EPPO Datasheet: *Phytophthora ramorum*

Last updated: 2020-11-23

IDENTITY

Preferred name: *Phytophthora ramorum*
Authority: Werres, De Cock & Man in 't Veld
Taxonomic position: Chromista: Oomycota: Oomycetes: Peronosporales: Peronosporaceae
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EPPO Categorization: A2 list
view more categorizations online...
EU Categorization: Emergency measures (formerly), A1 Quarantine pest (Annex II A), RNQP (Annex IV)
EPPO Code: PHYTRA

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Notes on taxonomy and nomenclature

Phylogenetically *Phytophthora ramorum* is placed within the genus in clade 8c and is closely related to *Phytophthora lateralis* and *P. foliorum* (Grünwald *et al.*, 2019). The species epithet '*ramorum*' refers to branch (Latin: ramus) and the pathogenicity of *P. ramorum* to twigs and branches (Werres *et al.*, 2001).

HOSTS

Phytophthora ramorum has caused severe damage in the 1990s and 2000s, e.g. on oak and tanoak (*Quercus* spp ., *Lithocarpus densiflorus*) in the USA, on larch (*Larix* spp.) in the United Kingdom and on ornamental plants in Central Europe. The disease is most commonly known as 'sudden oak death' or 'ramorum blight' (Rizzo *et al.*, 2002; Grünwald *et al.*, 2008, 2019). The pathogen is generally characterized by a broad host range with more than 170 species currently known to be hosts. These include many important shrubs and trees of ornamental or environmental significance and some herbaceous plants. *Camellia*, *Kalmia latifolia*, *Larix*, *Lithocarpus densiflorus*, *Quercus agrifolia*, *Pieris*, *Rhododendron*, *Syringa vulgaris*, *Vaccinium* and *Viburnum* are counted among the most important host plants (Garbelotto *et al.*, 2001; Werres *et al.*, 2001; Davidson *et al.*, 2005; EPPO, 2013; Grünwald *et al.*, 2019).

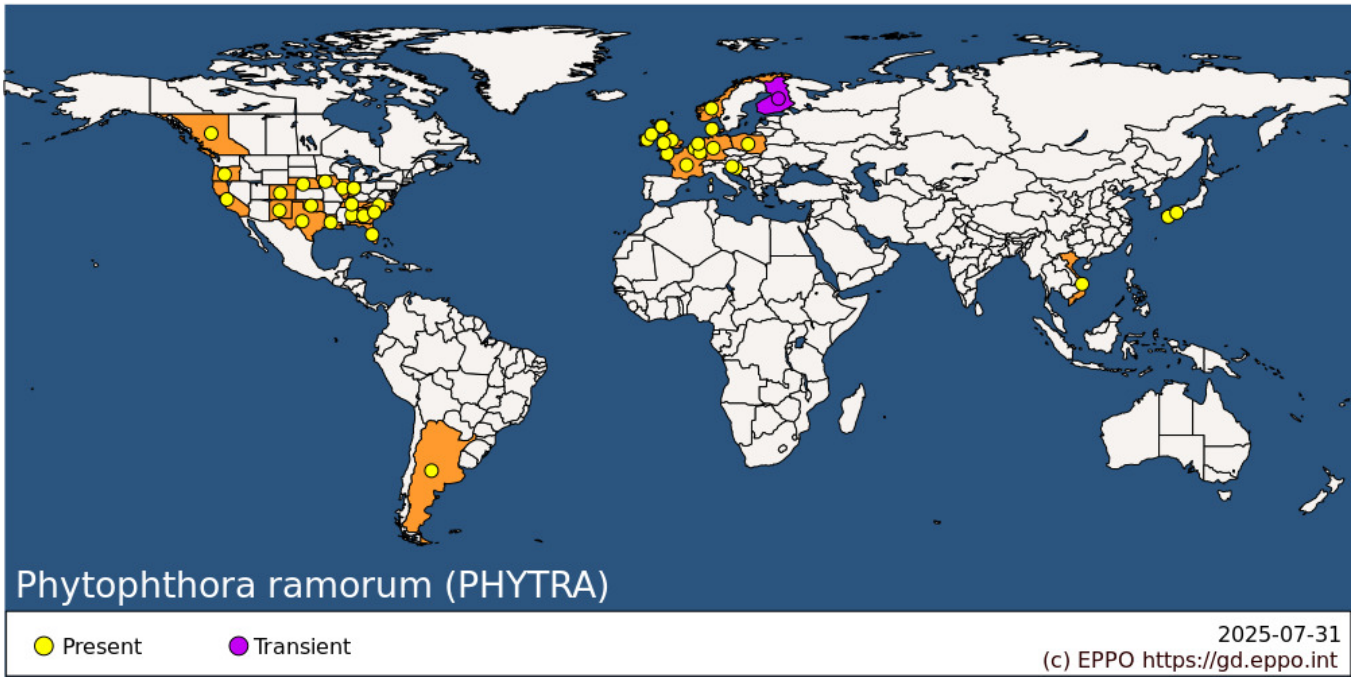
Host list: *Abies alba, Abies concolor, Abies grandis, Abies magnifica, Abies procera, Acer circinatum, Acer davidii, Acer laevigatum, Acer macrophyllum, Acer pseudoplatanus, Adiantum aleuticum, Adiantum jordanii, Aesculus californica, Aesculus hippocastanum, Alnus cordata, Arbutus menziesii, Arbutus unedo, Arctostaphylos canescens, Arctostaphylos columbiana, Arctostaphylos glauca, Arctostaphylos manzanita, Arctostaphylos pumila, Arctostaphylos sensitiva, Arctostaphylos uva-ursi, Arctostaphylos virgata, Arctostaphylos viridissima, Arctostaphylos , Ardisia japonica, Berberis aquifolium, Betula pendula, Calluna vulgaris, Calycanthus occidentalis, Camellia japonica, Camellia sasanqua, Camellia, Castanea sativa, Castanopsis orthacantha, Ceanothus thyrsiflorus, Cercis chinensis, Chamaecyparis lawsoniana, Chamerion angustifolium, Choisya ternata, Choisya, Chrysolepis chrysophylla, Cinnamomum camphora, Clintonia andrewsiana, Cornus capitata, Cornus hybrids, Cornus kousa, Corylopsis spicata, Corylus cornuta, Cotoneaster pannosus, Cotoneaster sp., Cryptomeria, Daphniphyllum glaucescens, Distylium myricoides, Drimys winteri, Dryopteris arguta, Epilobium ciliatum, Eucalyptus haemastoma, Euonymus kiautschovicus, Fagus sylvatica, Frangula californica, Frangula purshiana, Fraxinus excelsior, Fraxinus latifolia, Garrya elliptica, Gaultheria procumbens, Gaultheria shallon, Griselinia littoralis, Hamamelis mollis, Hamamelis virginiana, Hamamelis x intermedia, Heteromeles arbutifolia, Ilex aquifolium, Ilex chinensis, Ilex latifolia, Kalmia angustifolia, Kalmia latifolia, Kalmia, Larix decidua, Larix kaempferi, Larix x marschlinsii, Laurus nobilis, Leucothoe axillaris, Leucothoe fontanesiana, Lithocarpus glaber, Lonicera hispidula, Lophostemon confertus , Loropetalum chinense, Magnolia acuminata, Magnolia cavaleriei, Magnolia delavayi, Magnolia denudata, Magnolia doltsopa, Magnolia figo, Magnolia foveolata, Magnolia grandiflora, Magnolia insignis, Magnolia kobus, Magnolia liliiflora, Magnolia lotungensis, Magnolia maudiae, Magnolia salicifolia, Magnolia stellata, Magnolia wilsonii, Magnolia x loebneri, Magnolia x soulangeana, Magnolia x thompsoniana, Magnolia, Maianthemum racemosum*

, Nerium oleander, Nothofagus obliqua, Notholithocarpus densiflorus, Osmanthus decorus, Osmanthus delavayi, Osmanthus fragrans, Osmanthus heterophyllus, Osmanthus, Osmorhiza berteroi, Parrotia persica, Phoradendron leucarpum, Photinia x fraseri, Physocarpus opulifolius, Picea sitchensis, Pickeringia montana, Pieris formosa, Pieris hybrids, Pieris japonica, Pieris, Pittosporum undulatum, Prunus laurocerasus, Prunus lusitanica, Pseudotsuga menziesii, Pteris cretica, Pyracantha koidzumii, Quercus acuta, Quercus agrifolia, Quercus cerris, Quercus chrysolepis, Quercus falcata, Quercus ilex, Quercus kelloggii, Quercus parvula var. shrevei, Quercus petraea, Quercus phillyreoides, Quercus robur, Quercus rubra, Quercus, Rhododendron arboreum, Rhododendron catawbiense, Rhododendron macrophyllum, Rhododendron ponticum, Rhododendron yakushimanum, Rhododendron , Ribes laurifolium, Rosa gymnocarpa, Rosa rugosa, Rosa, Rubus spectabilis, Salix caprea, Sarcococca, Schima argentea, Schima wallichii, Sequoia sempervirens, Syringa vulgaris, Taxus baccata, Taxus brevifolia, Taxus x media , Torreya californica, Toxicodendron diversilobum, Trientalis latifolia, Tsuga heterophylla, Umbellularia californica , Vaccinium intermedium, Vaccinium myrtillus, Vaccinium ovatum, Vaccinium parvifolium, Vaccinium vitis-idaea, Vaccinium, Vancouveria planipetala, Viburnum davidii, Viburnum hillieri, Viburnum plicatum var. tomentosum, Viburnum tinus, Viburnum x bodnantense, Viburnum, Vinca minor

GEOGRAPHICAL DISTRIBUTION

The diversity of *P. ramorum* has recently been studied in Vietnam and it was hypothesized that Vietnam could be the centre of origin of this species. The pathogen was also found in Vietnam on *Rhododendron*, thus suggesting that *Rhododendron* may be part of its natural host range (Jung *et al.*, 2020). The species was introduced to Europe and North America where it was first discovered in the 1990s (Werres *et al.*, 2001; Rizzo *et al.*, 2002). In particular, oak trees in western North America and larch plantations in the United Kingdom were severely affected in the 1990s and 2000s by the pathogen, while in other areas of North America and Europe mainly ornamental plants were affected (Grünwald *et al.*, 2019). So far, *P. ramorum* is known to occur in Europe, North America, parts of Asia, and Argentina (Vélez *et al*., 2020).

Four clonal lineages have been characterized and named after the continent where they were first found (NA = North America, EU = Europe): NA1, NA2, EU1 and EU2. Only EU1 was found in Europe as well as in North America (Grünwald *et al.*, 2009, 2012, 2019; Van Poucke *et al.*, 2012). The Vietnamese lineage appears to be most closely related to NA2 with only one base pair difference on the genetic marker *cox1* (Jung *et al.*, 2020).



EPPO Region: Belgium, Croatia, Denmark, Finland, France (mainland), Germany, Guernsey, Ireland, Luxembourg, Netherlands, Norway, Poland, Slovenia, United Kingdom (England, Northern Ireland, Scotland, Wales)
Asia: Japan (Kyushu, Shikoku), Vietnam
North America: Canada (British Columbia), United States of America (Alabama, California, Colorado, Florida, Georgia, Illinois, Indiana, Iowa, Louisiana, Nebraska, New Mexico, North Carolina, Oklahoma, Oregon, South

Carolina, Tennessee, Texas)
South America: Argentina

BIOLOGY

For the dispersal of *P. ramorum*, the mycelium can form three different types of spores based on a sexual or asexual reproduction.

Sporangia containing flagellated zoospores (asexual reproduction) can be formed on the surfaces of infected leaves or twigs of some hosts. After being released, zoospores can colonize neighbouring plants by swimming through thin water films (e.g. via water splash) towards the plants. It is thought that the zoospores then penetrate the new host to initiate a new infection. When inoculating twigs of *Rhododendron* with *P. ramorum*, it has been observed that the first symptoms (twig discoloration) appeared three to seven days after inoculation (Werres *et al.*, 2001). Another mode of dispersal of *P. ramorum* can take place within the soil (or growing media), leading to root infection that is followed by a colonization of the vascular tissues and spread into the stem (Parke & Lewis, 2007; Grünwald *et al.*, 2008).

In the plant, chlamydospores (asexual reproduction) are often produced to survive adverse conditions, and may also play a special role in the dispersal within the soil (or growing media) (Shikoff, 2007; Tooley *et al.*, 2008).

Sexual reproduction via the production of gametangia has not yet been observed in plants, but only under laboratory conditions on culture media (Garbelotto *et al.*, 2001; Werres *et al.*, 2001, Brasier & Kirk, 2004). The known lineages of *P. ramorum* belong to different mating types (A1 or A2): NA1 and NA2 belong to mating type A2, EU1 predominantly belongs to mating type A1 and rarely to A2, EU2 belongs to A1 and the Vietnamese lineage comprises both mating types A1 and A2 (Grünwald *et al.*, 2009; Van Poucke *et al.*, 2012; Jung *et al.*, 2020).

DETECTION AND IDENTIFICATION

Symptoms

Two different disease syndromes can be distinguished, based on a foliar phase or on a bole canker phase: ‘sudden oak death’ and ‘ramorum blight’ (Grünwald *et al.*, 2008), but in general, symptoms are host specific and vary according to the host (Kliejunas, 2010).

‘Sudden oak death’ (including ‘sudden larch death’) is characterized by lethal cankers. The trunk of affected trees shows bleeding cankers or tarry spots, mostly in the lower part, but in some cases up to a height of 20 m. Sometimes sunken or flattened cankers can be observed nearby. After removing the outer bark, mottled areas and necrotic discoloration of the inner bark tissues can be seen, showing similarities with the normal oxidative reddening of phloem tissues. Dark zones are often present at the edges of these necrotic areas. In particular, young or thinner trees show a distinct edge between healthy and necrotic tissues. Vessel blockage caused by *P. ramorum* often results in a wilt of leaves or needles (without premature leaf fall or needle cast) and eventually in tree mortality (Hansen *et al.*, 2002; EPPO 2006; Parke *et al.*, 2007; Webber *et al.*, 2010).

‘Ramorum blight’ occurs in twigs in the form of brown or black lesions. On *Rhododendron*, the development of twig lesions begins at the tips and moves towards the base. In addition, cankers can form on shoots or stems, which can lead to a rapid wilting of the leaves, depending on the position of the canker. The wilted leaves remain attached. After removing the bark of a diseased twig, discoloration of the cambial tissue can be seen. The main characteristic leaf symptom is a blackening of the petiole that spreads into the leaf base. Further spread along the midrib can also occur. In other host plant species, not all the above described symptoms may appear. Another manifestation of ‘ramorum blight’ is the development of diffuse brown to dark-brown spots on the leaves. These spots are usually found at the leaf tips, but may appear elsewhere. The whole leaf area may turn brown to black, and leaves may fall prematurely (Werres *et al.*, 2001; Hansen *et al.*, 2002; EPPO 2006).

Morphology

P. ramorum is a heterothallic species with two mating types. Cultivated individuals can produce gametangia by pairing with opposite *Phytophthora* mating types of few strains or species, e.g. *P. ramorum* A1 with *P. cryptogea* A2.

Oogonia are produced terminally or laterally. They are subglobose and smooth with a size of 24-40 µm (average 29.8-33 µm). Oospores are plerotic and 20-36 µm in size (average 27.2-31.4 µm). Antheridia are amphigynous and mainly rounded to barrel-shaped with a size of 12-22 x 15-18 µm. Two-celled antheridia are very seldom.

Chlamydospores are produced intercalarily or terminally, occasionally laterally. They are globose and thin-walled with a size of 20-91 µm (average 46.4-60.1 µm).

Sporangia are ellipsoid, spindle-shaped or elongated-ovoid with a length x width range of 25-97 x 14-34 µm and an average (length x width) of 45.6-65 x 21.2-28.3 µm. The average length: width ratio is 1.8-2.4. Generally, they have a rounded base; a tapered base is seldom. The caducous sporangia retain a short pedicel, or none, and are semipapillate with one narrow papilla.

Isolates of *P. ramorum* grow between 2 and 30 °C. The optimal temperature is 20 °C for most isolates, but in exceptional cases, it can vary between 17 and 25 °C. Isolates grow 2.5-3.5 mm in 24 h at the optimal temperature (Werres *et al.,* 2001).

Detection and inspection methods

The presence of *P. ramorum* can be detected in different types of samples, e.g. plant material, water, soil or growing media. Visual inspections alone are not sufficient, because symptoms can vary between different plant species (Kliejunas, 2010), they can be visually undetectable (e.g. root infections), or they can be suppressed by the use of fungicides (EPPO, 2006).

Isolation from water or soil (or growing media) is possible by using a bait test with rhododendron leaves (Themann *et al.,* 2002; Junker *et al.,* 2018).

Isolation from plant material (selected plant parts or leaves previously used in a bait test) is possible after a surface disinfection followed by plating the plant material onto a suitable culture medium.

The identification of the pathogen is possible by using morphological methods combined with growth characteristics on culture media or DNA-based methods.

The typical morphological structures of *Phytophthora* (e.g. chlamydospores, sporangia, gametangia) in culture and the growth characteristics have to be checked and measured for an identification. An identification key (e.g. Gallegly & Hong, 2008) should be used together with a comparison with the original species description (Werres *et al.,* 2001). A comparison with closely related or similar species (e.g. *P. palmivora*) needs to be considered (EPPO, 2006).

DNA barcoding is another option for an identification and can serve as support for a morphological identification of *P. ramorum* (EPPO, 2016). Different DNA-based methods and primer combinations are possible (EPPO, 2006; Hughes *et al.*, 2006; Bilodeau *et al.*, 2007, 2009; Tomlinson *et al.*, 2007; Martin *et al.*, 2009, Vettraino *et al.*, 2010; Martin, 2013, Feau *et al.*, 2019; Wong *et al.*, 2020). The presence of inhibitors in some wood (e.g. larch) can cause difficulties to DNA-based testing (EPPO, 2006).

The EPPO diagnostic protocol for *P. ramorum* provides further information and recommendations on how to detect and identify the pathogen (EPPO Standard PM 7/66, 2006 – under revision).

PATHWAYS FOR MOVEMENT

By releasing zoospores, *P. ramorum* can colonize neighbouring plants via water splash (see Biology), but it can also colonize new hosts over greater distances via wind, rain, rivers or streams (Davidson *et al.,* 2005; Grünwald *et al.,* 2008). Transportation by humans, for example on their shoes or car tyres, is also possible (Davidson *et al.*, 2005; Frankel, 2008; Grünwald *et al.,* 2008). In nurseries, *P. ramorum* was found in field soil, various substrates, water sediments (e.g. in puddles, sediment runoff, water retention reservoirs), wind carried leaves, plants and plant debris

(Junker *et al.,* 2016). Nevertheless, an important pathway for the movement of the pathogen is the trade of infected plants or plant parts, especially on its main hosts (B?halová, 2006; Kliejunas, 2010; Grünwald *et al.,* 2019).

PEST SIGNIFICANCE

Economic impact

The main economic impacts of the disease affect forests and nurseries.

In the 1990s and 2000s, forests in the United States and the United Kingdom have been severely affected (Rizzo *et al.,* 2002; Brasier & Webber, 2010). Around 2240 km^2 were affected in the US and 200 km^2 in the United Kingdom with millions of trees being felled (Webber, 2017; Grünwald *et al.,* 2019). The broad host range of the pathogen aggravates the situation, because species of the understory vegetation (e.g. *Laurus nobilis*) are also hosts of *P. ramorum* and facilitate its establishment and survival (Grünwald *et al.,* 2019). Due to cascading effects, the ecological impact could be very high if some species are completely removed from ecosystems by *P. ramorum*. It is considered that *P. ramorum* has the potential to disrupt native ecosystems, to increase the need for chemical or biological control programs, and to threaten already endangered plant species (Cave *et al.,* 2008).

Nurseries in Europe and North America have also been strongly affected. In most cases, when samples from a nursery test positive for *P. ramorum*, quarantine measures are implemented and host plants are destroyed. This leads to significant extra costs or a change in the plant production (Grünwald *et al.,* 2019).

Control

Preventive fungicidal treatments can be useful for valuable plants in urban green areas. In a forest environment, the use of fungicides is usually not practical (Kliejunas, 2010). As in other *Phytophthora* species, metalaxyl, phosetyl-aluminium, copper sulfate or phosphonate are effective against *P. ramorum* (Garbelotto & Rizzo, 2001; Garbelotto *et al.,* 2002). In particular, phosphonate compounds are helpful in controlling the pathogen. The treatment of a tree prior to infection is significantly more effective than after infection (Garbelotto *et al.,* 2003b). Disinfection of contaminated water is possible with hydrogen peroxide, sodium hypochlorite and copper-based active ingredients (Sansford & Woodhall 2007, Colburn & Jeffers, 2010). Metalaxyl also eliminates the pathogen in the soil (Turner *et al.,* 2006), but some isolates are resistant to it (Wagner *et al.,* 2006, 2008; Turner *et al.,* 2008). Moreover, metam sodium, chloropicrin or iodomethane may also eliminate *P. ramorum* in soils (Kliejunas, 2010). A number of other substances have also shown positive effects against *P. ramorum*, these include: chitosan, chloropicrin, dazomet, dichloropropene with chloropicrin, film-forming polymers, iodomethane, metam sodium, phytosterols, strobilurins, surfactants and tannin (Orlikowski, 2004; Yakabe & MacDonald, 2008; Stong *et al.,* 2013; Elliott *et al.,* 2015; Peterson *et al.,* 2019).

Different biocontrol agents have also been tested against *P. ramorum*. Positive effects have been obtained when using the following bacteria: *Bacillus brevis, Bacillus subtilis, Paenibacillus subtimyxa, Pseudomonas fluorescens* and *Streptomyces lydicus* (Cohen *et al.,* 2006; Linderman & Davis 2006, Elliott & Shamoun 2008). Several isolates of *Trichoderma* can parasitize *P. ramorum*, and the incorporation of *Trichoderma asperellum* into potting media has shown promising results (Elliott & Shamoun, 2008; Widmer, 2008, 2014).

Essential oils of *Chamaecyparis lawsoniana, C. nootkatensis* or *Juniperus occidentalis* have shown positive effects against *P. ramorum* under laboratory conditions (Manter *et al.,* 2006), as well as caffeic acid, grapefruit or rice bran extract (Orlikowski, 2004; Widmer, 2008).

Sanitation is necessary to maintain pathogen-free plant material. This includes removing and testing symptomatic stock, sterilizing potting media and disinfecting tools, benches, worker's gloves, shoes and other equipment (Erwin & Ribeiro, 1996).

Research on resistance to *P. ramorum* shows some promising results. Various studies are being carried out and concern different plant species or hybrids within the broad host range of the pathogen (e.g. Parke *et al.,* 2002; Garbelotto *et al.,* 2003a; Dodd *et al.,* 2005; De Dobbelaere *et al.,* 2006; Grünwald *et al.,* 2006; Meshriy *et al.,* 2006;

Hayden *et al.*, 2010).

Phytosanitary risk

In the EPPO region, *P. ramorum* presents a risk to many different environmental and ornamental shrubs and trees, in numerous habitats such as woodland, heathland, maquis, shrubland, as well as in managed gardens, parks or public greens, and nurseries (Sansford *et al.*, 2008). *Camellia*, *Kalmia latifolia*, *Larix*, *Lithocarpus densiflorus*, *Quercus agrifolia*, *Pieris*, *Rhododendron*, *Syringa vulgaris*, *Vaccinium* and *Viburnum* are counted among the most important host plants that are particularly at risk (Garbelotto *et al.*, 2001; Werres *et al.*, 2001; Davidson *et al.*, 2005; EPPO, 2013; Grünwald *et al.*, 2019). The woodlands in North America, where the pathogen is established (i.e. California), have a Mediterranean type of climate similar to some EPPO countries. These countries are also particularly at risk, and include parts of Albania, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, France, Germany, Greece, Ireland, Italy, Montenegro, Netherlands, Portugal, Slovenia, Spain, Turkey and the United Kingdom (Sansford *et al.*, 2008).

PHYTOSANITARY MEASURES

In order to prevent entry or spread of *P. ramorum*, introduced plants should originate from a pest-free area or the areas must be found free from the pathogen after inspections, at least twice during the growing season at an appropriate time. Introduced host plants must comply with the relevant legislation and certification, such as requirements for phytosanitary certificates, a plant passport in EU countries or a scientific license if a phytosanitary certificate cannot be issued. For plants and plant products moving in trade of *Betula*, *Coniferae*, *Castanea*, *Fagus* and *Quercus*, guidance can be found in the EPPO Standards on commodity-specific phytosanitary measures (EPPO, 2017abc, 2018ab).

To guarantee the absence of symptoms, plants from nurseries should be inspected at appropriate times. For some host genera (*Abies*, *Pseudotsuga*), the import of plants for planting from countries outside the EPPO region is usually prohibited; for other host genera (*Castanea, Photinia, Prunus, Rosa, Quercus*) imports may only be allowed for plants that are in a dormant and/or leaf-less state. For imports of plants for planting from the USA, it is usually required that all deciduous trees and shrubs have to be dormant or free from leaves, except seeds and tissue cultures. Additional phytosanitary measures are required if the place of plant production is in the buffer zone of sporulating hosts. The buffer zone has a 10 m radius around host shrubs and 100 m around host trees (EPPO, 2013).

Countries should also apply appropriate measures if *P. ramorum* is detected in areas other than places of production, e.g. parks, gardens, forests. Eradication of the pathogen should be attempted, but if this is not possible, at least measures should be taken to contain the pest, by removing as much infected plant material as possible to reduce the pressure of infection. In each situation, the following elements of risk should be taken into account: scale of the outbreak, risk of further spread, conservation value of the habitat, heritage value in the case of parks or gardens and the local situation (e.g. topography, gradient). It is recommended to apply the following measures, depending on the decision for eradication or containment: (1) Prohibition of movement of susceptible plants, plant parts (including trees) and soil/growing media; (2) Phytosanitary measures to prevent spread of the pest; (3) Control measures; (4) Surveillance. The phytosanitary measures include the removing of plant debris, disposing of susceptible plants or plant material by burning or deep burying them, repairing and maintaining footpaths, restricting access to contaminated areas, hygienic measures such as cleaning and disinfecting shoes or machines, keeping dogs on short leashes and erecting of signs to inform the public about the measures mentioned (EPPO, 2013).

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