Development of a Pest Risk Analysis for *Phytophthora ramorum* for the European Union; the Key Deliverable from the EU-Funded Project RAPRA[1]

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Abstract

Pest Risk Analysis (PRA) is an internationally recognized, structured process of determining whether plant pests and pathogens that are absent from a country or area could enter, establish, and cause an economic or environmental risk that is deemed unacceptable. PRA is also used to help identify phytosanitary measures to reduce risks to an acceptable level. United Kingdom (U.K.) PRAs for *Phytophthora ramorum* have been produced and developed since 2000, starting with the unknown *Phytophthora* causing sudden oak death in California, United States (U.S.). Other European Union (EU) Member States (MS) have also assessed the risk. As a result of the PRAs, *P. ramorum* was identified as posing a risk to the environment, private and managed gardens, and woodlands as well as to the ornamental plant trade in the U.K./EU/EPPO region. The prediction that heathland habitats were at risk (based upon host range testing and climatic matching) has now been proven by recent findings of *P. ramorum* (and *P. kernoviae*) on bilberry (*Vaccinium myrtillus*) in heathland in the U.K. Supported by the PRAs, emergency legislation was implemented in the U.K. and subsequently in the EU, allowing action to be taken against *P. ramorum* whenever it was found. National research projects were commissioned in the U.K. and elsewhere to help fill the gaps in the PRAs; these were inevitable, given the lack of knowledge on this newly identified species.

A major, multi-faceted EU-funded research project 'RAPRA' (Risk Analysis for *Phytophthora ramorum*) commenced in 2004 (http://rapra.csl.gov.uk/). The overall aim was to develop a European-wide PRA for *P. ramorum* for the 27 MS of the EU; this was to be based on the project's research findings as well as those emerging in the scientific literature. The project documented the increasing host range and geographical distribution of *P. ramorum*, including the distribution of mating types; helped determine the potential for sexual recombination; and investigated the potential future host range and aspects of epidemiology related to establishment risk. Refinement of the risk of establishment within the PRA accounted for these findings as well as the results of climatic matching and mapping using several methods. Economic impacts were difficult to assess since currently in the EU *P. ramorum* affects the commercial plant trade, the natural environment, and historic gardens - with secondary effects on tourism, particularly for southwest England. Commercial forestry is not yet affected, but may be at risk. Recommendations for future management of the risk of entry (for pathways identified from an earlier European and Mediterranean Plant Protection Organization [EPPO] PRA for *P. lateralis* and by evaluating trade data and existing phytosanitary legislation) were made. Potential measures for managing outbreaks in the EU that were proposed in the PRA were based on a review of existing measures as well as experimental results for disease management. This PRA is the key output from RAPRA and is

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being used in 2009 to review existing EU phytosanitary policy for *P. ramorum*. This paper summarizes some of the processes for determining the risk of entry, establishment and impacts posed by *P. ramorum* to the EU, and highlights areas of uncertainty. Full details are available in the PRA at http://rapra.csl.gov.uk/.

Introduction

Phytophthora ramorum, first described in 2001, is considered to be exotic to Europe and North America and is thought to have been relatively recently introduced separately to both continents from an unknown area, or areas, of origin, speculated to be somewhere in Asia. Prior to being formally named and described, the pathogen was first observed infecting rhododendron and viburnum in Germany and rhododendron in the Netherlands, since at least 1993. At around the same time, increased mortality of tanoak and oaks (*Lithocarpus densiflorus* and *Quercus* species) was observed in California, U.S. and this was described as 'sudden oak death' (SOD); the causal agent was identified as a new and unnamed *Phytophthora* species in 2000. The first formal pest risk assessment in Europe for the U.S. 'unknown' *Phytophthora* was produced by the U.K. in September 2000 (Brasier 2000). No specific phytosanitary measures were identified as the assessment was undertaken using the European and Mediterranean Plant Protection Organization (EPPO) risk assessment scheme, which pre-dated the EPPO Pest Risk Analysis (PRA) scheme, thus not including the third stage of PRA risk management. The conclusion of the assessor was that the U.S. *Phytophthora* had potential to establish in the U.K., possibly entering on nursery stock, and that it posed a significant risk to (at least) U.K. native and exotic oaks. By January 2001, the *Phytophthora* causing SOD in California and the *Phytophthora* which had been isolated from shrubs in the Netherlands and Germany were considered to be the same species. EPPO, the Regional Plant Protection Organization for many European and Mediterranean countries including the EU, added the pathogen to their Alert List (an early warning, without a full PRA) in January 2001. A second PRA was produced by the U.K., connecting the U.S. and EU findings. An EPPO-style Datasheet was also produced but was never published, although it was updated with each subsequent revision of the U.K. PRA described below. The revised PRA highlighted the risks to the U.K., EU, and EPPO region; identified uncertainties and research needs; and recommended surveys in the EU/EPPO region to determine the pathogen's distribution. It also advised that phytosanitary measures should be considered, such as controls on imports of known susceptible hosts and their products into and within the EU/EPPO region from areas/countries where the pathogen had been found, to try and prevent further entry. It was recommended that the pathogen should continue to be on the EPPO Alert List and that consideration should be given to making it an EU/EPPO quarantine pest. As a result of the PRA, in the summer of 2001, the Department for Environment, Food and Rural Affairs (DEFRA) Plant Health and Seeds Inspectors (PHSI) for England and Wales and the Dutch Plant Protection Service commenced limited surveys for the as yet unnamed *Phytophthora*.

After the pathogen was formally named as *P. ramorum* in October 2001, a third formal U.K. PRA was published in January 2002 for this newly identified species. In February 2002, as a result of the ongoing survey work, DEFRA detected *P. ramorum* on a symptomatic *Viburnum tinus* plant from a garden center in southern England. This was the first U.K. record of *P. ramorum.*

Following on from the PRA work, U.K. (England) legislation aimed at *P. ramorum* was enacted in May 2002. This was somewhat earlier than the European Commission (EC) legislation which came into force in September 2002, based largely on actions taken by the U.K. and the Netherlands. The U.K. (England) legislation was revoked and replaced in November 2002, reflecting the first EC requirements. The EC legislation broadened controls on imports of susceptible material and had requirements for controls on movement of susceptible plants within the EU, as well as controls on outbreaks, and a requirement for EU Member States (MS) to conduct surveys to be reported back to the EC by December 2003. One other European PRA (a report of a PRA) was prepared by the Netherlands in October 2002 to ensure that phytosanitary measures arising from the new EC legislation to be taken in that country were technically justified.

Accounting for ongoing research results (the U.K. research program commenced in 2002), literature, and findings of *P. ramorum* in the EU and North America, the U.K. PRA was updated again and was published in March 2003. It was revised further and published again in October 2003. This last revision pre-dated the first tree findings in the U.K. and the Netherlands in late October 2003. In 2004, a full update of the Datasheet was prepared and a draft PRA begun, but prior to completion, the first U.K. findings of the new pathogen *P. kernoviae* (in October 2003), followed by the expansion in its host range over the following year, led to changing priorities, and the PRA work for *P. ramorum* was put on hold.

More informal assessments of risk have also been made by other countries for Europe and for specific regions, for example, for the Mediterranean and for Italy. The U.S., Canada, and Australia have also prepared PRAs.

In 2007, a full update of the U.K. Datasheet (Sansford and Woodhall 2007), accounting for the results of the U.K. research program; key aspects of the EU and U.S. research program, including elements of the RAPRA (Risk Analysis for *P. ramorum*) project; and EU and North American survey findings was prepared. This was done to re-examine the risks to the U.K. and to suggest risk management options in preparation for the 2008 DEFRA public consultation for the future management of *P. ramorum* (and *P. kernoviae*) in Great Britain (GB). The U.K. Datasheet was used as one of several resources for preparing the RAPRA PRA.

The RAPRA project commenced in January 2004. Its ultimate aim was to produce a PRA for the EU assessing the risks posed by *P. ramorum* to European trees, woodland ecosystems, and other environmentally important habitats (for example, heathlands), as well as ornamental plants in the nursery trade and public gardens. This PRA was intended to be used to support a review of EU policy for *P. ramorum*. Meanwhile, EC legislation for the pathogen was amended in April 2004 and March 2007, accounting for changes in host range, survey results, and assessed risk. Current measures (pending review) still require official surveys to be reported back to the EC at the end of the year, and broadly-speaking, import and internal movement controls of rhododendron, viburnum, and camellia (the three most commonly affected traded genera in the EU) with statutory action to be taken on findings.

The PRA Process; Dealing with Uncertainty Through Research

The PRA process is a structured and logical approach to assessing the risks of entry, establishment and potential impact of plant pests and pathogens (collectively known in the PRA world as 'pests'), and, if necessary, identifying risk management options to reduce the assessed level of risk to an acceptable level. In Europe, PRAs are undertaken for individual organisms. Before a PRA can be undertaken, it must be clearly identifiable as unique (at least to species level - even if they are yet to be formally named). Thus, for newly identified diseases/pathogens, once Koch's Postulates have been completed, it is possible to conduct PRAs on previously unknown *Phytophthora* spp. such as those undertaken for ***P. ramorum*** (initially *Phytophthora* sp.) and ***P. kernoviae*** (initially *Phytophthora* taxon C. sp. nov.).

Pest risk analysts use national or regional decision-support schemes which are based upon the framework of the Food and Agriculture Organization (FAO) International Standard for Pest Risk Analysis (FAO 2004). One such scheme is the EPPO Standard 'Guidelines on Pest Risk Analysis: Decision-support scheme for quarantine pests' (EPPO 2007) – the 'EPPO scheme'.

During the PRA process, pest risk analysts inevitably identify uncertainties, especially for new species, and, at least in the U**.**K**.**, we try to suggest further work that could be undertaken to address these and improve the PRA. The main areas under which these uncertainties are identified are in taxonomy, geographic distribution, hosts and potential hosts, pathways of entry, risk of establishment and spread, potential impact, and risk management – including non-statutory control. Suggestions for further work could be, for example, a relatively simple survey to help better determine the geographic distribution of an organism or, alternatively, a list of topics for which single or multi-faceted research projects could be commissioned to generate data to help fill the gaps in our knowledge. This allows us to revise our existing PRAs, update the assessment of risk, and, where appropriate, revise the suggested risk management options for consideration by national or EU policy makers.

The RAPRA Project

The RAPRA project was the second in a series of three EC-commissioned and part-funded projects, aimed at developing multi-faceted aspects of existing national PRAs for specific plant pathogens that had been assessed and predicted to pose a major threat to sectors of EU agriculture, horticulture, forestry, and/or the environment, and for which an EU-wide consensus on the risk was required.

The first project of this type was 'Karnal bunt risks' (http://karnalpublic.pestrisk.net/), conducted under the EU Fifth Framework program, which developed a PRA for *Tilletia indica*, the cause of Karnal bunt of wheat. The structure of this project became a model for two further projects under the EU Sixth Framework program: 'RAPRA' (http://rapra.csl.gov.uk/) and, subsequently, 'Pepeira' (http://www.pepeira.wur.nl/), to develop PRAs for ***P. ramorum*** and for Pepino mosaic virus (a damaging pathogen of tomato), respectively.

RAPRA was a project of 39 months duration, supported by >50 percent funding from the EC with nine partner institutes based in France, Germany, the Netherlands, Spain, the U.K., and the U.S., with three observer institutes in Belgium and Italy. The project was coordinated by the U.K. (Dr Joan Webber, Forest Research).

RAPRA was split into eight work packages (WP) which addressed eight scientific objectives. In numerical order of WP and objective, these were to

1. Collate and publish available information on the extent of entry and distribution of *P. ramorum* in the EU and Europe.
2. Establish the level of susceptibility (to both European and American isolates) of tree and non-tree species of significant environmental and economic value to the EU.
3. Quantify the sporulation, germination, infection, incubation period, latency, survival, and dispersal components of the epidemiology of European and American isolates of *P. ramorum*.
4. Establish the potential for mating between *P. ramorum* (predominantly A1 mating type) found in Europe and *P. ramorum* (predominantly A2 mating type) present in the U.S.
5. Evaluate the likely environmental and socio-economic impact of *P. ramorum* in the EU.
6. Evaluate at least three existing and at least two new chemical active ingredients for the control of *P. ramorum* in ornamentals.
7. Define outbreak scenarios, evaluate existing strategies for eradication and containment, and produce technical guidelines for management plans for dealing with *P. ramorum* in Europe while minimizing the need to disrupt free trade.
8. Develop, refine, and publish a European PRA for *P. ramorum* and provide information to underpin and advise EU plant health policy and legislation.

The newly generated experimental and economic data arising from WPs one to seven were incorporated into Deliverable Reports. These reports, along with a review of the literature up until November 2008, and earlier PRAs (most recently the 2007 U.K Datasheet), were used in WP8 to provide an assessment of the risk from North American and European isolates to the EU, and to determine risk management options.

The PRA was prepared using the EPPO scheme. The area for which the risk was assessed (the PRA area) was the 27 MS of the EU (fig. 1).

Figure 1—The PRA area: the European Union 27 MS. Source: http://encarta.msn.com/media_941538636_761579567_-1_1/map_of_the_european_union.html.

A summary of the process undertaken during the construction of the PRA, the data that were used, and the main findings (excluding risk management) and uncertainties are given below.

Assessment of the Risk of (Further) Entry of *P. ramorum* to the EU

The first step in determining the risk of further entry of *P. ramorum* into the EU was an assessment of the current geographic distribution documented in the RAPRA database (http://rapra.csl.gov.uk/objectives/wp1/distribution.cfm) of 'distribution and potential for spread of *P. ramorum* in Europe' (WP1). This assessment also took account of the known distribution of the three currently known distinct genetic lineages (EU1, NA1, and NA2) and mating types (A1 and A2). We also used the EU MS survey results from 2002 onwards, and published reports from the literature. The second step was to determine the main pathways of entry and the commodity types for which were selected as those identified in a 2006 EPPO PRA for *P. lateralis* (http://www.eppo.org/QUARANTINE/Pest_Risk_Analysis/PRA_documents.htm). Lists of known and potential hosts on which *P. ramorum* could enter were generated from the WP1 natural host database and WP2 (experimentally susceptible hosts are listed in the WP1 database), plus published literature and unpublished results. Trade data for 2003 to 2007 were obtained from the Eurostat Comext database and supplied by DEFRA. The EC phytosanitary legislation was also reviewed.

Current Geographic Distribution of *P. ramorum* – Potential Sources of Entry

A short summary of the distribution of *P. ramorum*, which identifies the likely sources of further entry to the EU, is given below.

U.S.–

Phytophthora ramorum is present in the wild in California and Oregon. The first nursery findings were made in California in 2001, with subsequent finds in Oregon and Washington State. In 2004, trade from California and Oregon led to the detection of *P. ramorum* in nurseries in 22 U.S. states; all were subject to eradication. Additional nursery finds have been made in the U.S. in subsequent years.

Canada–

Phytophthora ramorum has been reported (under eradication) in British Columbia, Canada in a few nurseries (first finding in 2003) and some related residential plantings.

Europe–

Phytophthora ramorum is found in 19 EU countries, but under official control in: Belgium, Czech Republic (eradicated nursery finding), Denmark, Estonia, Finland, France, Germany, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Slovenia, Spain (including Mallorca), Sweden, and the U.K. (all countries including the Channel Islands). Norway and Switzerland (not EU countries) also report findings of *P. ramorum.* Many findings have been in nurseries. Records outside of nurseries (including managed parks, gardens, public greens, woodlands, and forests) have arisen from Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Slovenia, Spain, Switzerland, and the U.K. *P. ramorum* was also recently reported in Serbia (Bulajić and others 2009).

Asia–

It is speculated that *P. ramorum* may have originated from somewhere in Asia, such as the Yunnan, Taiwan, or the eastern Himalayas.

Distribution of Lineages (NA1, NA2, EU1) and Mating Types (A1, A2) Based Upon Isolate Testing

U.S. woodlands–

NA1, A2 and one EU1, A1 mating type isolate in a woodland stream in California

U.S. nurseries–

NA1, A2 and a few isolates of NA2, A2 and EU1, A1

Canada–

Not described, but some EU1, A1 isolates in British Columbia nurseries

Europe–

EU1, A1 and three EU1, A2 isolates in Belgium

Based upon genetic analysis, the NA1 and NA2 lineages are likely to have a separate geographic origin to the EU1 lineage and all three lineages are considered to have been introduced.

Risks from Entry of Exotic Lineages and Mating Types to the EU

Should NA1 and NA2 isolates enter the EU from North America, because they are of the A2 mating type, there is a risk of sexual reproduction with EU1 isolates. Any progeny that might be generated may show new adaptive behaviors and present new risks. There is uncertainty over whether the mating system is fully functional (data generated in the RAPRA project, WP4, and through other research work), but there is still potential for somatic recombination to occur. Until the origin/origins of *P. ramorum* is/are identified, there is another unquantifiable risk.

Current risks to the EU arise from: (1) the further establishment and spread of the EU1 lineage in EU MS, especially into the wider environment; (2) the introduction and spread of non-EU lineages from North America or from other unknown areas of origin; and (3) the introduction and spread of isolates of A2 mating type, regardless of lineage.

Major Pathways of Entry

We identified eight main **potential** pathways of entry for *P. ramorum* into the EU. Significant direct pathways are:

1. Plants for planting (PfP) (excluding seeds and fruit) of known susceptible hosts;
2. PfP (excluding seeds and fruit) of non-host plant species accompanied by contaminated, attached growing media;
3. Soil/growing medium (with organic matter) as a commodity; and
4. Soil as a contaminant (for example, on footwear, machinery).

Less significant direct/indirect pathways are:

5. Foliage or cut branches (for ornamental purposes) of susceptible foliar hosts;
6. Seeds and fruits of susceptible hosts;
7. Bark from susceptible hosts; and
8. Wood from susceptible hosts.

Probabilities of entry for each commodity type along with the associated level of uncertainty were assessed for the four geographical origins where *P. ramorum* has been recorded: U.S.; Canada; non-EU European countries (Norway and Switzerland, but not Serbia whose first finding post-dated the production of the PRA); and the unknown area or areas of origin for *P. ramorum,* speculated to be Asia – thus imports from China and Taiwan were included in the assessment. Although phytosanitary controls exist in both the emergency legislation for *P. ramorum* (Anonymous 2007) as well as the EC Plant Health Directive (Anonymous 2000), the assessment of the **overall** risk of entry was judged in the absence of these controls (this allows a reappraisal of the controls).

The EPPO scheme requires consideration of the probability of the 'pest' being associated with the commodity; the likely concentration of the 'pest' being high at the origin of the pathway accounting for cultivation practices, consignment treatments, and so on (excluding phytosanitary controls); and the volume and frequency of trade of the commodity on the pathway (trade data for 2003 to 2007 from the Eurostat Comext database). These data are very limited in their detail which led to a high level of uncertainty overall for pathway one – PfP of known susceptible hosts (see below), for which only rhododendrons and roses have specific data. Data

on PfP of non-hosts with associated growing media was generic, thus it was likely to include hosts of *P. ramorum*. Soil is prohibited entry into the EU (specifically soil and growing media containing soil or solid organic matter from certain countries – only Norway and Switzerland were considered potential sources of entry for *P. ramorum*) (pathway three); soil as a contaminant (pathway four) is obviously not documented. Data on foliage/cut branches of susceptible hosts (pathway five) was generic and so included non-hosts. Data for seeds and fruits of susceptible hosts (pathway six) were specified only for nuts of *Corylus* spp. and *Castanea* spp., and fruits of several *Vaccinium* spp. Data for susceptible bark (pathway seven) was not specified in the Eurostat database at all and so generic data for 'wood waste' was used. Data for known susceptible wood (pathway eight) were available for *Quercus* and *Fagus* spp. The probability of survival as well as multiplication of *P. ramorum* during transport and storage, and the probability of the pathogen remaining undetected during inspections were based upon data on the pathogen's biology generated in WP3 and 4 and in the literature. Distribution and end-use of the commodity in the EU, time of arrival, and likelihood of transfer of the pest to a suitable host/habitat, were also considered.

Host Plants and Plant Material on Which *P. ramorum* Can Move

For pathways one, five, six, seven, and eight, natural hosts were known to occur in 37 plant families, with 75 plant genera and more than 130 plant species affected (to 9 October 2008) (WP1). Results of experiments testing host susceptibility (WP2) predicted more potential hosts as well as some of the now known natural hosts. We did not consider potential hosts in our assessment of the risk of entry, since species which are only experimentally-susceptible cannot be regulated in the EU. Additionally, there are limited data generated in WP3 and from the literature on the susceptibility of fruits and the potential of fruits and seeds of various hosts to be significant pathways.

Table 1 summarizes the overall risk of entry by pathway using a five category rating.

Table 1—Estimated overall probability of entry for *P. ramorum* by pathway (PW) in the absence of phytosanitary controls. VL-Very Low; L-Low; M-Medium; H-High; VH-Very High

PW	Commodity	Pathway type	U.S.	Canada	Unknown origin	Europe (Non-EU)
1	Plants for planting (Hosts)	Direct	H	M	H	M
2	Plants for planting (Non-Hosts)	Direct	L	L	L	L
3	Soil as a commodity	Direct	M	M	M	M
4	Soil as a contaminant	Direct	L	VL	L	VL
5	Foliage/cut branches of susceptible hosts	Indirect	VL	VL	VL	VL
6	Seeds and fruits	Direct/ Indirect	VL	VL	VL	VL
7	Susceptible/ isolated bark	Direct	M	VL	M	VL
8	Susceptible wood	Indirect	L	VL	L	VL

In the absence of phytosanitary controls, the overall probability of further entry was considered to be high, mainly due to the wide host range and the ability of *P. ramorum* to persist in a variety of substrates (soil, growing media, bark, wood, foliage). Plants for planting of susceptible hosts (excluding seeds and fruits) from the U.S. and the unknown area/areas of origin represented the highest risk. The level of uncertainty for the overall probability of entry was low for all pathways with the exception of PfP for the unknown area/areas of origin, which was medium.

Assessment of the Risk of Further Establishment of *P. ramorum* in the EU

The assessment of the risk of establishment was based upon biological data arising from the RAPRA project, as well as a review of the literature and the deployment of various climatic matching techniques and models to produce a series of maps of potential establishment risk. *P. ramorum* has already been found on nurseries in many EU countries and although eradication has been feasible, *P. ramorum* has the potential to continue to become established in nurseries in the PRA area. Beyond nurseries, managed parks, gardens, woodlands, and now heathland (U.K.) have already become affected in parts of the EU. To determine the risk of further establishment, the EPPO scheme requires responses to a series of questions related to host range (known and experimental – WP1 and 2; in the WP1 database) as well as

the distribution of susceptible hosts and habitats in the PRA area. In this respect, the presence of sporulating hosts which are key to driving epidemics and which can lead to tree mortality through the development of stem cankers (for example, California bay laurel, *Umbellularia californica*, in California) had to be determined for the EU. In northern Europe, rhododendron has so far been the most important natural host in this respect, although RAPRA work (WP3) has identified the known natural hosts holm oak (*Quercus ile*x) and sweet chestnut (*Castanea sativa*) as possible inoculum sources for tree stem infection. *Vaccinium myrtillus* and other heathland species have been shown to be experimentally susceptible and potential sporulators for heathland and woodland habitats; *V. myrtillus* was recently identified as being naturally infected in the U.K. In southern Europe, epidemics in Mediterranean forests and in maquis shrubland have yet to be detected, but are likely to depend on evergreen foliar hosts such as *Q. ilex*, *Rhamnus alaternus*, and *Pistacia lentiscus,* shown in WP3 to support significant levels of sporulation. Questions on climatic suitability were tackled using observations of the abiotic requirements of the pathogen in the field as well as *in vitro* data from the RAPRA project (WP3) and the literature. Climatic comparisons of areas of the U.S. and the EU where *P. ramorum* is damaging plants (including trees), with the rest of Europe, was undertaken in RAPRA using CLIMEX (WP8). Because the area, or areas, of origin of *P. ramorum* are unknown, it is not possible to fully assess climatic favorability by this method. Comparisons between Oregon/California and Europe indicated that areas of northwest Spain, northern Portugal, southwest England, and parts of Italy and western Albania have the most similar climates. Larger parts of the U.K., Ireland, France, Belgium, the Netherlands, western Germany, Italy, the Adriatic coast of the Balkan peninsula, as well as north-west Turkey and east Bulgaria on the Black Sea coast, also have relatively good climate matches.

An additional approach to mapping establishment risk was undertaken using the methodology of Meentemeyer and others (2004) which has been used to predict potential *P. ramorum* distribution in California based upon a ranking system for climatic parameters which favor *P. ramorum* and a host species index. We were constrained in this work by the lack of high-resolution data for host distribution and host associations for the whole of Europe, and so could only deploy the climatic parameters. See fig. 2.

With respect to the semi-natural (including managed parks, gardens, public greens, and so on) or the natural environment, the parts of the PRA area that are most endangered based upon ranking of climatic factors alone are **Atlantic Central** and **Lusitanian** climatic zones. **Mediterranean** and **Atlantic North** climates are also potentially favorable, especially in coastal locations (see PRA for details). Although mild and wet climates are most likely to favor establishment and spread, the pathogen's ability to form long-lived chlamydospores enables it to survive Mediterranean climates with hot and dry summers, as demonstrated in California, and potentially also colder climates with cold winters. Areas of the EU with the most suitable climates coincide broadly with the areas that potentially have the most at-risk habitats, including potentially suitable broadleaved hosts/habitats, heathland and maquis areas. Those areas that are climatically favorable are only at risk where there are susceptible host plants that are capable of supporting sporulation, as tested in WP3. The most suitable predicted climatic locations for establishment based upon Meentemeyer and others (2004) are northern Portugal, northwestern Spain, the southern tip of Spain, the Adriatic coast of the Balkan peninsula (western parts of

Greece, Albania, Montenegro, Bosnia and Herzegovina, Croatia, Slovenia), southwestern France, northwest France (Brittany), northern coastal Spain, southern Turkey, western U.K., and southwest Ireland.

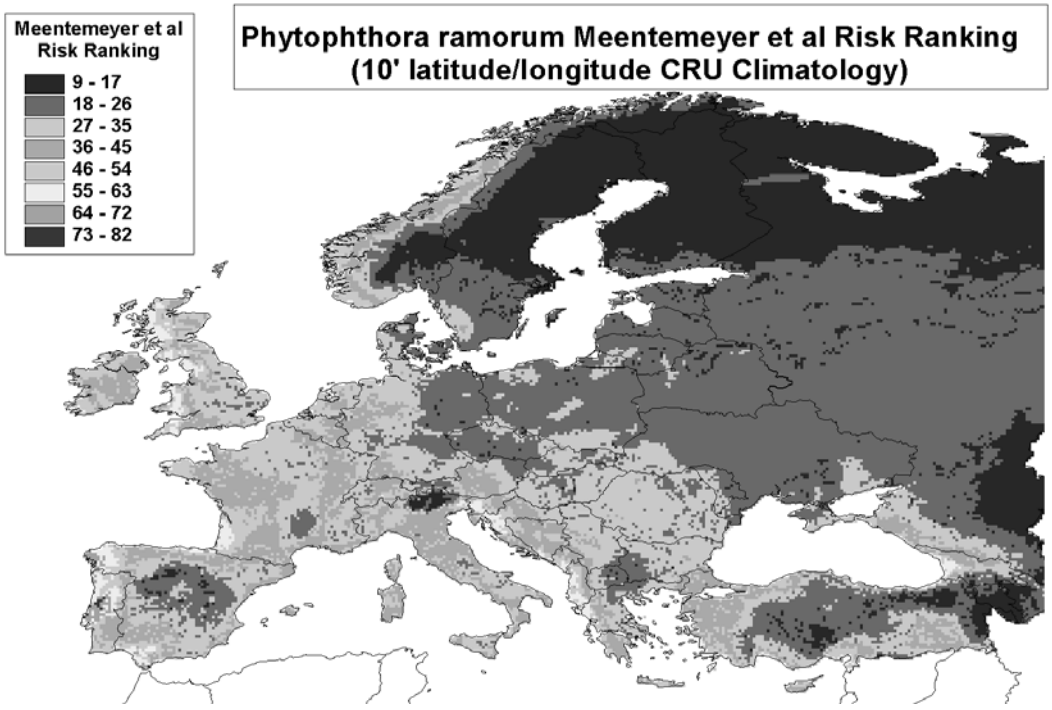

Figure 2—*P. ramorum* risk ranking model based on Meentemeyer and others (2004) for Europe (excluding host data), using 10' lat./long. resolution global climatology December to May 1961 to 1990.

With respect to susceptible hosts of cultivated shrubs and trees on nurseries, the whole of the PRA area is potentially endangered wherever these are produced because *P. ramorum* is favored by certain nursery practices (for example, overhead watering, use of contaminated irrigation water, use of chemicals containing metalaxyl-M for which some resistance has been identified, use of fungistatic compounds that may mask symptoms), and there are no sources of genetic resistance for an increasing list of hosts.

The main uncertainties arising in determining the risk of further establishment of *P. ramorum* in the EU are: mating system functionality – still uncertain (WP4); lack of high-resolution data on host distribution – this limited the determination of the endangered areas outside of nurseries (WP8); and rate of spread in the absence of phytosanitary controls. Other less significant uncertainties are listed in the PRA. The probability of further establishment in the PRA area is high.

Assessment of the Potential Economic (Including Environmental and Social) Consequences

The data that were used to complete this section of the PRA arose in part from a literature review, inquiries made to RAPRA partners and contacts in the U.S., plus a DEFRA impact assessment undertaken for the 2008 public consultation for the future management of *P. ramorum* (and *P. kernoviae*) in Great Britain. Additionally, within the RAPRA project (WP5), estimates of the current and future economic and environmental impacts of *P. ramorum* in three systems/scenarios were made. These were: the 'nursery system'; the 'northern European tree system' - broadly defined as trees with stem cankers in association with infected rhododendron in the Netherlands and the U.K.; and the 'southern European tree system' - a hypothetical system based upon the presence of the infected foliar host holm oak.

This section of the PRA proved to be particularly difficult, with varying degrees of uncertainty associated with the different elements that make up the overall assessment of potential impact. *P. ramorum* is subject to official control in the countries where it is known to occur; thus, the direct economic impact that it has caused is not quantifiable. Disentangling the costs of phytosanitary measures from the effect the pathogen has, or will have to be, estimated. In the EU, the intensity of *P. ramorum* surveys of nurseries, parks/managed gardens, woodlands, and so on has varied, and some countries have not reported survey findings to the EC, thus current impacts are underestimated. EU MS also vary in the availability of data on the costs of phytosanitary controls. Production and trade data for named host species grown in nurseries in the EU were not available, so generic data were used. Potential ecological and environmental impacts were estimated based upon the US experience. The impact in the area of origin/origins of *P. ramorum*, like the origin itself, is unknown. The potential for *P. ramorum* to establish in timber plantations in the EU is uncertain. For these reasons, financial estimates of the current and potential impact of *P. ramorum* were not possible for the EU. The scores assigned in responding to the questions in the EPPO scheme are subjective, and individual MS have/will vary in their assessment of the impact. However, the majority view of the potential impacts was presented in the PRA based upon the limited evidence that was available.

Current Impact of *P. ramorum* in the EU–

Currently *P. ramorum* has a direct effect on the quality of nursery stock as well as plants in managed parks and gardens. The current impact on nurseries in the EU is considered to be moderate in terms of quality and control costs (but excluding phytosanitary controls); including these controls, the impact is major. The current impact on plants in managed gardens is minor in many EU MS, but major in the southwest and west of the U.K., where damage in historic gardens is thought to be having a negative effect on tourism. In the natural/semi-natural environment of the EU, unlike the U.S., limited tree death has occurred only in the U.K. and the Netherlands since 2002. Heathland (*V. myrtillus*) has recently become affected in the U.K. In WP5, the current impact to the 'northern European tree system' is thought to be moderate as it is limited to a few parts of the EU and is fairly localized. In the 'southern European tree system' the current impact is minimal (zero) because *P. ramorum* is yet to be introduced there.

Potential (Future) Economic Impact in the EU–

Phytophthora ramorum has the potential to increase its host range and to become more widespread in the nursery trade and in the natural and semi-natural environment. The long-term potential for ecological damage is difficult to predict as the pathogen is considered to be at the start of the disease progress curve in the areas currently affected.

If phytosanitary controls are maintained at the current level or increased/reduced (but not removed), costs to nursery production and managed gardens will be major. Costs borne by National Plant Protection organizations will increase if increased controls are implemented to reduce further spread to the environment. However, there will be environmental benefits if controls focus on removal of foliar sporulating hosts that are invasive species, such as *Rhododendron ponticum* in the U.K., as planned for the new Food and Environment Research Agency (FERA) *Phytophthora* program.

Should phytosanitary controls be lifted globally, there will be an increase in production costs which will principally fall on nurseries producing hardy ornamental nursery stock (HONS) and on managed gardens. Quality effects on HONS will increase. These costs are major**.** Export losses may occur depending upon other countries' phytosanitary requirements.

In managed gardens (especially heritage plants in gardens involved in tourism), without control measures, effects on plant quality is likely to be moderate overall, but massive on a local scale. Social impacts may increase as a result of damage to plants in gardens visited by the public, potentially reducing visitor numbers, and ultimately affecting tourism where such gardens are part of that economy. Over all of the EU, the impact is likely to be moderate**.**

If controls are lifted, in the 'northern European tree system' the environmental impact will increase as the pathogen becomes more widespread in the environment, increasing the number of infected foliar hosts that sporulate, which may infect tree stem hosts - with potential for tree mortality. This impact has the potential to be major on a local basis, but moderate over the whole of the PRA area. In the 'southern European tree system', if *P. ramorum* is introduced, the impact would shift from minimal (zero) to major as the environment is considered to be highly favorable to the establishment of *P. ramorum*.

At-risk habitats that are yet to become affected by *P. ramorum* include most heathlands in northern Europe (the U.K. is now affected), as well as evergreen oak woodlands and laurel forests (laurisilva) and maquis/matorral habitats in southern Europe, but only where they contain susceptible hosts capable of sporulating, and favorable climatic conditions. Should these areas become affected, there will be knock-on effects on the ecology of the area.

The pathogen has yet to be found in timber plantations, but should it establish there long-term, the impact may be minor to moderate in the absence of controls.

Risk Communication

The final version of the PRA, dated 26 February 2009, was published online on the

RAPRA website (http://rapra.csl.gov.uk) and has been disseminated to the EC to help determine future phytosanitary requirements.

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