradication.

Slawson (2006) summarised the legislation and gave a synopsis of actions being taken at all sites where *P. kernoviae* has been found both <u>within the zone and on sites outside of the zone as appropriate, which have arisen since the zone was established:</u>

When the order was established the movement of susceptible material from within the zone to outside the zone was prohibited without the written authority of an ‘inspector’. Inspectors are provided with powers to enter premises for the purpose of inspecting and seizing any susceptible material that they have reasonable grounds for suspecting is being or has been moved in contravention of the prohibition. Inspectors may also, for the purpose of preventing the spread of *P. kernoviae*, close footpaths within the zone.

Any nurseries and garden centres in the management zone (and any others where *P. kernoviae* is present in the vicinity but not on the nursery itself) are subject to an intensive programme of official inspection and testing. The inspection and testing programme consists of at least the following:

i Fortnightly inspections of all plants on the premises. Suspect symptoms to be tested by LFD (for *Phytophthora* spp.) with laboratory testing of positive results
ii Fortnightly pre–despatch checks on consignments of susceptible plants leaving the premises except for direct sales to the public including mail order
iii Laboratory testing of a representative random sample of one leaf from every 30 susceptible plants taken once every 3 months from around the premises
iv Laboratory testing of water-bait samples once every 3 months from water courses/irrigation water within or near the premises (noting that recovery rates may be lower in summer months). Supplementary baiting of soil, gravel beds, paths etc. may also be required.

No plants, or parts of plants, are allowed to be moved outside the zone without the prior written authority of an inspector confirming that the following criteria have been met:

Movement of susceptible plants may only be permitted if:

i No signs of *P. kernoviae* are observed during the programme of official inspections.

ii No *P. kernoviae* is detected during the programme of official testing
iii All plant debris is removed from the surface of growing containers
iv Susceptible plants must not have received any treatment with anti-*Phytophthora* fungicides during a 6 week period prior to despatch

Movement of all other plants only be permitted if all plant debris has been removed from the surface of growing containers. A site hygiene protocol has to be agreed with the inspector. The boundary of the nursery/garden centre has to be cleared of susceptible host plants and trees that are potential sources of inoculum.

In addition to these requirements the following has been done at the affected nurseries :

i Destruction by burning or deep burial (infected plants, susceptible plants within a 2m radius of infected plants and associated plant debris)
ii Disinfection of surfaces
iii Prohibition on the movement of susceptible plants within a 10m radius of infected plants and remaining plants in the infected lot for at least 3 months
iv Advice on the cessation of overhead irrigation as appropriate
v Trace-back and trace-forward of related plant material

Also, in parks, gardens and on uncultivated land action includes:

i Prohibition on the movement of the infected plants and parts of the plants
ii Destruction by burning or deep burial
iii Prevention of regrowth
iv Felling or pruning of infected trees
v Measures to prevent re-infection at the site

As referred to under 19, even if eradication is not feasible, in order to contain the pathogen it is important that *P. kernoviae* is not allowed to enter and then spread within the nursery trade. With only three nurseries affected to date it may be that the existing national controls for *P. ramorum* and the controls listed above are minimising the risk of this happening. However, the recent Scottish findings may be related to infected planting material. Maintaining these controls would be one way of preventing further spread within the UK. The potential for the pathogen to spread from infected woodlands/gardens is probably limited to those nurseries that are located within these sites or nearby. There is evidence that *P. kernoviae* has the potential to move in watercourses but no substantial investigation of the presence of the pathogen in these environments has been undertaken to date. Limited data suggest that rhododendron baits are more sensitive to the presence of *P. ramorum* than *P. kernoviae* and there would need to be further validation of the existing bait test if surveillance of watercourses for *P. kernoviae* was to be undertaken on a larger scale.

Investigation of the efficacy of fungicide treatments has been limited. As part of the investigation of control of *P. ramorum* in hardy nursery stock (Turner *et al.*, 2006b) one isolate of *P. kernoviae* was tested for sensitivity to fungicides under evaluation in this project. The fungicides were evaluated against mycelial growth on agar and against spore germination by a photometric method. Those products containing metalaxyl-M in the formulation were most effective. Fungicide treatments are not used as a phytosanitary management tool for *Phytophthora* species of quarantine concern as they have the potential to suppress symptom development in newly-infected host plants. In the absence of eradication they should not be used for containment. (N.B. As a general rule, products containing metalaxyl-M have the potential to become ineffective due to the development of resistance and should only be used in formulated mixtures or in regular rotation with other active ingredients).

A joint Defra/HDC-funded Project ongoing until 2008 (Anon., 2006; Jennings and Humphries 2006) has shown that slow sand filters have been very effective at removing zoospores of *P. kernoviae* from contaminated water. A range of disinfectants have been shown to decontaminate Mypex inoculated with either *P. ramorum* or *P. kernoviae* (applied as a soil-based inoculum) the most effective requiring only 5 minutes exposure.

Studies on the efficacy of heat treatment for host plants infected with *P. kernoviae* have been undertaken in two Defra-funded projects (Anon., 2006b; Turner *et al* 2006a). Experiments show that dry heat treatment has the potential to kill inoculum of *P. kernoviae* on leaf surfaces, however, once the pathogen has infected the leaf and symptoms have developed the treatments are no longer effective.

Controls on imports of wood of susceptible hosts, particularly beech (*F. sylvatica*) and oak (*Q. robur*) may be required but at present the only other country which has found *P. kernoviae* is New Zealand and these host species are not known to be infected in that country. However, small quantities of timber of radiata pine (*P. radiata*) is imported from New Zealand and may be a potential pathway of entry. MAF New Zealand has implemented requirements for Pest-Area Freedom Declarations for *P. kernoviae* and *P. ramorum* for exports of timber to Australia. See: http://www.biosecurity.govt.nz/exports/forests/standards/australia-pest-area-freedom.htm.

Wood of species susceptible to *P. ramorum* is already prohibited entry to the EU from the USA unless it has been treated in some prescribed way or is declared to have originated in an area where non-European *P. ramorum* is known not to occur. Susceptible bark is prohibited. (Anon., 2002, 2004, 2007). Treatment or pest-free area declaration requirements for *P. kernoviae* on susceptible species of imports of wood from NZ may need to be considered.

Controls on movement of wood harvested from an infected tree in the UK requires that the stem and branches be stripped of bark under the general powers under the Plant Health (Forestry) Order 2005 (article 31.4 (d)). (R. Burgess, FC, *personal communication*, 2007). This may need to be reconsidered to include removal of xylem down to 3cm if the wood is to be used without treatment. Destruction of known infected trees may be a safer option.

The potential for developing genetic resistance in host species is unknown at this stage but would be a long-term strategy for consideration if there is a risk of wide-scale mortality of important plant species. Brown *et al*., 2006 described some variation in lesion development in affected beech (*F. sylvatica*) tree stems in some individuals being continuous and in others being arrested by the edge of a lesion in the phloem becoming sealed off by callus tissue. They suggest that this may reflect genetic factors or may be due to seasonal influences, host physiology and the host-pathogen interaction. No work on breeding for resistance has been undertaken to date.

SUMMARY OF THE PEST RISK ANALYSIS

Phytophthora kernoviae is a new and damaging exotic pathogen of trees and shrubs which was first detected in Cornwall, UK in October 2003 affecting beech (*Fagus sylvatica*) and rhododendron understorey in woodlands. *P. kernoviae* is considered to be established in the UK with a limited distribution and is subject to official control. It is on the EPPO Alert List but is not currently listed as a quarantine pest by the EC.

This pathogen was initially detected because of the intensive surveys being undertaken in the south-west of England by the UK Plant Health Service. These were aimed at determining the distribution of *P. ramorum* as part of the EU member state surveys for this other damaging, exotic pathogen. In March 2003 the south-west and west of the UK had been identified as an area where the climate was most likely to be favourable for the establishment of *P. ramorum*. (See Appendix 1). The surveys for *P. ramorum* were particularly intensive in the south-west because of this.

Between October 2003 and February 2008 *P. kernoviae* has been found at 52 sites in England and Wales, mainly affecting rhododendron (*R. ponticum*) in small areas of woodland in Cornwall as well as a number of trees of a range of species. Various managed gardens have been found affected. One finding has been made in Devon. Outside of Cornwall the pathogen has been found in six managed gardens/parks in south Wales and one managed garden on one large mature rhododendron in north-west England. Only three findings have been made on nurseries, two in Cornwall and one in Cheshire in August/September 2004; the latter has been eradicated. The first nursery in Cornwall to become affected was detected in January 2006 on the nursery adjacent to the site of the first woodland finding in October 2003. The second nursery was detected in September 2007. All outbreaks are the subject of an eradication/containment programme. At one of the outdoor sites eradication is considered to have been achieved since *P. kernoviae* has not been found there for at least 1 year on plant material. There have been two findings in Scotland and none in Northern Ireland.

Based upon the location and number of findings and the climatic conditions prevailing where the pathogen has been found affecting trees and shrubs it seems likely that the south-west and west of the UK is most favourable to the establishment of *P. kernoviae*. However, other areas may be at risk depending upon the microclimate and the availability of host species especially those that are likely to act as sporulating hosts. Rhododendron has been found at all of the affected outdoor sites and research shows that this genus (especially *R. ponticum*) plays a key role in the epidemiology of *P. kernoviae* as a primary source of inoculum for infection of beech and possibly other tree or shrub hosts. Trees with stem infections only are not thought to be a direct source of inoculum but because *P. kernoviae* is now known to survive for at least 2 years in the xylem, infected timber may pose a small risk of moving the pathogen to new areas. Other natural hosts that may be a source of inoculum include all of the foliar hosts and especially *Magnolia* species and holm oak (*Quercus ilex*). Beech (*F. sylvatica*) has the most susceptible bark and is considered to be the most at-risk tree in areas where it is in close association with rhododendron, especially *R.*

ponticum but potentially other foliar hosts. Other tree species appear to be less at risk from stem infection although oak (*Quercus robur*) has now been found affected albeit only 2 individuals. Heathland plants, especially *Vaccinium* spp. were identified as being experimentally susceptible to *P. kernoviae* and recently *V. myrtillus* was found infected in a woodland valley in Cornwall. No heathlands, moorlands or grasslands where this and related species are known to occur have been found affected to date and it is not known whether the local environment there is favourable to spread of the pathogen, especially as the sporulation potential of *Vaccinium* spp. has been found by experiment to be relatively low. Disease spread in these environments would rely in part on the presence of sporulating hosts such as *R. ponticum* and a favourable environment. Managed gardens that attract tourists because of the ornamental plantings of *Rhododendron*, *Magnolia*, *Pieris* etc and those with woodlands growing in association with these hosts are at risk of direct damage to the landscape and to local economies which depend on tourism.

The number of positive samples (1,556) findings compared to the number of symptomatic samples tested (22,991) by CSL (1 December 2003 to 22 March 2007) shows that the incidence of the pathogen in the UK (*ca.* 7% of the samples with suspect symptoms) is low. The percentage figure is in fact most likely to be lower, as since 2006, many samples have been tested onsite using a Lateral Flow Device (LFD); thus negative samples have not been included in these figures (suspect material was not duplicate tested in the laboratory if it came up negative for *Phytophthora* spp.). A breakdown of the number of samples tested in the laboratory (excludes on-site testing) for both *P. ramorum* and *P. kernoviae* in the calendar years 2004, 2005 and 2006 according to whether they came from a nursery, a managed garden or a woodland showed that 77% came from parks, gardens and woodlands, 21% from nurseries and garden centres and the remaining 2% from forestry sites.

Natural hosts in the UK fall into the families Aquifoliaceae, Araliaceae, Ericaceae, Fagaceae, Magnoliaceae, Podocarpaceae, Proteaceae, Rosaceae, and Winteraceae. Symptoms include bleeding bark cankers on trees of beech, oak and the tulip tree (*F. sylvatica*, *Q. robur* and *Liriodendron tulipifera* respectively), foliar blights and shoot dieback on a range of trees and ornamentals (especially rhododendron and various Magnoliaceae and recently on *V. myrtillus*), as well as bud blast on *Magnolia.*

The number of ornamental shrubs affected in the UK is not available. FR have reported on the number of trees that they have found affected to mid-October 2007 and have included PHSI positives to April 2007. Fifty-nine trees have been found affected with bleeding cankers at 9 sites. These are: beech (*F. sylvativa*), 56 trees (including one tree with *P. ramorum* infection too); oak (*Q. robur*), 2 trees; and one tulip tree (*L. tulipifera*). Forty-six trees have exhibited foliar symptoms at 8 sites. These are mainly magnolia (*Magnolia* spp.) with 19 affected individuals, plus 5 holm oak (*Q. ilex*) (including one PHSI sample), 16 *D. winteri*, 2 *M. doltsopa*, one Chilean hazelnut (*G. avellana*), one tulip tree (*L. tulipifera*), one *Podocarpus* sp. and one unspecified tree.

The most commonly affected and worst affected tree host is beech. Rhododendron, magnolia and *Drimys* are the most/worst affected shrubs and ornamental trees. Both beech and rhododendron have been killed by *P. kernoviae*.

Experimental tree hosts that have been tested by a range of methods and found to have high susceptibility to *P. kernoviae* but are not yet recorded as natural hosts are noble fir (*A. procera*), *Eucalyptus* sp., *Nothofagus* spp., birch (*B. pendula*), sweet chestnut (*C. sativa*), *Pinus* spp. and western hemlock (*T. heterophylla*).
The pathogen currently appears to be more damaging to beech (*F. sylvatica*) in woodlands with rhododendron understorey than *P. ramorum*. It poses a risk to ecosystems where beech trees (*F. sylvatica*), magnolias and rhododendrons or other known or potential foliar hosts co-exist. Denman and Orton (2007) suggest that beyond the UK this includes the Central Appalachian Rock Chestnut Oak/Catawba (*Rhododendron catawbiense*) Rhododendron Forest of the USA (mainly northern Virginia Blue Ridge) which contains a range of tree species as well as *R. catawbiense*, *Pieris floribunda* and *Kalmia latifolia* in the shrub layer. Other major ecosystems in Europe and Asia are potentially at risk.

P. kernoviae is also now known to occur in New Zealand. It has only been recorded on one host in New Zealand to date (cherimoya – *Annona cherimola*, a member of the Annonaceae) causing shoot and fruit necrosis. It has also been found in soil from under symptomless stands of *P. radiata* (radiata pine) in the 1950s. Although outdoor surveys are underway in New Zealand it has recently been acknowledged that no surveillance of the nursery trade has been undertaken (or is currently planned).

P. kernoviae has the potential to enter the UK in imported nursery stock and possibly timber arriving from New Zealand both of which are long-standing major trades. Natural hosts (not known to be affected in New Zealand) exported to the UK include *Magnolia* spp., *Rhododendron* spp. and *Pieris* spp. It is known that timber exports include *P. radiata* and *Nothofagus* spp. These genera have been shown by experiment to be highly susceptible to stem infection but they are not yet known to be natural hosts; however the presence of the pathogen in soil of stands of *P. radiata*, first detected in the 1950s may indicate that this species is a potential natural host. *P. kernoviae* is known to penetrate and survive in the xylem of beech (*F. sylvatica*). If this occurs in New Zealand's forestry plantations (mainly *P. radiata*) and indigenous forests (*Nothofagus* spp. are exported from here), then New Zealand timber exports may also pose a small but potential risk of entry for *P. kernoviae* to the UK. Kiln-drying of timber would help to prevent this. MAF New Zealand has implemented requirements for Pest-Area Freedom Declarations for *P. kernoviae* and *P. ramorum* for exports of timber to Australia which may require consideration or an option to treat timber bound for export to the UK/EU.

The origin of *P. kernoviae* is unknown but prior to the reports from New Zealand it was speculated that it was most likely to be from Asia, possibly from a temperate climate, as it seems adapted to cool wet conditions. Suggested locations have included the temperate forests of the eastern Himalayas, China or

Taiwan. Favoured origins were Yunnan in south-west China and the Himalayas as these have been frequented by plant collectors. Patagonia was another option. Because of this uncertainty it is not known by which other routes the pathogen could enter but host plants and possibly untreated timber from Asia are potential pathways.

The main threats to the UK are in fact the current infected areas of Cornwall and south Wales although it seems possible that the pathogen is moving in planting material given the distance between the recent findings in Scotland and the nearest known outbreak in north-west England. Maintenance and possible extension of the *P. kernoviae* Management Zone is recommended as *P. kernoviae* has been found at many south-west sites outside of the zone (apart from the geographically distant sites in south Wales) including a cluster around Penzance in Cornwall and one location in Devon. The recent finding on *V. myrtillus* is in a woodland valley in Cornwall. This finding continues to support the view that the pathogen may pose a risk to this and related species where they occur in other environmentally important environments including heathland, moorland and grassland. The controls that are implemented within the *P. kernoviae* Management Zone and now beyond it should continue to be deployed. Eradication activities to date have concentrated at removing *R. ponticum* from some affected woodlands in Cornwall and south Wales. This has significantly lowered the level of inoculum in those areas of Cornwall where this has been undertaken (no data have been collected in south Wales). However, *P. kernoviae* can still be detected at the sites (albeit at low and possibly epidemiologically insignificant levels) where spore monitoring has been ongoing since clearance commenced in October 2004. No new trees have become symptomatic in these woods since the clearance work was undertaken. Treatment of rhododendron stumps to prevent regrowth has been done but where regrowth has occurred the shoots have occasionally become infected. Monitoring at an outbreak site in the south-west of England has shown that inoculum can persist in soil/leaf litter for at least two years. The pathogen has the potential to survive for much longer periods if oospores are found to occur naturally. If *P. kernoviae* is to remain limited in its distribution in the outdoors environment then it seems vital that rhododendron (and possibly other natural foliar hosts) be cleared from all of the affected sites and that treatment to try to prevent regrowth of stumps is maintained. Most effective of all would be to remove the stump altogether, but this is very costly. Control of newly emerging seedlings of rhododendron which arise post-clearance should also be undertaken. In managed gardens planting schemes could be modified to increase the distance between susceptible hosts. Removal of infected and adjacent vaccinium and *R. ponticum i*s being undertaken in the woodland where *V. myrtillus* has recently been found infected – the success of this activity in eradicating *P. kernoviae* will need to be monitored.

Existing controls on nurseries for *P. ramorum* and *P. kernoviae* seem to be preventing the pathogen from entering and becoming disseminated in trade within the UK; this is essential to limit further spread of the pathogen over long distances through the movement of infected plants. However, the recent findings in Scotland may be related to infected plant material being planted on site. This has not been proven to date however. Controls on imports of ornamentals from

New Zealand may need to be considered, particularly as it has been acknowledged that there is currently no surveillance of nursery stock for *P. kernoviae* in New Zealand. It may be necessary to propose measures for pre-export testing of known hosts from New Zealand.

Pre-export testing of host plants to the EU and third countries from the first affected UK Cornish nursery where the pathogen is known to occur should be continued until it has been eradicated from this site. This may prove difficult, as the pathogen has not been eradicated from the adjacent woodland where it has been present since at least October 2003. If safe trade is to continue then a full survey of this woodland and clearance of host plants may need to be considered.

The EU may need to consider requesting continuing formal surveys of *P. kernoviae* including laboratory testing of suspect material in the EU member states in order to determine the distribution of the pathogen in Europe and whether it should become listed as a quarantine pest.

CONCLUSION AND RECOMMENDATIONS OF THE PEST RISK ANALYSIS

Phytophthora kernoviae is a pathogen that is distributed in the outdoor environment of western parts of the UK and has only been found at three UK nurseries. It is considered to be a recent, exotic introduction to the UK. It has also been found in New Zealand but there is insufficient information currently available as to how long it has been there for but it is from at least the 1950s. Its origin is unknown, but prior to the New Zealand reports it was speculated to be possibly Asian in origin.

P. kernoviae has moved out of the original Management Zone (PkMZ) in Cornwall and until recently was restricted to the south-west of England and south Wales. In north-west England there has been one finding at a managed garden and one finding in a nursery, both of which have been eradicated. It has been found in western mainland Scotland and on the Isle of Arran. It has also been found for the first time on *V. myrtillus* in a woodland valley in Cornwall and this finding supports the view that the pathogen may pose a risk to heathland, moorland and grassland where this and related species occur. *P. kernoviae* continues to pose a threat to the managed and unmanaged environment, the timber and ornamental plant trade and the tourism industry both in the UK and overseas.

It may not be possible to eradicate *P. kernoviae* completely from the outdoor (non-nursery) environment but it is possible to reduce the level of inoculum by removal of *R. ponticum*, as well as other foliar hosts. This will help prevent further spread beyond the currently affected areas and will help to protect susceptible trees and other host plants. However, it requires a long-term, and undoubtedly large, financial input.

It is recommended that:

i Consideration be given to extending the PkMZ to include all of the affected outdoor sites in south-west England (Cornwall and Devon) with a separate zone defined in Wales. A zone for north-west England should be considered but this depends upon the results of follow-up surveillance of the outdoor location where the pathogen was found. Consideration needs to be given to defining separate zones in western mainland Scotland and on the Isle of Arran.

Based upon the outcome of (i) the following actions are suggested:

ii That the actions taken within the existing PkMZ be reviewed and deployed in any extended or new PkMZs
iii Consideration be given to surveillance of watercourses within the extended or new PkMZs to determine the limit of distribution of the pathogen. This will be helpful in delimiting the PkMZs
iv That consideration be given to funding for total removal of *R. ponticum* within woodlands in any extended or new PkMZs including follow-up action to prevent sprouting of stumps, or removal of stumps altogether. Control of newly-emerged seedlings of *R. ponticum* will also need to be undertaken
v That consideration be given to removing other known infected foliar host plants at sites within any extended or new PkMZs
vi That consideration be given to removing uninfected foliar host plants at sites within the new or extended PkMZs
vii That timber from known infected trees be destroyed rather than allowing it to be used so as to prevent the (low) risk of distribution of *P. kernoviae* with infected wood
viii That imports of naturally susceptible genera of plants for planting from New Zealand (and possibly Asia) be monitored for *P. kernoviae* – this may be supported by consideration of a requirement for pre-export testing of these genera from this country/continent, requiring a change in legislation
ix That consideration be given to a specific requirement for timber exported from New Zealand to be from an area known to be free from *P. kernoviae* or to receive a treatment that would most likely eradicate any inoculum that may be present. This would also require a change in legislation. This would be particularly relevant for timber of *P. radiata* and possibly other species.
x That surveillance methods for UK nurseries be reviewed and then continued with appropriate eradication and containment action being taken on detection of *P. kernoviae* to prevent establishment in the nursery trade and to limit the potential for further spread into the UK environment as well as to other countries
xi That consideration is given to a formal request for <u>continued</u> surveillance of nurseries and outdoor sites in the EU to determine the status of *P. kernoviae* within the EU Member States. This could continue to form part of the official survey for *P. ramorum* which is already an EC requirement

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Version 5: September 13th 2004 Version 4: September 10th 2004 Version 3: September 2nd 2004 Version 2: March 12th 2004 Version 1: February 23rd 2004	

Uncertainties and further work

Section of PRA	Uncertainties	Further work which may be needed to improve the PRA
Taxonomy	None.	None.
Distribution	The true origin of the pathogen is unknown.	Sampling and testing of plant material originating in Asia and NZ imported to the UK.
	Distribution in the EU.	Surveys and testing are needed as a formal requirement in the EU to determine whether *P. kernoviae* occurs there.
Hosts	Host-range of ornamental species appears limited (though still relatively wide) but experimental host testing has been limited to tree and heathland species.	Host-range testing of ornamental species commonly grown in the UK other than known natural hosts.
Pathway	Entry pathways need elaboration.	Sampling and testing of plant material originating in Asia. Surveys and testing of known natural hosts in the EU. Information on surveys of outdoor situations including forests in New Zealand especially those involved in timber production and exports. Sampling and testing ornamental hosts exported from New Zealand. Information on presence of *P. kernoviae* in wood of harvested beech and oak in affected areas of the UK.
Establishment	Potential for establishment beyond the south-west and west of the UK.	Identification of areas in the UK where beech, rhododendron and magnolia co-exist along with climatic data. Identification of areas in the UK where rhododendron is present in heathland, moorland and grassland Climatic favourability of heathland, moorland and grassland. Determination of whether oospores are being formed naturally and measurement of their long-term survival in a range of situations. Determination of potential for survival in roots/rhizomes.

Spread	Potential for long-distance aerial dissemination. Information on connections between known affected sites.	Spore-trapping. Watercourse survey. Determination of potential for survival in roots/rhizomes. Dates of testing and first finding of *P. kernoviae* at the outdoor sites. Information on host material received at the 3 affected nurseries. Epidemiological modelling of current datasets.
Impact	Potential to affect other as yet unknown natural hosts.	Information on the distribution of natural and experimental hosts in the currently affected areas
Management	Likelihood of eradication/containment based upon existing measures. Need for treatment of timber harvested from trees with stem lesions.	Long-term monitoring of the presence of the pathogen and the disease at sites where clearance of rhododendron has been undertaken and where it has not yet been done. Determination of whether oospores are being formed naturally and measurement of their long-term survival in a range of situations. Determination of potential for survival in roots/rhizomes. Information on presence of *P. kernoviae* in wood of harvested beech and oak in affected areas of the UK.
Potential for future adaptation.	The potential for *P. kernoviae* to adapt intrinsically to its new environment via hybridisation with other species is not known.	The findings of the Defra Project PH0312 will help address this.

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Appendix I.

This work was undertaken by Richard Baker, CSL, York, UK in March 2003 to determine the extent to which areas of the UK have climatic conditions similar to those where Sudden Oak Death has been recorded in Oregon. Using the CLIMEX "match climate" routine to compare world climate grids at 'Sudden Oak Death' (SOD) outbreaks with those in Europe and the UK, mean monthly differences in max-min temps, monthly and annual rainfall were calculated. On a scale of 0-100 European and UK climate grids were mapped highlighting those which were the closest match. Areas of SW England and S Wales had climatic conditions which were most similar to those of Oregon, USA where SOD occurred in Oregon at the time of the work.