EUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION
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Pest Risk Analysis for

Thekopsora minima
(Fungi: Pucciniastraceae)

Taxonomic studies have concluded that *Thekospora minima* should be transferred to the genus *Pucciniastrum* resulting in the species being called *Pucciniastrum minimum* (Padamsee & McKenzie, 2014). The pest is now listed under this name on the EPPO A2 List. The content of the PRA has not been changed.

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This risk assessment follows the EPPO Standard PM 5/5(1) *Decision-Support Scheme for an Express Pest Risk Analysis* (available at http://archives.eppo.int/EPPOStandards/pra.htm) and uses the terminology defined in ISPM 5 *Glossary of Phytosanitary Terms* (available at https://www.ippc.int/index.php). This document was first elaborated by an Expert Working Group and then reviewed by the Panel on Phytosanitary Measures and if relevant other EPPO bodies.

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Photo: *Thekopsora minima*. Courtesy: Wolfgang Maier, JKI (DE)

Pest Risk Analysis for *Thekopsora minima*
(Fungi: Pucciniastraceae), causing Blueberry rust

Based on this PRA, *Thekopsora minima* was added to the A2 Lists of pests recommended for regulation as quarantine pests in 2017.

PRA area: EPPO region
Prepared by: EPPO Secretariat with input from Wolfgang Maier (JKI, Germany), Annemiek Schilder (Michigan State University, USA), Panel on Phytosanitary Measures.
Date: developed in February-June 2017, videoconferences with experts on 16 May and 1 June 2017.

CONTENTS

Summary of the Pest Risk Analysis for *Thekopsora minima* (Fungi: Pucciniastraceae)

PRA area: *EPPO region*

Describe the endangered area: The areas more at risk would be those where evergreen *Vaccinium* are grown and *T. minima* may overwinter and continue its cycle outdoors in the absence of *Tsuga*, as well as areas of extensive cultivation of hosts under protected conditions. Areas with wet conditions during the growing season might be especially at risk. *T. minima* may also have a higher impact where *Tsuga* (e.g. private gardens and parks) and especially where it is frequent (i.e. close to plantations).

Main conclusions

Overall assessment of risk: The risk of entry of *T. minima* into the EPPO region is mostly linked to the trade of *Vaccinium* plants for planting. *T. minima* is a serious pest in some countries. In the EPPO region, the disease has a limited distribution in the Netherlands and is under eradication in several others countries.

The likelihood of entry was assessed as being:

- *High* for *Vaccinium* plants for planting
- *Low* for plants for planting of *Tsuga* and other hosts
- *Moderate* for natural spread from the Netherlands to neighbouring countries
- *Very low* for natural spread from non-EPPO countries

T. minima would have impact on cultivated North American blueberries, which is an expanding crop in the EPPO region. It is likely to spread naturally and through the trade of *Vaccinium* plants for planting. Damage is expected to be more severe in areas with sufficient humidity and where evergreen *Vacciniums* are grown, while in general it would mostly present a problem for nurseries. In areas where *Tsuga* occurs, these may increase the build-up of inoculum, spread and impact of *T. minima*. The wild *Vaccinium* species in the EPPO region are currently not known to be hosts, but damage may be higher if they are.

The Panel on Phytosanitary Measures emphasized that eradication of rusts is very difficult, and that NPPOs should aim at preventing the introduction of the fungus. *T. minima* still has a very limited distribution at the scale of the EPPO region, and although it will spread naturally, such spread will be slow at the scale of the region, and phytosanitary measures have to be strengthened to prevent its introduction into other EPPO countries. Trade of plants for planting is a major pathway and large quantities are traded from the USA and also within the EPPO region.

Phytosanitary measures to reduce the probability of entry: Measures were recommended for the high risk pathway, i.e. *Vaccinium* plants for planting. Because *T. minima* has often been found in association with *V. corymbosum* and hybrids, measures on plants for planting of those, and possibly *V. angustifolium* and *V. ashei*, would be especially important. However, there is still an uncertainty about the host range. For *Vaccinium* fruit, even if the risk of entry if considered as very low, producers should be encouraged to not import bulk fruit to be repacked in their production units (or at least to manage any waste safely to avoid spread of spores).

Phytosanitary risk for the _endangered area_ (*Individual ratings for likelihood of entry and establishment, and for magnitude of spread and impact are provided in the document*)	High ☐	**Moderate** ☒	Low ☐
Level of uncertainty of assessment (*see Q 17 for the justification of the rating. Individual ratings of uncertainty of entry, establishment, spread and impact are provided in the document*)	High ☐	**Moderate** ☒	Low ☐

Other recommendations: The experts made recommendations regarding encouraging the reporting of blueberry leaf rust outbreaks in the EPPO region, in order to help early detection of *T. minima* (see detailed recommendations in section 18).

Stage 1. Initiation

Reason for performing the PRA:
Thekopsora minima is a heteroecious rust that lives on needles of *Tsuga* spp. (hemlock) (spermogonial and aecial stage) and leaves of ericaceous plants (uredinial and telial stages). On *Vaccinium corymbosum*, *T. minima* can lead to extensive defoliation. *Thekopsora minima* was initially known from Eastern North America and Japan, and it has been detected in other areas since 2000. In 2015, it was identified as a potential risk during the preparation of an Alert List of pests of concerns for *Vaccinium* fruit (EU project DROPSA). In Europe, *T. minima* was detected in Germany in 2015, in Belgium in 2016, in Portugal in 2016 (in all cases, under eradication), and in the Netherlands in 2017. A German express PRA concluded that this pathogen might present a high risk for Germany and other parts of the EPPO region. The NPPO of Germany has suggested that *T. minima* should be added to the EPPO Alert List. The Working Party supported that a PRA should be conducted for the EPPO region. A draft was prepared by the EPPO Secretariat in February 2017. Considering the need for rapid recommendations, the Panel on Phytosanitary Measures in March 2017 decided that the draft PRA would not be developed in a PRA Expert Working Group, but only by the Secretariat with input from a few experts, and presented to the Working Party for recommendations.

The EPPO standard PM 5/5 *Decision-Support Scheme for an Express Pest Risk Analysis* was used, as recommended by the Panel on Phytosanitary Measures. Pest risk management was conducted according to the EPPO Decision-support scheme for quarantine pests PM 5/3(5) (detailed in Annex 1).

PRA area: EPPO region (map at www.eppo.org).

Stage 2. Pest risk assessment

1. Taxonomy
Taxonomic classification. Kingdom: Fungi / Phylum: Basidiomycota / Class: Pucciniomycotina / Order: Pucciniales / Family: Pucciniastraceae / Genus: *Thekopsora* Magnus / Species: *Thekopsora minima* (Arthur) Syd. &. Syd. 1915.

Disease. Blueberry rust.

Synonyms. *Uredo minima* Schwein. 1822, *Uredo azaleae* (Schwein.) Sacc., *Pucciniastrum minimum* (Schwein.) Arth. 1906, Anamorph: *Peridermium peckii* Thüm. 1880.

Note. *Thekopsora minima* was described in 1915, but a broad species concept was later applied, that grouped several rusts under the name *Pucciniastrum vaccinii*. Sato et al. (1993) attempted to clarify the systematics of the Tsuga-Ericaceae rusts, separating (again) *Thekopsora minima* from *T. vaccinii (=Pucciniastrum vaccinii)*, which he moved to a new genus, *Naohidemyces vaccinii* (present in Europe, Asia and North America). In addition Sato et al. described a new Tsuga-Ericaceae rust, *N. fujisanensis*, which is so far only known from Japan. However, many people continued applying the broad species concept and thus still using the name *Pucciniastrum vaccinii* relating to both the North American and the European blueberry rust (W. Maier, pers. comm.). Consequently there is some confusion in the literature between *Naohidemyces vaccinii* (syn. *Pucciniastrum vaccinii* s. str., *Thekopsora vaccinii*, *T. myrtillina*) and *T. minima*, and some records of *N. vaccinii* or *P. vaccinii* may relate to *T. minima*.

The records (hosts or distribution) that can be considered to be most reliable for *T. minima* are those given in Sato et al. (1993) and subsequent records for which DNA sequencing was used (see *Detection and identification* in section 2). Records of *Peridermium peckii* on *Tsuga* are also considered to relate to *T. minima*.

Therefore, in this PRA, blueberry rust on *V. corymbosum* is generally considered to be *T. minima*. This assumption is made, because so far all rust specimens that were identified by sequence comparisons from *V. corymbosum* in the recent outbreaks of the disease in various countries were identified as *T. minima* (W. Maier, pers. comm.). In addition there is no record of *N. vaccinii* on *V. corymbosum* in Sato et al. (1993). Nevertheless, there is still a lack of data to reliably confirm this, and in particular it remains to be clarified if some records of rust on *V. corymbosum* in North America (when sequence comparisons have not been performed) could still relate to *N. vaccinii* instead of *T. minima*. However the few recent reports of the disease from North America where the causal agent had been determined by sequencing were also attributed to *T. minima.*

Similarly, records of *P. vaccinii* on *V. angustifolium* or *V. ashei* most likely also refer to *T. minima* (they relate to older records of *P. vaccinii* from US States where *T. minima* is known to occur on a known host of *T. minima* but not of *N. vaccinii*).

The elements above lead to uncertainties regarding a number of records of *P. vaccinii* or *N. vaccinia* (or *P. vaccinii* s. str., =*T. vaccinii*), in countries where the broad species concept was applied. For example, in North America (where both *T. minima* and *N. vaccinii* occur naturally), the narrow concept started being used more recently after proper identification (e.g. Schilder and Miles, 2011). In some other countries (detailed in section 6, Table 2), *P. vaccinii* or 'blueberry leaf rust' were reported on *V. corymbosum*, and DNA sequencing was not carried out, leaving an uncertainty on whether the species present is *N. vaccinii* or *T. minima*.

Finally, it was considered in this PRA that records on species that are hosts of *N. vaccinii* but not of *T. minima* in Sato et al. (1993) relate to *N. vaccinii*.

2. Pest overview

2.1 Biology and epidemiology

Life cycle

Thekopsora minima is a heteroecious rust. The spermogonial/pycnial and aecial stages occur on *Tsuga* spp., and uredinial and telial stages on Ericaceae. The full cycle is outlined in Figure 1 below:

- Teliospores of *T. minima* hibernate in blueberry leaves on the ground and after germination in spring, basidia are produced and basidiospores infect the alternate host *Tsuga* spp.
- On *Tsuga* needles, first spermogonia are produced and, after dicaryotisation, aeciospores are produced which in turn infect *Vaccinium* or other ericaceous host plants.
- On Vaccinium or other ericaceous hosts, uredinia are formed and urediniospores are released. These are mostly found on leaves, but infection of fruit has also been reported, in Australia. The secondary cycle with urediniospores is repeated on *Vaccinium* or other ericaceous hosts, leading to inoculum build-up and disease spread throughout the summer. In some places, where climatic conditions are favourable, it is believed that the rust survives only through this secondary cycle (see *Need for the alternate host* below). Uredinia release large numbers of spores that are easily and quickly transported by wind (see section 11 *Spread*), but can also be spread via infected plants and fruit, packaging, equipment, clothing and hands (Victoria Agriculture, 2016b).

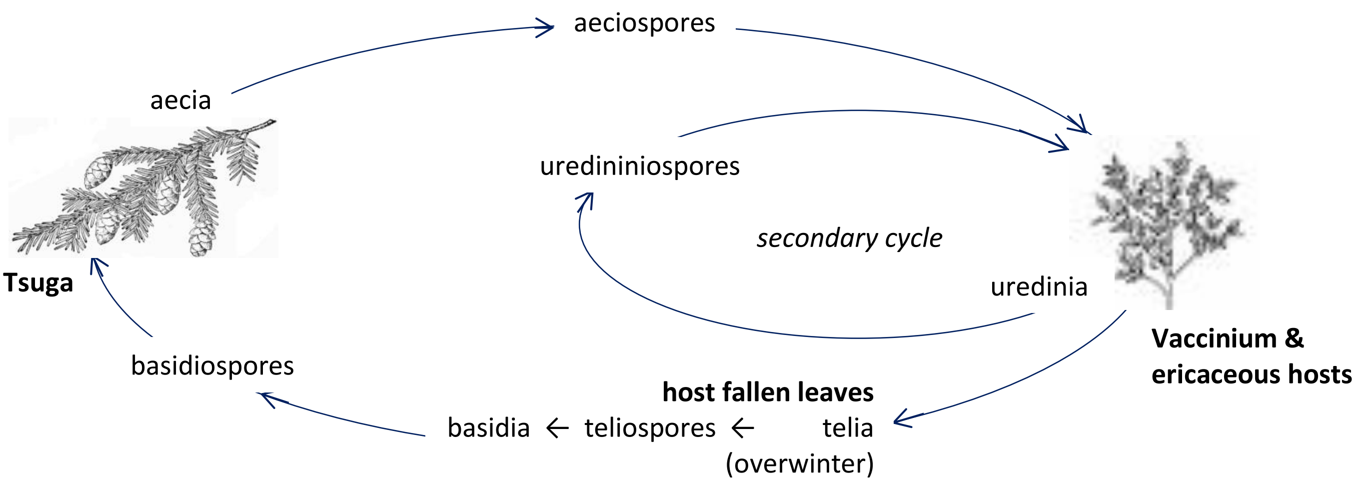

Figure 1. Outlined life cycle of *T. minima* (EPPO Secretariat - *Tsuga* drawing: from Manual of the Trees of North America (Exclusive of Mexico) 2nd ed., C. Sprague Sargent, 1922, Riverside Press)

Need for the alternate host. Agriculture Victoria (2016b) note that, in colder climates, *Tsuga* is needed to complete the life cycle. However, New Brunswick (2009) mentions that fields which do not have *Tsuga* on their perimeter can still be severely affected by rust. In Michigan, *Tsuga* are assumed to play an important role in the epidemiology of the disease because leaf rust tends to be more severe near *Tsuga* trees (Schilder and Miles, 2011). However, in part of its distribution area, *T. minima* appears to survive in the absence of the alternate host *Tsuga* (hemlock), only through the uredinial cycle (without completing its life cycle). With its recent spread, *T. minima* is now present in areas where *Tsuga* is not present naturally or rare (all records except Asia, USA and Canada), although Tsuga species may be grown as ornamentals in home or botanical gardens. In Sichuan, China, no *Tsuga* were found in the surroundings of infested blueberry fields (Zheng et al., 2017). Two mechanisms may explain how *T. minima* could maintain itself in the absence of alternate hosts, including under conditions where host shed leaves in winter (e.g. generally *V. corymbosum*). Both are mentioned in Gäumann (1959) as occurring in other *Thekopsora* species (specifically *T. myrtillina* on *V. myrtillus* and *T. vacciniorum* on *V. vitis-idea*, which are now treated under *N. vaccinii*):

- *T. minima* may overwinter systemically as mycelium on the host (e.g. in or on buds or stems) and directly produce urediniospores in spring. This appears to be supported by recent observations in a glasshouse in Germany, where symptoms of *T. minima* appeared in spring on one *V. corymbosum* plant that had lost all leaves over the winter (W. Maier, pers. comm.). However, this would need to be repeatedly confirmed by experiments, and the part of plants infected would need to be determined.
- Uredinia of *T. minima* may overwinter on leaves that remain green through the winter. Among hosts of *T. minima*, evergreen (low-chill) varieties of *V. corymbosum*-hybrids are used in regions with mild winters; and there are other evergreen hosts of *T. minima* are evergreen, such as *Rhododendron* spp. *Thekopsora minima* is serious in evergreen *Vaccinium* fields in Australia (Simpson et al., 2016). Daniel (ppt, date unknown), for New South Wales, mentions a doubt on whether the spores are dormant over cooler months or whether they infect plants and do not develop. Finally, varieties that are not evergreen may retain leaves over the winter when grown in glasshouses.

Consequently it is considered likely in this PRA that *T. minima* will be able to maintain itself in the EPPO region in the absence of *Tsuga*, although the above are hypotheses and the conditions that would allow this are not precisely defined (i.e. whether overwintering in buds would occur under all climatic conditions, presence of evergreen host plants).

Conditions favorable to the fungus. There is limited knowledge on the biology and epidemiology of *T. minima*. In places where *T. minima* has been present longest, no information was found for Japan, and in the USA and Canada, information focuses on management. Even in Australia, where *T. minima* appears to be especially damaging, information deals mostly with management and avoiding spread. Daniel et al. (2013) mentions that the infection process of *T. minima*, the susceptibility of leaves and shoot tips at different physiological development stages and the environmental factors that are conducive to infection were recently studied in Australia; no publications presenting the results were found.

Experimental data is limited. A laboratory study on the effect of temperature on uredinia and urediniospores of *T. minima* on *Rhododendron* (excised leaf disks, 14-h photoperiod) (Pfister et al., 2004) found:

- The number of uredinia produced was similar at 15, 20 and 25°C, but reduced six-fold at 30°C.
- 21.5°C as predicted optimum for urediniospore germination, with an optimum range of 19-23°C. This range was similar to those reported for some other rust pathogens.
- 19.5°C as predicted optimum for uredinial production, and 22°C for germ tube growth.
- Great reduction of germination and germ tube growth at 30°C and below 15°C, with no germination at 10°C, and a germination rate nearly halved at 15°C, and significantly decreased above 25°C.
- Mean incubation period of 14.1, 10.7, 10.0, and 12.9 days post-inoculation at 15, 20, 25, and 30°C, respectively. The incubation period was shortest at 20 and 25°C, the predicted optimum being 23°C. Rebollar-Alviter et al. (2011) obtained similar results on incubation period during pathogenicity tests, where uredinia were observed 13 and 10 days after inoculation on two cultivars (at 22°C, 12-h photoperiod).

The authors concluded that further research was needed to determine if the optimal temperature range is consistent for populations of *T. minima* and other ericaceous hosts over a range of elevations and latitudes.

In Australia uredinia can be produced and release uredinospores every 10-14 days, with more rapid spore production under favourable climatic conditions, and *T. minima* is favoured by warm weather with periods of

rain and heavy dews (Wilk et al 2016-17). The optimum temperature for spore production is around 21°C, but new infections are unlikely when the temperature is over 30°C (Victoria Agriculture, 2016b). Daniel et al. (2013) mentions that subtropical climates, such as where *T. mimima* is present in Australia, favour such disease.
For leaf rusts (mentioning *N. vaccinii* but probably also adressing *T. minima*) a leaf wetness period of 48 h is sufficient for infection under controlled environmental conditions (Heidenreich et al., 2005). Shorter incubation periods are reported in other experiments: 24 h and 12 h in Pfister et al. (2004) and Rebollar-Alviter et al. (2011) respectively. The minimum leaf wetness duration needed for infection is currently not documented, nor whether high relative humidity is sufficient for infection (see section 18. Remarks).

Temperature and moisture need to be favorable only at critical stages of the life cycle (e.g. for spore germination). Cool temperatures, while less favourable for infection, may prolong uridiniospore viability. The climatic conditions and host cultivar susceptibility would influence the severity of the disease.

Location of the spores and survival. The fungus mostly infects needles and cones of *Tsuga* and leaves of its other hosts. Infection of the blueberry fruit has been reported from Australia. Daniel (powerpoint presentation on the Internet, year not known) reports damage and sporulation on fruit, and mentions that the mechanisms for infection are not known. Other sources mention that rust spores may be found on other parts of the plant (such as fruit and stems) if they become dislodged from the pustules (Agriculture Victoria, 2016b). No data were found on the duration of survival of spores on *Vaccinium* plants or other hosts. Biosecurity Tasmania (2014b) note that blueberry rust spores may last in the soil, and on materials such as mulch or pots, for up to 6 weeks, but cannot survive longer than this unless a host plant is present. It is not clear if this is a general assumption, or if it has been specifically studied for urediniospores of *T. minima*.

Timing of the life cycle. In Nova Scotia, Canada, aeciospores produced on *Tsuga* are generally released through late June and early July ; symptoms on lowbush blueberry initially appear in late July and severe premature defoliation by early to mid-September (Hildebrand et al., 2010). In Michigan, aeciospores have been observed on *Tsuga* needles as early as mid-June and symptoms on blueberries usually occur from August to October (A. Schilder, pers. comm.). In China, blueberry leaf rust symptoms were first observed in April, causing extensive defoliation in the following months (Zheng et al., 2017). In Australia, Wilk et al. (2016-17) note that rust mostly affects older leaves, so its initial effects in the north are during spring and summer and in the south after February (end of summer).

The susceptibility of cultivars varies. In China, the incidence of the disease was measured and varied between cultivars of *V. corymbosum*, with 87.2%, 5.1%, 3.5% and 0.0% on Sharpblue, Misty, Bluegold and O'Neill [possibly referring to O'Neal], respectively. O'Neill also did not develop symptoms in pathogenicity tests (Zheng et al., 2017). In Australia, southern highbush varieties and their cultivars are more susceptible than other varieties (Agriculture Victoria, 2016b). In the southeastern US States, the disease can be particularly severe on some rabbiteye and southern highbush varieties. Agriculture Victoria (2016c) and Niedersachsen (2016) mention lists of susceptible cultivars, and Heidenreich et al. (2005) resistant cultivars (it is not clear in these publications whether this relates to fully or partially resistant cultivars, and *N. vaccinii* or *T. minima*). In Michigan, northern highbush cultivars were ranked from most to least susceptible: Bluecrop, Liberty. Rubel, Jersey, Legacy, Bluehaven, Duke, Draper, Elliott, Berkeley, Liberty and Aurora (A. Schilder, pers. communication).

2.2 Symptoms (except where specific references are mentioned, all is from EPPO, 2016, which cites original sources)
Symptoms appear on the upper surface of blueberry leaves as small, yellow spots that later become necrotic as they enlarge and coalesce, eventually covering large areas of individual leaves. Older lesions are more angular and sometimes surrounded by a purplish border; in the fall, a 'green island' effect is sometimes apparent around the lesions (Schilder and Miles, 2011; Wiseman et al., 2016). On the undersides of leaves, small flecks surrounded by watersoaked halos appear, turning into yellow-orange pustules. Infected leaves may curl (Agriculture Victoria, 2016b). In case of severe infection, premature leaf drop and plant defoliation is observed. Loss of leaves reduces plant vigour which may lead to reduction in cold hardiness, and a decline in fruit yield and flower production during the following season. Serious defoliation may lead to the death of susceptible cultivars (Victoria Agriculture, 2016b ; Wilk et al., 2016-2017). The production of fruit buds in

severely affected sprout fields of lowbush blueberries can be reduced by 30% or more (New Brunswick, 2009).

In Australia, fruit infection is reported, with pustules developing on fruits later in the season, leading to crop losses (Agriculture Victoria, 2016b). The experts noted that this appears to be reported only in Australia; the reasons are not fully clear, but it may be that in other places, such as the USA, the inoculum occurs too late in the season for fruit to become infested.

2.3 Detection and identification

Symptoms of rust on *Vaccinium* plants can be readily identified as such (Schrader and Maier, 2015). It is not clear if symptoms on other Ericaceae hosts (e.g. *Rhododendron*) can be discovered as easily. Visual inspection should be carried out from spring onwards, especially when conditions are conducive (Wilk et al 2016-17). *T. minima* can be difficult to detect in very early stages of infection (Biosecurity Tasmania, 2014b). Advanced detection techniques, e.g. hyperspectral remote sensing, are being developed in Australia for early detection before the appearance of symptoms (Ahlawat et al., 2011). Although the leaf rust on *V. corymbosum* (and possibly *V. angustifolium* and *V. ashei*) is likely to be *T. minima* in most locations, there is still uncertainty about this, and the identity of the fungus should be confirmed with molecular methods.

Morphologically, *T. minima* is very similar to the other *Vaccinium* rusts, *N. vaccinii* (present in Europe) and *N. fujisanensis* (endemic in Japan). Aecial, uredinial and telial characteristics allow distinguishing *N. vaccinii*, *N. fujisanensis* and *T. minima* (Sato et al., 1993), but differences are rather subtle, and require experience with rust fungi. In case of detection on leaves of *Vaccinium* or other ericaceous hosts, the diagnosis needs to be normally based on the morphology of uredinia/urediniospores.

Consequently, morphological characters can allow detection of one of the blueberry leaf rusts, but reliable identification requires the use of molecular methods (e.g. DNA-sequencing using ITS or LSU rDNA sequences). Such methods are available and allow rapid and reliable identification of the pest.

3. Is the pest a vector?

Yes ☐ **No** ✓

4. Is a vector needed for pest entry or spread?

Yes ☐ **No** ✓

5. Regulatory status of the pest

T. minima is not listed as a quarantine pest by EPPO countries according to EPPO Global Database (EPPO GD, 2017). It was identified as a pest of concern for *Vaccinium* in the preparation of an Alert List in the EU project Dropsa in 2015 (EPPO, 2017). It was added to the EPPO Alert List in 2016 (EPPO, 2016).

Regarding non-EPPO countries, the pest is a regulated pest in Peru (Minagri-Senasa, 2015; Naohidemyces vaccinii and Thekopsora minima), and is regulated in Australian States that are free (such as Victoria, Western Australia; Agriculture Victoria, 2016, as well as *N. vaccinii*). Some countries regulate *P. vaccinii* (e.g. Chile, *P. vaccinii* (=*P. myrtilli*); Gobierno de Chile, 2015), which may also cover *T. minima* according to the broad species concept (see Section 1). No further information was sought.

6. Distribution

T. minima was originally identified from the Eastern part of North America and Japan (Sato et al., 1993). *T. minima* has been introduced to other areas in the last decades. In North America, *T. minima* seems mostly present in the Eastern part (now also confirmed in Oregon and California) ; in the Western part, only the closely-related *N. vaccinii* (also endemic to Europe) was found when the two species where separated by Sato et al. (1993) (not on *V. corymbosum*). Table 1 lists known records of *T. minima*.

There is an uncertainty about the distribution of *T. minima* in the EPPO region, given that confirmed reports (Germany, Belgium, The Netherlands, Portugal) are recent, and some uncertainties for other countries.

Because of the difficulties mentioned in section 1, there is a strong uncertainty about whether records of *N./P. vaccinii* on *V. corymbosum* relate in fact to *T. minima*. Uncertain records are given in Table 2, with reasons for the uncertainty (as well as the source for the first finding, where relevant, and subsequent literature and extension advice, which still refer to *P/N. vaccinii*).

Finally, it is interesting to specifically mention the situation in South American countries, where cropping of *Vaccinium* has greatly increased over the last decades and from which there is an increasing trade of fruit. *T. minima* is present in Colombia (Table 1) and there are uncertain records for Argentina and Uruguay (Table 2). *T. minima* is not present in Brazil (DefesaVegetal, 2016) and is a quarantine pest for Peru (Minagri-Senesa, 2015). In Chile, *P. myrtillii* was reported as intercepted in a seemingly old report (Guerrero, no date), and *P. vaccinii* is a regulated pest.

Table 1. Known distribution of *T. minima*

Continent	**Distribution (first finding)**	**Comments on pest status**	**Reference**
Europe	Germany (2015)	Transient, under eradication. See Note 1	Schrader and Maier, 2015, EPPO RS 2016/057
	Belgium (2016)	Transient, under eradication. See Note 2.	FASSC 2016, EPPO RS 2016/171
	Netherlands (2017)	See Note 3.	NPPO
	Portugal (2017)	See Note 4	NPPO
Asia	Japan: Honshu, Kyushu, Shikoku	From localities in the article. Hokkaido is named, but the locality seems to be on Honshu.	Sato et al., 1993
	China: Sichuan (2015)	Presumably introduced	Zheng et al., 2017 (under publication)
North America	Canada • Nova Scotia, Ontario, Quebec • New Brunswick • Prince Edward Island	Eastern part. See Note 5.	 • Sato et al., 1993 • Percival and Dawson, 2009 • Dalhousie University, 2012
	USA: • Delaware, New York, Connecticut, Massachussets, Michigan, Maine, Wisconsin, Vermont • Georgia • Oregon (2015) • New Hampshire Virginia, West Virginia • California	Eastern part, as well as Oregon and California. See Note 5. • As *Peridermium peckii* on *Tsuga canadensis*	• Sato et al., 2003 • Jogi and Williams-Woodward, 2013; Scherm et al., 2008 • Wiseman et al. 2016 • Farr and Rossman, 2017, citing Arthur & Kern. 1906. North American species of *Peridermium* • Thien Ho, pers. comm.
	Mexico: Jallisco, Michoacan (2007)		Rebollar-Alviter et al. 2011
South America	Colombia (2012)		Salazar Yepes and Buritica Cespedes, 2012
Africa	South Africa (2006)		Mostert et al., 2010
Oceania	Australia (2001) • New South Wales, Queensland • Tasmania (2014, 2016) • Victoria	See Note 6. • Established • Restricted distribution. • Eradicated	 • McTaggart et al., 2013 • Biosecurity Tasmania, 2014a&b, 2016 • Agriculture Victoria, 2016a, b, c.

Note 1. Germany (NPPO of Germany, 2016-03; reported in EPPO RS 2016/057). *T. minima* was first found in June 2015 on young potted plants of *V. corymbosum* in the greenhouse of a nursery located in Niedersachsen. It has been found in a few nurseries and a garden centre in Niedersachsen, and in a garden centre in Hamburg. Tracing-back and forward investigations were going on as of 2016-03 and it was suspected that *T. minima* might have been introduced with young plants imported from the USA. Official control measures have been taken to prevent the spread of the disease. Some plants have been destroyed and quarantine has been imposed. Further inspections were planned. Niedersachsen (2016) mentions that the presence of the pathogen in the wild in Germany has been sporadically observed, but significant symptoms are observed on young plants in glasshouses.

Note 2. Belgium (NPPO of Belgium, 2016-09; reported in EPPO RS 2016/171, additional information in 2017-03). *T. minima* was first identified in April 2016 in one nursery in the province of East-Flanders. All infected *Vaccinium* plants in the nursery were destroyed. These plants were grown outdoors. Tracing-back and forward studies were ongoing (at 2016-09). Two deliveries to other EU countries were identified, and the NPPOs concerned were notified. Surveys for symptoms will continue.

Note 3. Netherlands (NPPO of the Netherlands, 2017-02; report to PPM March 2017), *T. minima* was found on wild *V. corymbosum* plants during an official survey, in a natural green area in the municipality of Horst aan de Maas, province of Limburg. In this area, *V. corymbosum* is invasive and under eradication. *T. minima* was identified by morphological methods and sequencing. The source of the infestation is unknown. No eradication measures will be taken, since eradication is considered not possible, because the fungus is airborne and has already been found at several places in the EU. During the survey only a few leaves were left on the shrubs, and these leaves were heavily infected. It is considered likely that the fungus is already widespread in the green areas because of the high density of blueberry bushes in that area and the fact that the leaves left on the bushes were heavily infected. Surveys were also conducted on *Vaccinium* in nurseries in the same area, but the pest was not found.

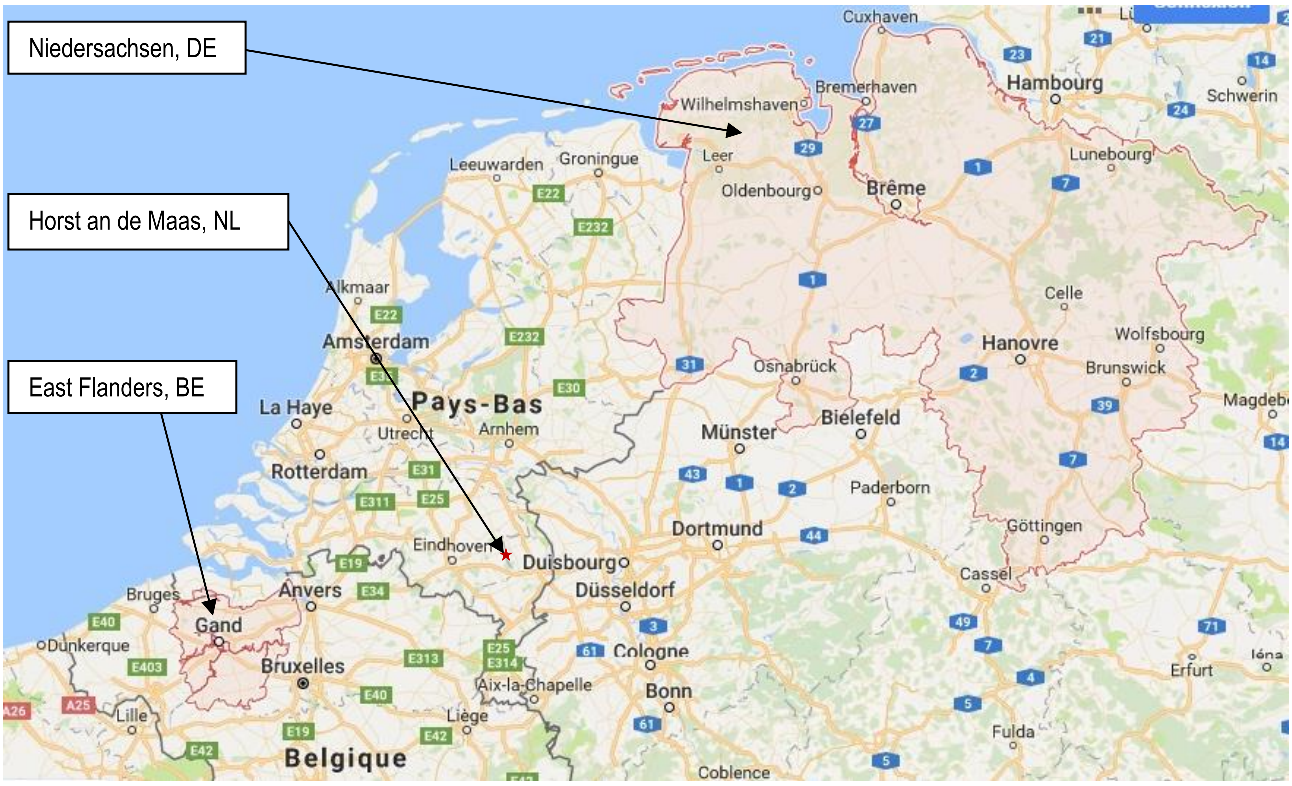

Figure 2. Location of outbreaks in Belgium, The Netherlands and Germany

Note 4. In Portugal (NPPO of Portugal, 2017-02 & 2017-03), investigations were carried out in a nursery following the notification by the Spanish NPPO (2016-12) of the detection of an infected lot of *V. corymbosum* (cv. 'Berkeley') sent to a Spanish operator on 2015-03-12. The nursery (open-air) is located in the municipality of Caminha, North of Portugal [border with Spain]. No plants from the lot concerned were present in the nursery (all had been dispatched to the Spanish operator). All *Vaccinium* plants in the premises were subject to inspection and sampling, i.e. 35066 *V. corymbosum* plants in total (266 mother plants cvs. Legacy and Ivanohé and 34800 seedlings from those mother plants). Symptoms were observed only on the mother plants. The presence of *T. minima* was confirmed on 2017-01-13 by morphological characteristics and molecular methods (sequencing of the 28S gene). All 266 mother plants of *V. corymbosum* were infected; no seedlings from these mother plants were found to be infected. Eradication measures were taken. All the *Vaccinium* plants present in the nursery (mother plants and seedlings) were destroyed by fire on 2017-01-24. Disinfection of equipment and tools was carried out. Other potential hosts (*Azalea* and *Pieris*) belonging to the same operator, located in a distant plot, showed no symptoms but samples were taken on 2017-01-25; results were negative. Trace-back studies are carried out to identify the source of the infection. The lot of *V. corymbosum* found infected in Spain was dispatched from Portugal on 12-03-2015 and had been received from France 2 months earlier. The mother plants of *V. corymbosum* were received from a French nursery in 2011 and 2012. The mother plants of *V. corymbosum* and the lot of *V. corymbosum* sent to Spain were supplied by the same operator.

Note 5. In USA and Canada, *T. minima* is considered to be present mostly in the East (and now Oregon [Wiseman et al., 2016], California [Thien Ho, pers. comm.] and one uncertain records in Table 2). Information from places where both species occur is not always clear. The University of Georgia (2015) notes that newer publications continue to use the name *P. vaccinii* even if it is known that there are two species. This is because positive species identification has not conducted in most states. Sources from Canada often refer to *N. vaccinii* and *T. minima* as synonyms (e.g. Anon., 2010; Hildebrand et al., 2010, Hildebrand, 2016). Agriculture and Agri-Food Canada (2011) mentions *N. vaccinii* in the text on leaf rust on lowbush blueberries, but *T. minima* in relation to control methods. Such confusion also exists in extension publications from the Eastern part of the USA that deal with leaf rust and mention either *T. minima* or *N. vaccinii*.

Note 6. Australia is the only location (in addition to Europe) where eradication and containment attempts are reported (succesful in Victoria ; successful in a first outbreak in Tasmania, but a new outbreak found in 2016). In Victoria, *T. minima* was detected in the Melbourne metropolitan area in September 2014. An eradication programme was implemented and the pest is now considered absent (Agriculture Victoria, 2016a). In Tasmania, *T. minima* was first detected in September 2014 during inspection of plants imported from Victoria (Biosecurity Tasmania, 2014a). The plants were destroyed, and the fungus considered eradicated. In August 2016, a new outbreak was found (only on one property, but representing the major part of blueberry crops in Tasmania). A containment and management strategy was adopted, and it is 'present but restricted in distribution and/or under official control' (Biosecurity Tasmania, 2016).

Table 2. Uncertain records

Continent	Distribution (first finding)	Comments	Reference
Europe	Spain (2002): Andalucia. Cantabria in nurseries?	*P. vaccinii* (Barrau et al. 2002), on *V. corymbosum*, morphological id.. Was identified to the broad species level. Sequencing will be conducted; the only confirmed finding of *T. minima* in Spain was on *V. corymbosum* plants imported from Portugal (Spanish NPPO). There is currently no more information (March 2017).	Barrau et al., 2002 ; Bascon Fernandez, 2011 ; Fundacion Cajamar, 2011; Gobierno de Cantabria, 2010; Spanish NPPO, 03-2017
	France	Infected plants in Portugal were imported from a French nursery (see Table 1-Portugal). Trace-back studies are being attempted in France, but retrieval of information may be complicated as the nursery closed in 08-2016 (PPM, March 2017)	NPPO of Portugal, NPPO of France

Continent	Distribution (first finding)	Comments	Reference
South America	Argentina (1997)	*P. vaccinii*. Morphological id. on *V. corymbosum*	Dal Bello & Perelló, 1998 ; Sinavimo, 2017, with other references, Gordó, 2011
	Uruguay	*P. vaccinii* (as post-harvest disease) on *V. corymbosum*.	Pérez et al. (2014). Also photos at http://www.pv.fagro.edu.uy/fitopato/Galeria/Enf_Ara.htm
North America	USA : • Hawai (2007)	 • *P. vaccinii*. Morphological id. On *V. corymbosum*.	 • Keith et al., 2008 ; Hamasaki et al., 2015. Agriculture Victoria (2016a, Australia) reporting on *T. minima* uses photos from the University of Hawaii, at least one from Keith et al. (2008).
	• Alabama	• *P. vaccinii* specimen in US national collection from *V. corymbosum*. Recent alert, on *V. ashei*, but referring to sources using the broad species concept.	• Coneva, 2014
	• Mississipi	• 'rust'/southern highbush cultivars	• Brannen, 2016
	• New Jersey	• *T. minima* specimen from *Azalea pontica* var. *daviesii*. The authors cite a US national fungus collection, but this record was not found in that collection	• Farr and Rossman, 2017
	• Washington	• *P. vaccinii* on *V. corymbosum* (1973 ref.)	• Farr and Rossman, 2017
Oceania	New Zealand	See Note 7. Collection specimens (2014-2015) with name *T. minima.* Some prior observations attributed to *N. vaccinii*. 'Blueberry rust' occurs.	New Zealand Fungi, 2017; Landcare research, 2017; Barlow, 2014

Note 7. Three collection specimens of *T. minima* (collected in 2014 and 2015), two of which mention collection in the field with details of locations (Auckland – North Isl. and Mid-Canterbury – South Isl.); for one specimen, *V. corymbosum* is specifically indicated (New Zealand Fungi, 2017; Landcare research, 2017). There are also collection specimens of *N. vaccinii* from the North Island dated from 2004-2005 (New Zealand Fungi, 2017), some from *V. corymbosum*. NZ Herald (2004) reports that blueberry rust was first found on *V. ashei* and *V. corymbosum* in January 2004 and had since spread. It could not be linked to imports and was thought to have been blown from Australia. [However only *T. minima* is known to have occurred in Australia]. Barlow (2014) mentions blueberry rust as a major issue on the North Island (species not mentioned). Blueberry rust is also a main disease on blueberry in New Zealand and a concern for research (Buck et al., 2012). In Victoria (Australia), requirements are made for New Zealand fruit only if they have transited through another Australian State, i.e. seemingly implying that the rust is not considered present in production in New Zealand (Agriculture Victoria, 2016a).

7. Host plants and their distribution in the PRA area

The (telial) hosts of *T. minima* belong to the family Ericaceae, and *Tsuga* spp. are alternate (aecial) hosts. Known host species are listed in Table 1. Most data available relate to *Vaccinium*, and there is little data for other ericaceous hosts in Table 1. The main *Vaccinium* species identified as hosts so far (*V. corymbosum*, *V. angustifolium*) are North American species. They are grown in the wild or cultivated in North America, but in the EPPO region (and in other countries where the disease was found), they are present only in cultivation or as invasive species in the case of *V. corymbosum*. In areas where the rust was introduced or found recently, observations were made on *V. corymbosum* or hybrids (Buritica Cespedes et al., 2014; McTaggart et al., 2013 ; Mostert et al., 2010). In Australia, *T. minima* has only been found on *Vaccinium* to date (Agriculture Victoria, 2016b).

There may be other Ericaceae genera and species that are hosts, because *T. minima* is already known to attack a number of species in several genera, and that the related *N. vaccinii* has a larger host range among *Tsuga* and Ericaceae. Uncertainties on hosts are listed below Table 1.

Table 3. Known hosts of *T. minima*

Species	Common name	Presence in EPPO	Reference
Vaccinium			
V. angustifolium	late sweet blueberry/lowbush blueberry	Cultivated for fruit (Starast et al., 2014), gardens	Sato et al., 1993
V. ashei	rabbiteyeblueberry	Cultivated for fruit (Ripa and Audrina, 2009), gardens?	Scherm et al., 2008 (assumed to be *T. minima, H. Scherm,* pers. comm.)
V. corymbosum	northern highbush blueberry	Commercial cultivation for fruit, gardens	Sato et al., 1993
V. corymbosum hybrids, such as with *V. darrowii* or multiple species	southern highbush blueberry, other hybrids	Commercial cultivation for fruit, gardens	e.g. Mostert et al., 2010, Agriculture Victoria, 2016c
V. erythrocarpum	mountain cranberry (wild in N. Am.)	Possibly not	Sato et al., 1993
Other Ericaceae			
Gaylussacia baccata	Black huckleberry		Sato et al., 1993
Gaylussacia frondosa	Dwarf huckleberry		Mostert et al., 2010 citing Sato et al., 1993
Lyonia nezikii	nejiki		Sato et al., 1993
Lyonia ovalifolia var. *elliptica*			Farr and Rosman, 2017
Menziesia pilosa			Sato et al., 1993
*Rhododendron canadense (*syn. *Rhodora canadensis)*	Candian rhododendron		Sato et al., 1993
Rhododendron canescens	Hoary azalea		Sato et al., 1993
Rhododendron lutescens	Pinxterbloom		Sato et al., 1993
Rhododendron ponticum		Widespread	Sato et al., 1993
Rhododendron prunifolium	Plum-leaved azalea		Sato et al., 1993
Rhododendron viscosum	Clammy azalea		Sato et al., 1993
Rhododendron x grandavense		Note: possibly a synonym of R. ponticum (according to The Plant List)	Sato et al., 1993
Alternate hosts			
Tsuga canadensis	Canada/eastern hemlock,	plantations, ornamental (see section 9.2)	Sato et al., 1993
Tsuga diversifolia	kometsuga	ornamental only?	Sato et al., 1993
Tsuga sieboldii	tsuga	ornamental only?	Sato et al., 1993

Uncertainties on hosts

- Other *Vaccinium* species, in areas where the pest occurs and potentially in the EPPO region. In North America, other *Vaccinium* species are cultivated (such as *V. vitis-idaea*) or present in the wild, such as *V. myrtilloides* (Canadian blueberry), *V. uliginosum; s*ome species are used as rootstocks (*V. arboretum*), some only as ornamentals (*V. ovatum*, *V. parvifolium*). In the EPPO region, a number of species in the wild or cultivated are detailed in section 9.2. Among those, species that are particularly important because they are widespread in the wild are *V. myrtillus*, *V. uliginosum*, *V. oxycoccos* and *V. vitis-idaea* (the latter is also cultivated), and in cultivation *V. macrocarpon*, *V. angustifolium*. Hybrids (especially of *V. corymbosum*) are used. There is currently no indication that cranberries are hosts. Caruso and Ramsdell (1995) also mention that wild evergreen *Vaccinium* may play a role in the epidemiology of the disease (without mentioning species).
- *Rhododendron nudiflorum*: collection specimens in Farr and Rossman (2017).

- *Azalea* species are mentioned in several publications. The known hosts are synonyms of *Rhododendron* species.
- Other Ericaceae. Several publications mention the ericaceous genera *Hugeria*, *Leucothoe*, *Pernettya*, *Pieris* as hosts, and *T. minima* is regulated on these genera in Australia (e.g. Agriculture Victoria, 2016a ; Biosecurity Tasmania, 2014b). However, no specific host records were found. (e.g. Agriculture Victoria, 2016a). There are other Ericaceae genera that are important in the wild or in cultivation in the EPPO region, such as *Calluna*, *Erica*, *Kalmia*.
- *Tsuga* spp. Three species are known hosts but it is considered in this PRA that others may be hosts. Worldwide there are four North American species of *Tsuga* (West – *T. heterophylla* and *T. mertensiana*, East – *T. canadensis* and *T. caroliniana*) and five Asian species. The distribution of the North American eastern and western species do not overlap (Farjon and Filer, 2013). In Oregon, Wiseman et al. (2016) note that two native species, *T. mertensiana* and *T. heterophylla* can serve as alternate hosts of *T. minima* and are necessary for the completion of the life cycle (although the fungus was not specifically found on these hosts) (note: these two species are known hosts of *N. vaccinii* – Sato et al., 1993). These species are also alternate hosts of *N. vaccinii* (Sato et al., 1993). The host status of the fourth North American species is not known (*T. caroliniana*). From Asia, the known hosts *T. sieboldii* and *T. diversifolia* are Japanese species (Farjon and Filer, 2013). All *Tsuga* species, including the Asian *T. chinensis* and *T. dumosa*, may be used as ornamentals in the EPPO region (see section 9.2).

8. Pathways for entry

Infested plants (for planting), possibly fruits and dispersal via persons (e.g. clothes) are considered as a pathway by Biosecurity Tasmania (2014a). Existing regulations in Australia address plants for planting of various genera, Vaccinium fruit, agricultural equipment and packaging (Western Australia (https://www.agric.wa.gov.au/qtine/results.asp; Agriculture Victoria, 2016a). Daniel et al. (2013) mentions infection of fruits. Spores may also be present as contaminants on the host plants and on fruits, as well as on equipment and packaging.

The following pathways for entry of *T. minima* are discussed in this PRA. Pathways in bold are studied in section 8.1; other pathways were considered very unlikely and are in section 8.2.

- **host plants for planting (except seeds, tissue cultures, pollen)**
- ***Vaccinium* fruit**
- **machinery and equipment**
- **natural spread**
- seeds, tissue culture, pollen
- wood and wood products of *Tsuga* and other trees
- *Tsuga* Christmas trees
- soil traded as such
- passengers

8.1 Consideration of pathways

Host plants for planting are studied in detail in Table 2. *Vaccinium* fruit, machinery and equipment and natural spread are considered after the table. Packaging was considered in association with individual pathways.

For all pathways and at the scale of the PRA area, it is considered that the current phytosanitary requirements in place are not sufficient to prevent the introduction of *T. minima*. There are prohibitions on the movement of *Tsuga* (e.g. into the EU), but no known prohibitions on *Vaccinium* plants for planting that may restrict the pathways.

Examples of prohibition or inspection are given in individual pathways for some EPPO countries (it was not possible in this express PRA to fully analyse the regulations of all EPPO countries). Similarly, the current phytosanitary requirements of EPPO countries in place on the different pathways are not detailed in this PRA (although some were taken into account when looking at management options). EPPO countries would have to check whether their current requirements are appropriate to help prevent the introduction of the pest.

Table 4. Host plants for planting

Pathway	Host plants for planting (except seeds, tissue culture, pollen)
Coverage	• Commodities such as bare-rooted plants, pot plants, cuttings. • *Tsuga* and known ericaceous hosts in Table 1. Because of uncertainties on hosts, all *Vaccinium* species were considered here, but not Ericaceae genera not known to be hosts.
Pathway prohibited in the PRA area?	*Vaccinium* and other known ericaceous hosts: No for the EU. *Tsuga*. Yes for the EU. Probably also for some other countries due to generally strict requirements for conifers (not searched further).
Pathway subject to a plant health inspection at import?	Presumed in most EPPO countries. Yes in the EU, as a general requirements for plants for planting. In addition, *Vaccinium* plants for planting are regulated in relation to *Diaporthe vaccinii* (except seeds; EU Directive 2000/29) and *Xylella fastidiosa* (except tissue cultures, Emergency measures – Commission Decision 2015/789) (both of these pests are present in the USA and Canada, but not in other countries where *T. minima* occurs). *Rhododendron* are regulated in relation to *Phytophthora ramorum* (Emergency measures – Commission Decision 2002/757/EC).
Pest already intercepted?	Not known, but incursions in Belgium and Germany. Found on *Vaccinium corymbosum* plants imported from Portugal into Spain. *P. myrtillii* (*N. vaccinii*) was intercepted in Chile (Guerrero, no date).
Most likely stages that may be associated	The experts considered that the inoculum on imported plants is more likely to be uredinia/urediniospores than other spore types. Host plants with leaves/needles may carry spores. On *Vaccinium*, the fungus may be present on plant parts other than leaves in winter when leaves are not present (dormant plants). In other seasons, other plant parts may only carry spores if those land on them (but would not be infected). Uredinia and urediniospores could be carried by ericaceous hosts and lead to further infection (telia may also develop but would not lead to further infection in the absence of *Tsuga*). Spores may be present in soil or mulch (Biosecurity Tasmania, 2014b) or in dead leaves lying on the potting mix surface in potted plants..
Important factors for association with the pathway	Different types of *Vaccinium* plants for planting are imported for berry production: plug plants (derived from tissue culture) grown in protected greenhouses, cuttings produced indoors or outdoors, and large potted plants grown outdoors at the production site; *Vaccinium* plants are also traded for ornamental purposes (including bonsai plants) and they may have a lower quality than plants for berry production (details on the different types of plants are given in the EFSA PRA on *Diaporthe vaccinii* - EFSA PLH Panel, 2017). Although the risk of infection would be higher for large plants, small plants may also be exposed to *T. minima* prior to export. In nurseries, 1-2 year old *Vaccinium* plants that are produced in the USA may be grown outdoors (A. Schilder, pers. comm.), which increases the risk of infection if blueberry leaf rust is present in surrounding areas. In nurseries, there may be plants with green leaves at many stages, from just coming out of tissue culture to later growth stages present year round (A. Schilder, pers. comm.). *T. minima* may not be detected. The infection may be latent for 10-15 days. In addition, low levels of infection are difficult to detect due to the small size of the pustules. In addition, only part of the imported plants would be inspected. Spores may also be associated with packaging material. In countries where *T. minima* was introduced, it seems to be reported so far on *Vaccinium* only. In the USA, a concern for *Rhododendron* is expressed (Pfister et al., 2004), but *T. minima* is considered a concern mostly for *Vaccinium* (A. Schilder, pers. comm.). There is a clear association of *T. minima* with *Vaccinium* in all countries where the fungus occurs, but not for other ericaceous hosts.
Survival during transport and storage	Uredinia/urediniospores on plants and telia on fallen leaves are expected to survive (although there is no detail on how long). Dormant plants are usually transported under refrigerated conditions (e.g. 1°C). A 6-week survival period of urediniospores on soil, mulch and pots is mentioned

Pathway	Host plants for planting (except seeds, tissue culture, pollen)
	(Biosecurity Tasmania, 2014b). It is not known how long basidiospores would survive on *Tsuga*; after a few weeks, aeciospores would be released. Basidiospores especially, but also aeciospores are expected to be rather short-lived (W. Maier, pers. comm.).
Trade	Comprehensive data on the trade of *Vaccinium* host plants from countries where *T. minima* is lacking. For the period 2000-2011, ISEFOR data (regarding imports from non-EU countries into the EU) show that there were massive imports of *Vaccinium* plants at the beginning of the 2000s; some other hosts were also imported (see Annex 2). 2/3 of *Vaccinium* consignments were imported in the period Feb.-April (21), with others in Jan. May, June, Sept., Nov, Dec. The trade of blueberry plants is also analysed in the draft EFSA PRA on *Diaporthe vaccinia* (EFSA PLH Panel, 2017). Some elements are extracted here: - Cropping is still increasing in the EU; parts of the plants for planting would be imported. - The destination countries of recent exports of blueberry plants for planting from the USA to the EU were primarily Spain, Germany, UK, the Netherlands, Poland and Italy. - The majority of new highbush blueberry varieties have been created by US plants producers, and there is a trade in such plants, although some varieties may also be multiplied within the EU from imported mother plants. Export data from the USA (from State Certification Agencies and Vaccinium nursery) indicated exports of ca. 6 million blueberry plants for planting to the EU in 2016, most as small plants (plugs) in trays derived from tissue culture. It is worth noting that this exceeded the estimated number of plants needed per year in the EU and that most plants needed are thought to be produced within the EU, but other factors may explain this discrepancy (see EFSA PLH Panel, 2017). Data is lacking on the trade of other hosts (including *Rhododendron*). Regarding the alternate hosts *Tsuga*, import of plants for planting is prohibited at least in the EU. No data was available from other countries. However, the trade is presumed to be much smaller than that of *Vaccinium* plants for planting.
Transfer to a host	Under the hypothesis that the pest does not need alternate hosts, it would survive on the plant and could be easily transported to other hosts (wind, contact). If infected *Tsuga* were imported, ericaceous hosts in the vicinity may also become infected.
Likelihood of entry and uncertainty	• *Vaccinium* plants for planting: high (with low uncertainty) • *Tsuga* plants for planting: low (with low uncertainty) • Plants for planting of other hosts: low (with moderate uncertainty – association of *T. minima* with these hosts, trade)

Natural spread (from current presence or outbreak to an EPPO country). All information on natural spread is given in Section 11.
Natural spread from non-EPPO countries where *T. minima* occurs to the EPPO region is very unlikely as the pest is very far from the borders of any EPPO country. There is no obvious major climatic phenomenon that may favour natural spread over very long distances.
Natural spread from the Netherlands is likely: *T. minima* was found in the wild and no measures are applied against the fungus (although invasive *V. corymbosum* are currently under eradication). From the Netherlands, the finding on wild *V. corymbosum* plants in the municipality of Horst aan de Maas is close to the borders with Nordrhein-Westfalen (Germany) and Limburg province (Belgium) (respectively about 20 and 30 km).
In Niedersachsen (Germany) and East Flanders (Belgium), the pest was found in nurseries and garden centers and control measures were taken; it is not clear if infected plants were in protected conditions. Niedersachsen (2016) mentions sporadic findings outdoors (see also map in section 6). However, *T. minima* is under eradication.
The finding in Portugal is close to the Spanish border. Measures were taken and *T. minima* is under eradication.
Natural spread can occur from places where the pest is present outdoors, but there need to be hosts present. *Rhododendron* or *Tsuga* hosts may help natural spread. Although *Vaccinium* crops are widespread in the

EPPO region, the area of cultivation is still small and patchy compared to other crops. Therefore spores that are spread by the wind are less likely to land on a suitable host, which reduces the likelihood of natural spread beyond the individual fields. It is not known to date if any wild European *Vaccinium* or Ericaceae are hosts, which would favour natural spread.

At the scale of the whole EPPO region, the fungus would not be likely to spread naturally to most countries in the short term (but might do so by human-assisted spread).

On a more local scale, *T. minima* will likely spread within individual fields if single infected blueberry bushes are planted. However, it is not known if *V. corymbosum* or other hosts are present in the vicinity of the areas where *T. minima* had been detected in the countries mentioned above. Because of the limited spread distance and presumed patchy host presence, the fungus is not expected to spread fast naturally.

Likelihood of entry:
- from the Netherlands to neighbouring countries: ***moderate*** *with a moderate uncertainty (whether the density of host plants would allow spread, quantity of inoculum/size of the infested area in the Netherlands and effect of V. corymbosum eradication on the inoculum).*
- from non-EPPO countries: ***very low*** *with a low uncertainty*

8.2 Very unlikely pathways

The following pathways are considered very unlikely:

- ***Vaccinium* fruit.** *T. minima* mostly occurs on leaves, but *Vaccinium* fruit may also be infected, and carry uredinia and urediniospores. Such infection has been reported from Australia; in other places, authors consider that spores may only contaminate *Vaccinium* fruit incidentally. Mechanical harvesting may lead to higher contamination of the fruit by spores than hand-picking, especially late in the season when the rust inoculum levels are higher (A. Schilder, pers. comm.). However, most machine-harvested fruit is going for the process market and is frozen for use in preserves, pies, yogurt, and juice. In addition, fruit goes through a blower, color and soft fruit sorter and water bath (with bleach) before being frozen. Thus, these steps would lower the chance of rust spores being imported with machine-harvested fruit (A. Schilder, pers. comm.). In the EPPO region, *Vaccinium* fruit may be subject to phytosanitary requirements (such as in the EU, with a general inspection requirement), but these would not be sufficient to prevent introduction. Processes prior to export (e.g. washing) as described above may also remove spores. Infected leaves may be also harvested together with fruit, and fruit consignments contain such leaves if they are not removed at packing. Spores may also be associated with packaging material.

  If uredinia/urediniospores are present on the fruit, or on leaves contaminating fruit consignments, they may survive: a 6-week survival period is mentioned for spores of *T. minima* in the literature (without details). There is a trade of blueberries from countries where *T. minima* occurs (from FAO Stat, 2013 data): ca. 300 t from non-EPPO countries where the pest is present or suspected to be present* (USA, Mexico, China, South Africa, Argentina*, Uruguay*), ca. 4300 t from Germany and Belgium and 9400 t from Spain*. Healthy-looking berries are used for consumption or processing. If they are infested, spores may be washed in waste water, but there is no indication that the spores would survive. In addition, for spores to reach the foliage of hosts, such water would need to be used for overhead irrigation, which is unlikely. If damaged infested berries are discarded in the open, or infected leaves contaminating consignments, the fungus would need to be transported to *Vaccinium* hosts. As spores are known to be transported by wind or locally by contact, it is unlikely to happen. The only case when infested waste may be discarded close to *Vaccinium* plants is when if fruit are imported in bulk and repackaged by *Vaccinium* producers to complement their fruit supply in the close vicinity of their production site.. However, waste berries are usually either rotten or dry and shrivelled, and spores are unlikely to remain viable when berries rot or dry (A. Schilder, pers. comm.).

  Import of bulk blueberry fruit appears to be a recent development of *Vaccinium* trade, and may increase the risk of entry if imports occur during the growing period. Bulk fruit may also contain leaves and other plant debris. *Vaccinium* fruit imported in smaller containers may also be resorted and repacked at destination (EFSA PLH Panel, 2017). Given the other elements above, especially relating to the association of spores with fruit, the likelihood of entry was rated as very low.

  Likelihood of entry: ***very low*** *with a moderate uncertainty (whether there are bulk imports of Vaccinium fruit to Vaccinium production facilities, transfer from fruit).*

- **Machinery and equipment.** There is possibly a trade of used machinery and equipment that have been used in infected *Vaccinium* plantations (even if it is unlikely that such material is traded in the middle of a growing season, when the rust would also be present). Spores may be carried if the material has been used in infested areas. However, the spores may fall, and are unlikely to survive for more than a few weeks on this material. This pathway is therefore less likely for far-away origins, but could be important locally. However, the equipment would have to be used in host crops at a suitable time of the season so that infection may occur, and the conditions should be favourable for infection. It is not known if there is transboundary movement of equipment between the areas where the pest was found (and is not under eradication) in the Netherlands and neighbouring countries.

*Likelihood of entry: **very low** with a low uncertainty.*

- **Seeds, tissue culture, pollen.** *T. minima* is not associated with these plant parts.

  *Likelihood of entry: **very low** with a low uncertainty.*

- **Wood and wood products of *Tsuga* or other trees.** Although spores released from *Tsuga* needles may incidentally land on wood of *Tsuga* or other forest trees, spores might be dislodged during felling and processing (extraction from forests, cutting, debarking, transport). In addition, aeciospores are unlikely to survive for long periods, and this is therefore is a very unlikely pathway.

  *Likelihood of entry: **very low** with a low uncertainty.*

- **Cut branches of hosts (*Tsuga* Christmas trees, cut branches of *Rhododendron* or other Ericaceae hosts).** *Tsuga* used as Christmas trees imported from countries where *T. minima* occurs (and spends part of its cycle on *Tsuga*; i.e. especially USA and Canada) may be exposed to the rust. However, *Tsuga* would not carry aeciospores in late autumn/winter when this material would be traded. In addition, *T. canadensis* is apparently a poor Christmas trees as it sheds needles upon drying (Paul Smith's College, 2017) and it would probably not be imported to the EPPO region. There are no details on whether *Rhododendron* (or other Ericaceae hosts) are traded as cut branches.

  Likelihood of entry:
  *- Tsuga Christmas trees: **very low** with a low uncertainty*
  *- Cut branches of Rhododendron and other Ericaceae hosts: **low** with a moderate uncertainty (trade of Ericacea hosts cut branches, association of the rust with these hosts)*

- **Soil traded as such** (soil associated with plants is covered in the pathway for plants for planting). This commodity is prohibited in most EPPO countries. *Vaccinium* leaves on the soil may carry spores. However, soil traded as such is unlikely to come from forest areas (not fertile soil), or production places of *Vaccinium* or rhododendron.

  *Likelihood of entry: **very low** with a low uncertainty.*

- **Travellers.** Persons exposed to rust, e.g. mostly producers or workers, may carry spores on their clothes or hands, and could transport them to facilities in other countries. However, there is probably no transboundary movement of workers between facilities in Belgium, Germany and Netherlands and other EPPO countries. This pathway is considered very unlikely for international spread, but is relevant for local spread.

  *Likelihood of entry: **very low** with a low uncertainty.*

Overall rating of the likelihood of entry

Rating of the likelihood of entry		*Very low* ☐	*Low* ☐	*Moderate* ☐	*High* ✓	*Very high* ☐
Rating of uncertainty				*Low* ✓	*Moderate* ☐	*High* ☐

9. Likelihood of establishment outdoors in the PRA area

If *T. minima* is introduced on infected plants for planting, it will become established on these plants, and may spread to neighbouring hosts under suitable conditions.

9.1 Climatic suitability

T. minima is reported to be more prevalent under warm and wet conditions (Agriculture, 2016b). However, it occurs and causes epidemics in a wide range of climates, from subtropical Australia to areas in North America with temperatures well below 0°C for long periods in winter. Throughout its range, epidemics are favoured by humidity and moderate to high temperatures. InMichigan, the rust spread especially severely in the 2009-2011 growing seasons, with above-average precipitation in mid- to late summer (Schilder and Miles, 2011; Schilder et al., 2016).

The survival of the pest and completion of the uredinial cycle during the growing season would require suitable temperatures and humidity only at critical stages of the life cycle (e.g. spore germination). The optimum range of temperatures for urediniospores germination is 21-23°C, but can occur between 15-25°C. Uredinial production can occur over the same temperature range. Other epidemiologically important parameters, such as the number of uredinia produced, are similar in the temperature range between 15-25° C (Pfister et al., 2004). In addition, sufficient humidity is required. A leaf wetness period of 48 h was sufficient for infection under controlled environmental conditions in Heidenreich et al. (2005), while shorter incubation periods were used in Rebollar-Alviter et al. (2011) and Pfister et al. (2004) (12 and 24 h).

During other periods, the fungus is expected to be able to maintain populations even under less favourable conditions. In Michigan, infection may not be observed in unfavourable (i.e. very dry) growing seasons, and reappear several years later when conditions are more favourable. However, the fungus is presumed to survive at low levels in 'hot spots' during dry seasons (A. Schilder, pers. comm.).
In colder climates, the capacity for overwintering would be an important factor for successful establishment. Wiseman et al. (2016) note that in Oregon the alternate host is needed, implying that the local conditions would not allow the survival of the fungus during winter. However, in cold climates, other mechanisms may allow the fungus to survive, for example overwintering systemically on plants outdoors (in which case it may sustain very low temperatures), or overwintering in glasshouses on plants that do not shed leaves (see section 2). In mild climates, the pest may overwinter outdoors on evergreen blueberry leaves (Victoria Agriculture, 2016b).

There is an uncertainty regarding whether *T. minima* would be able to maintain a population outdoors, beyond the initial infected plants, under drier conditions (e.g. in irrigated crops).

9.2 Host plants
Vaccinium and other Ericaceae hosts would allow establishment of the pest. Persistance of the disease would be facilitated in the presence of alternate hosts in the genus *Tsuga*, as these would allow completion of the life cycle, and probably facilitate survival even in more northern locations. If *Tsuga* is not present in the vicinity, the climatic conditions should be favourable for the survival of the pest during winter.

Evergreen blueberry varieties may favour establishment as, under suitable climatic conditions, the fungus may survive on leaves. Evergreen varieties normally require the absence of frost, or that plants are protected during frost. *V. corymbosum* is deciduous, but numerous hybrids with southern species and cultivars have been produced and some are evergreen (i.e. they always bear some green leaves; even if old leaves are falling off, new leaves are forming). Among native *Vaccinium* species, which are both present in the wild and in cultivation, *V. myrtillus* is deciduous, while *V. vitis-idaea* is evergreen (Gerdol et al., 2000).

In Europe, several *Vaccinium* species are present in the wild or cultivated. The known/proven hosts *V. corymbosum*, *V. angustifolium*, *V. ashei*, as well as potential hosts *V. macrocarpon*, *V. oxycoccos* and *V. vitis-ideae* are cultivated commercially for fruit production and present in the wild. Bush blueberries (especially V. corymbosum) have become popular garden plants, and are widely available in garden centers. Hybrids are also cultivated commercially, in particular half-high hybrids of *V. corymbosum* and *V. angustifolium*. Plants of *V. myrtillus* (major wild *Vaccinium* species in the EPPO region) are available in nurseries; no evidence was found of commercial cultivation. Some other species are present in the wild: *V. uliginosum* and *V. microcarpon*. Finally, some species are present in limited parts of the EPPO region, such as: *V. cylindraceum*, wild and cultivated in the Azores; and *V. arctostaphylum* (Caucasian whortleberry) in the wild in South-East Europe and Turkey (Celik and Islam, 2014). In Germany *V. corymbosum* is cultivated on approximately 800 hectares. Main cultivation regions are the Luneburg Heath, Brandenburg, parts of Oldenburg as well as regions in the South of Germany and Central Baden (Schrader and Maier, 2015). There are invasive *V. corymbosum* where the pest was found in the Netherlands (currently under eradication); it is not known if the invasive *V. corymbosum* is a common situation in the EPPO region; one finding is known from Germany (W. Maier, pers. comm.).

The production of blueberry in the EU was analysed in the framework of the EFSA PRA on *Diaporthe vaccinii:* blueberry production in the EU is still increasing; the largest blueberry production area was in Poland, but production is expanding rapidly in Spain (EFSA PLH Panel, 2017; see Figure 3). In the EPPO region, based on data in FAOStat, blueberries are cultivated throughout Europe and in non-EU countries such as Morocco, Norway, Russia, Switzerland, Ukraine and Uzbekistan. Blueberries are also cultivated in Belarus. It is noted that there are inconsistencies in data between FAOStat and Eurostat. According to FAOStat, blueberries are grown on over 18 000 ha in 17 EPPO countries (this total in FAOStat does not include at least Spain or Portugal, where there is a production area, as shown on Figure 3).

The natural range of *Vaccinium* in Europe (*V. myrtillus* and *V. vitis-idaea*) was illustrated in the framework of the EFSA PRA on *Diaporthe vaccinii* (EFSA PLH Panel, 2017 ; see Figure 4).

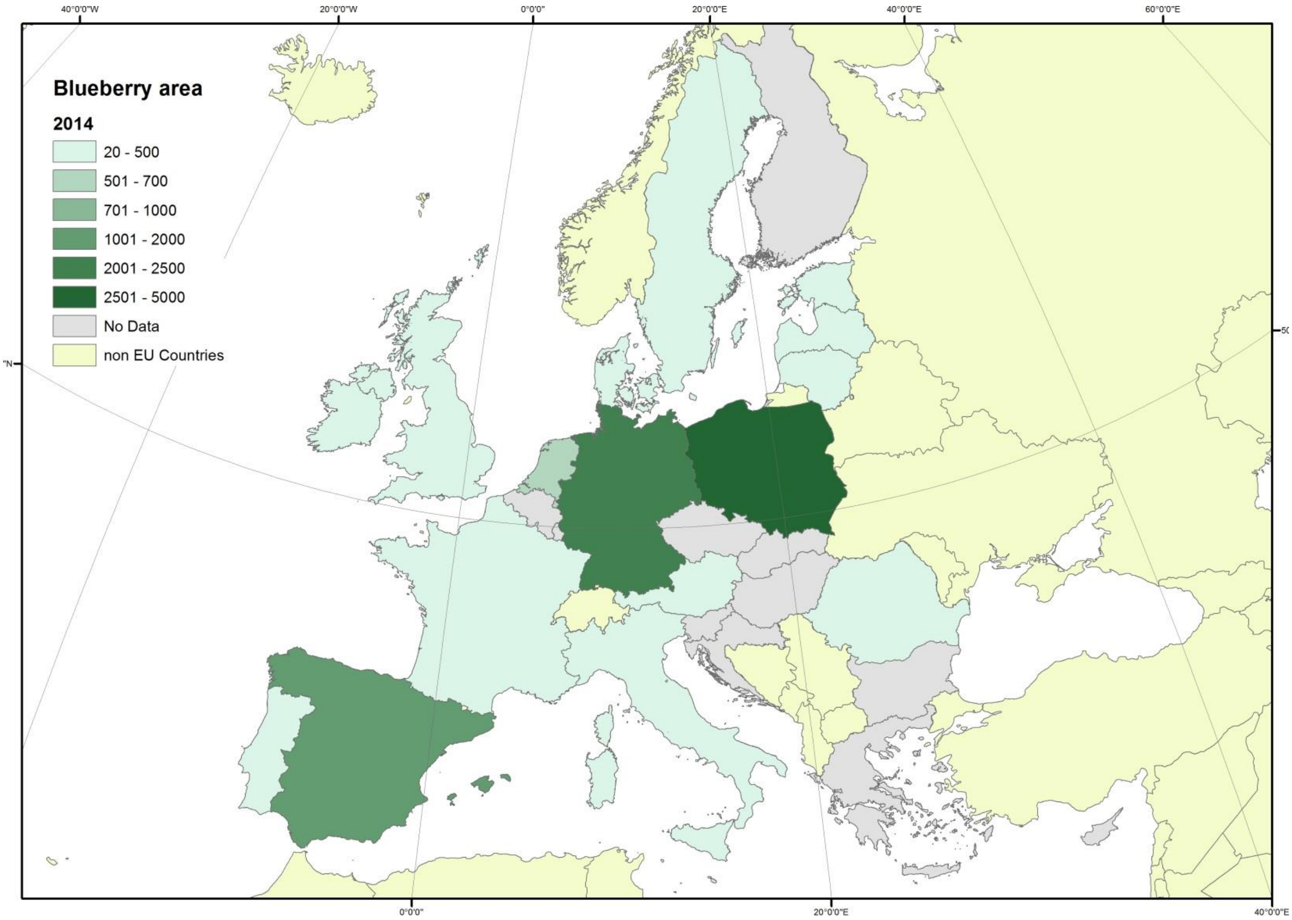

Figure 3. Blueberry cultivated areas in EU countries in 2014 (in ha) (EFSA PLH Panel, 2017 citing others).

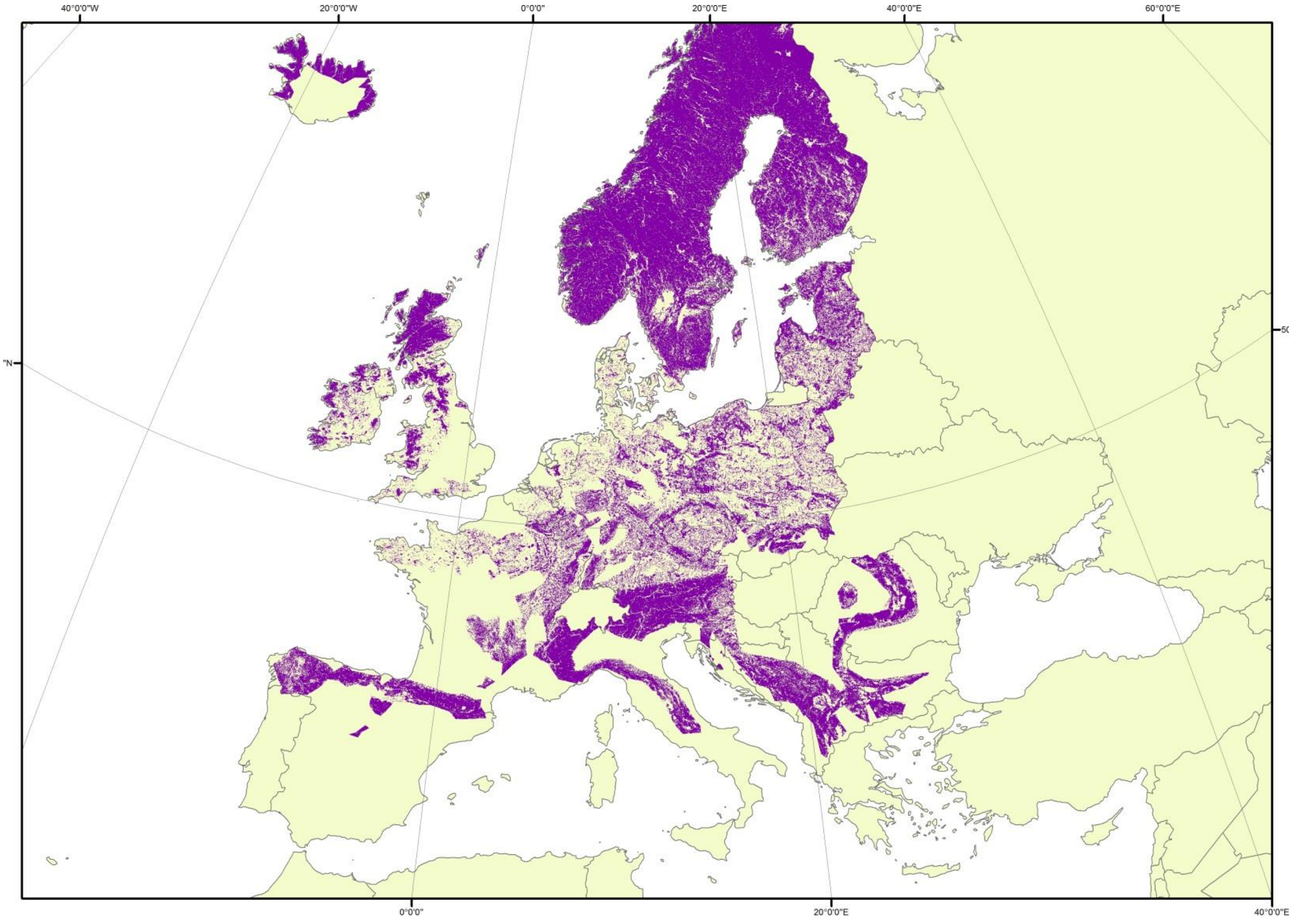

Figure 4. Distribution of *Vaccinium* species (*V. myrtillus* and *V. vitis-idea*) in natural and semi-natural vegetation in Europe (EFSA PLH Panel, 2017). [Note: this map does not show the distribution of wild *Vaccinium* in some countries (e.g. Switzerland)]

Rhododendron species are widely used as ornamentals, probably throughout the EPPO region. They can also be found in the wild.

All *Tsuga* species are probably used to a certain extent, at least as ornamentals. In addition, *T. heterophylla* is used in commercial plantations (EEA, 2006). *T. canadensis* is cultivated in some parts of Germany (Schrader and Maier, 2015, citing others) and probably other countries. In countries of the former-USSR, the following *Tsuga* are reported as cultivated (no information on whether this relates to plantations or ornamentals): *T. canadensis* in S.E. Russia; Belarus; Ukraine, *T. diversifolia*, *T. caroliniana* and *T. dumosa* in Georgia, and *T. sieboldii* in S.E. Russia and Georgia (EPPO, 2000). *T. dumosa* is the only species present in the wild, in Tadjikistan. *Tsuga* is absent in the wild in Scandinavia and Russia-Siberia (Farjon and Filer, 2013).

Rating of the likelihood of establishment outdoors	*Very low* ☐	*Low* ☐	*Moderate* ☐	*High* ☐	*Very high* ✓
Rating of uncertainty			*Low* ✓	*Moderate* ☐	*High* ☐

10. Likelihood of establishment in protected conditions in the PRA area

Thekopsora minima is known to occur in glasshouses in some countries. In Michigan it was observed in cultivated blueberry fields and on greenhouse-grown blueberry plants nearby (Schilder and Miles, 2011). In Oregon, it is problematic for nurseries and greenhouse production (Wiseman et al., 2016). Consequently, it is very likely that it can establish in protected conditions in the PRA area.

Rating of the likelihood of establishment in protected conditions	*Very low* ☐	*Low* ☐	*Moderate* ☐	*High* ☐	*Very high* ✓

Rating of uncertainty	*Low* ✓	*Moderate* ☐	*High* ☐

11. Spread in the PRA area

The fungus may spread naturally and through human-assisted pathways. Wilk et al. (2016-17) mention that spores are very easily and quickly transported by wind, but can also be spread via rain, infected plants and fruit, packaging, equipment, clothing and hands.

Spores are airborne. In the USA, infrequent outbreaks of blueberry rust in the mid-Atlantic USA may be caused by windborne urediniospores from the South (Caruso and Ramsdell, 1995). The spread to Oregon has possibly not occurred through natural spread, as there have been no records in the states situated between the current known distribution area and Oregon. In Australia, spread to Tasmania was linked to infested plants, and although Western Australia regulates plants and other material originating from areas closer than 200 km from known outbreaks, there is no indication that natural spread would occur over such distances. Spread via wind is understood to mostly occur within a few hundred meters (e.g. Wilk et al., 2016-2017 for Australia). Long distance spread with wind is mentioned by some authors for *T. minima*, but no specific data is available to document it. *Vaccinium corymbosum* is commonly grown in relatively small fields surrounded by woodlots and windbreaks, which it less prone to large air masses carrying massive amounts of spores as might occur with rust of soyabean, which may be grown on very large fields. .
Consequently, although urediniospores can be transported by air potentially over long distances,it is unlikely that they will land on distant blueberry fields. Therefore spread is likely to be mostly within a few hundreds meters (e.g. to neighbouring fields).

In areas with cold winters, the maintenance of uredinia/urediniospores in winter on plants in glasshouse nurseries (where plants retain leaves) may favour the spread of the disease to nearby production fields in the following spring.

Regarding the possible role of *Tsuga* in the spread of *T. minima*, in Maine, the disease has been observed on lowbush blueberries as far as 0.4 km from *Tsuga* (Caruso and Ramsdell, 1995). In the EPPO region, *Tsuga* occurrence is very limited and there is no evidence that it could play a role in the European situation so far.

Among human-assisted pathways, trade of infected planting material (*Vaccinium* or other hosts) is likely to play the main role. Trade of blueberry fruit could hypothetically play a role, although fruit infections have only been reported from Australia and transfer to hosts at new locations would require very specific conditions (see 8). Transport with equipment or persons may play a role in spread locally, including between fields or facilities. Trade of infected plant material would be important for the establishment of new foci.

Rating of the magnitude of spread: ***natural spread only***	*Very low* ☐	*Low to Moderate* ✓		*High* ☐	*Very high* ☐
*Rating of the magnitude of spread: **with human spread***	*Very low* ☐	*Low* ☐	*Moderate* ☐	*High* ✓	*Very high* ☐
Rating of uncertainty			*Low* ✓	*Moderate* ☐	*High* ☐

12. Impact in the current area of distribution

Nature of the damage

In case of severe infection, premature leaf drop and plant defoliation is observed. Such defoliation may be extreme during the sprout year of lowbush blueberry production; the production of fruit buds in severely affected fields in the sprout year can be reduced by 30% or more the following year (New Brunswick, 2009, for lowbush blueberry). The presence of the fungus on the fruit leads to crop loss (Biosecurity Tasmania, 2014a). In Australia, premature fruit drop and a late ripening crop have been reported (Daniel et al., 2013). Where *Vaccinium* is grown in evergreen systems (i.e. southern highbush varieties), defoliation is undesirable, as maintaining healthy leaves from the previous season is important to produce fruit for the early season high priced market (Simpson et al., 2016). In cold climates, premature defoliation can also reduce winterhardiness, which can lead to winter injury. Blueberry rust (reported as *P. vaccinii*, but most likely *T. minima*) is considered as a post-harvest disease (cosmetic damage) in Uruguay (Perez et al. 2014).

Limited data is available for other hosts. Only one reference was found for *Rhododendron*: in Vermont, there is a concern that incidence and severity of *T. minima* on ornamental *Rhododendron* spp. will increase where *Tsuga* and *Rhododendron* are grown in close proximity (Pfister et al., 2004). In addition, Fraser (1912), in his outdoor infection studies linking the pycnidial and aecial stages of *Peridermium peckii* on *Tsuga canadensis* with the uredinial and telial stages of *T. minima* (as *Pucciniastrum minimum*), mentions "splendid growth of the uredinia and telia of this rust" on the leaves of *Rhodora canadense* in a native habitat in Canada.

Impact in countries where it occurs

The overall picture is that leaf blueberry rust is more serious in the warmer part of its range (Australia, southern USA), but data seem to point to an increased impact in more northern areas where the pest was previously not considered a problem (e.g. Canada and Northern USA). In mild 'intermediate' areas, the impact is higher if *Tsuga* is also present.

- **Australia** appears to be the country where damage is highest. *T. minima* causes economic damage in both New South Wales and Queensland (almost 90% of Australian blueberries are produced in northern New South Wales and southern Queensland; Daniel et al., 2013). The impact in Tasmania is unknown to date – new outbreak. *T. minima* causes a significant disease of evergreen blueberries and costs tens of millions of dollars each year in lost production and control expenses (Simpson et al., 2016). Scalzo et al. (2016) mention that growing the evergreen cultivar Sharpblue commercially is no longer an option; it was the most profitable cultivar in Australia for nearly 20 years, but is severely affected by leaf rust, resulting in defoliation and reduced ability to produce fruit over long periods of the year. The combination of a subtropical climate in the region, extended growing season and evergreen cultivars is conducive to fungal diseases, incl. *T. minima*. Such diseases are becoming more severe and persistent in blueberry plantings, particularly during wet years (Daniel et al., 2013). Blueberry rust is qualified a 'significant impediment' to blueberry production. It has high incidence and severity.
- **Canada** (unclear whether some publications refer to *T. minima* or *N. vaccinii* or both). In the maritime provinces of Canada, leaf rust may be severe in lowbush blueberry fields due to high humidity in the planting and coastal fog (A. Schilder, pers. comm.). In New Brunswick, rust has minimal affect on fruiting fields (usually harvested before the disease has an impact), but it is a major disease (especially on lowbush blueberry, *V. angustifolium*, in semi-managed wild plantations) in the sprout year, causing extensive leaf spotting and leaf drop (New Brunswick, 2009; Hildebrand et al., 2010). Severe premature defoliation results in reduced yields the following year (Hildebrand et al., 2010). In parts of Canada (Nova Scotia), it has caused significant yield reductions in wild lowbush blueberry (*Vaccinium angustifolium*) (Percival and Dawson, 2009).
- **Mexico**. Since the first finding in Jallisco, Michoacan in 2007, *T. minima* has become a serious pest of *V. corymbosum* in these states (Rebollar-Alviter et al., 2011). It is economically damaging.
- **USA** (most publications refer to blueberry rust without specifying whether they refer to *T. minima* or *N. vaccinii* or both). Caruso and Ramsdell (1995 – using the broad species concept *P. vaccinii*, and relating also to *T. minima*) mention that leaf rust is 'of minor importance' and 'occasional' or 'rare' on highbush blueberry. Recently published reports from the USA suggest that damage has been increasing in the last few years, and current evidence points towards *T. minima*. Blueberry leaf rust is reported as being more prevalent in the southeastern USA (Heidenriech et al., 2005). Although some control methods are available (fungicide treatments, use of tolerant varieties, appropriate irrigation, removal of volunteer hosts), these constitute additional constraints to the growers (EPPO, 2016). There are many other extension publications and alerts that refer to blueberry leaf rust in recent years, and that most likely relate to *T. minima* (e.g. rust alerts for Alabama and Mississipi in Coneva, 2014 and Brannen, 2016). Leaf rust is more severe in warmer climates (Laemmlen and Gaskell, 2006 for California). Nevertheless currently in California, *T. minima* is reported on the central coast, but there is no impact on production as it is present at very low levels of infection (Thien Ho, pers. comm.). In Michigan, specimens collected in the 1920s on *Gaylussacia baccata* were identified as *T. minima* by Sato et al. (1993). On *V. corymbosum*, symptoms had been observed since the beginning of the 2000s; they were initially sporadic, but the disease has become more common since then. It became prevalent in 2009-2011 after several particularly rainy summers (Schilder and Miles, 2011; Schilder et al., 2016). In California, *T. minima* has been observed on the central Californian coast; it is present at very low levels of infection and there is no

impact on production as (Thien Ho, pers. comm.).SRBIMG (2016), for South East USA, mentions that blueberry rust is predominantly a problem in the extreme southern blueberry production areas such as South Georgia, but occurs in South Carolina and other locations. In Western Oregon, *T. minima* is mainly problematic for nurseries and greenhouse production, as symptoms typically do not recur in field plantings after premature defoliation (Wiseman et al., 2016). When *Tsuga* and *Rhododendron* grow in close proximity, there is concern that incidence and severity of *T. minima* on *Rhododendron* will increase (Pfister et al., 2004). No information was found on whether this was confirmed later.

- **South Africa**. Mostert et al. (2010) reported the presence and spread of *T. minima* in commercial plantations in 2006-2010, but did not give information on impact. No further information was found.
- **Colombia**. No details were found, other than that the susceptibility of cultivars had been studied. Cortés-Rojas et al. (2016) mention that rust (among other diseases and pests) was part of an experiment to compare the susceptibility of the cultivars Biloxi and Sharpblue (*V. corymbosum* x *V. darrowii*) in a commercial crop.
- **China**. *T. minima* was recently found at several locations in Sichuan, no information on impact is given (Zheng et al., 2017).
- **Netherlands.** Defoliation of wild (invasive) *V. corymbosum* was observed. Few leaves were left on plants, and they were heavily infested by *T. minima*. As *V. corymbosum* is invasive and under eradication, this may be considered as a positive effect for control. The fungus has not been found so far in nearby nurseries.
- **Germany, Belgium, Portugal**. Found in nurseries or garden centers. Eradication measures included destruction of plants. No further impact recorded in available information.

No mention of environmental or social impacts were found in the literature.

Control [note: this reflects what is done in countries where the pest occurs]
Control of *T. minima* appears to be similar in countries where the pest occurs. The following measures are mentioned:

- using disease-free planting material (Agriculture Victoria 2016c)
- avoiding susceptible cultivars (Agriculture Victoria 2016c)
- chemical control with fungicide applications (details below)
- hygiene and sanitation measures (details below)
- avoiding overhead irrigation (Michigan State University, 2009)
- in addition, in the USA where the alternate host occurs, removing alternate hosts (*Tsuga*) within a third of a mile (0.5 km); Note: the reason for this distance is not explained, but Caruso and Ramsdell (1995) noted that in Maine the disease has been observed on lowbush blueberries as far as 0.4 km from hemlock.
- Monitoring at an appropriate period, when the climate favours more frequent spore production (spring in Australia). New pustules can be produced within 10 days of infection and plants should be checked every two weeks during this period (Agriculture Victoria, 2016c)

Chemical control: The recommendations depend on the situation and climate. In New Brunswick, a single fungicide application in late July provides good control and suppresses both leaf infection and leaf drop (New Brunswick, 2009). In Australia (Wilk et al., 2016-17), fungicide application should be conducted in weather that is conducive to the disease. In the north, protectant fungicides are applied from December onwards. Once the disease is observed it is difficult to control. Rust mostly affects older leaves so its initial effects in the north are during spring and summer and in the south after February.

The following active ingredients are mentioned in the literature. Those in bold are authorized in the EU.

- **prothioconazole** (Agriculture and Agri-Food Canada, 2011).
- **benzovindiflupyr** , **azoxystrobin**, **chlorothalonil** (Syngenta 2015.)
- hydrogen dioxide and peroxyacetic acid (OxiDate 2.0 ; Biosafesystems.com)
- **prothioconazole**, **pyrazole carboxamide**, **pyraclostrobine** + **boscalid** (Dalhousie University 2012)
- Signum, azoles (Niedersachsen, 2016)

In trials, the following were found to be effective :

- **chlorothalonil** (Percival and Dawson, 2009)

- **azoxystrobin**, **azoxystrobin+cyproconazole**, **dithianon**, **fenbuconazole**, **tebuconazole** and **mancozeb** (all reduced disease incidence); fenbuconazole and dithianon were the most effective (Simpson et al., 2016).
- **pyraclostrobin** + **boscalid** was the most effective, followed by **fenbuconazole** and **metconazole**. The organic fungicide *Bacillus subtilis* was moderately effective (Schilder et al., 2016).

Hygiene and sanitation measures:

- where possible, all diseased branches and leaves should be removed during pruning and all fallen and pruned leaves from branches disposed of (Wilk et al., 2016-17). Note: this may be detrimental to the plant.

In an eradication situation, the following is recommended in Germany or Australian States where the fungus does not occur:

- In case of high infestation in glasshouse, hygiene measures should be combined with the application of fungicides (Niedersachsen, 2016)

<u>Relating to plants</u>

- Destruction of infected plants. Disposal of infected material by double bagging and sealing in black plastic bags, then placing it in direct sunlight for four weeks before disposing into landfill (Agriculture Victoria, 2016c).
- Measures to favour the rapid decomposition of dead leaves (Niedersachsen, 2016): e.g. application of urea, mechanical, mowing over should be possible, although they are not specifically documented in the literature. Research is being conducted to evaluate efficacy of application of fungicide (e.g. copper, lime sulfur) on the ground to limit the development of inoculum.
- Checking nearby host plants for signs of infection during this time (Biosecurity Tasmania, 2014b)
- Not planting plants in place of the blueberry plants for at least 6 weeks (longest survival period of the spores) (Biosecurity Tasmania, 2014b)
- Restrict movement of infested plants (Agriculture Victoria, 2016c)

<u>Relating to persons</u>

- Changing clothes or using disposable overalls, washing clothes before wearing them again (Agriculture Victoria, 2016c)
- Implement restrictions on movement of persons (Biosecurity Tasmania, 2014a) :
  - Limit the access of people (visitors and staff) on the property
  - Implement hygiene protocol for essential visitors (contractors, suppliers, etc.)
  - Minimise or allocate specific staff who might come in contact with host material

<u>Relating to equipment and vehicles</u>

- Disinfecting benches or other equipment (including tools and gloves) with suitable products (Agriculture Victoria, 2016c)
- Wiping electronic items with a disinfectant cloth, or use them in a plastic bag and wash or dispose of the bag before moving to another property (Agriculture Victoria, 2016c)
- Scrubbing materials that have been in contact with an infected plant (e.g. pots, wooden stakes) with detergent (or apply a disinfectant) and leave them to dry completely before reusing (Agriculture Victoria, 2016c). Any pots or gardening equipment exposed to blueberry rust disinfected with a 70% alcohol (methylated spirits) and 30% water solution (Biosecurity Tasmania, 2014b)
- Disinfect vehicles used to transport blueberry rust host materials after delivery of a consignment (Agriculture Victoria, 2016c).
- Implement restrictions on movement of vehicles (Biosecurity Tasmania, 2014a) :
  - Disinfect equipment/vehicles that move off-site and return to operate on the property
  - Restrict all non-business vehicles from entry onto the property

Australia

Rating of the magnitude of impact in the current area of distribution	Very low ☐	Low ☐	Moderate ☐	High ✓	Very high ☐
Rating of uncertainty			Low ✓	Moderate ☐	High ☐

Other countries

Rating of the magnitude of impact in the current area of distribution	Very low ☐	Low ☐	Moderate ✓	High ☐	Very high ☐
Rating of uncertainty			Low ☐	Moderate ✓	High ☐

Uncertainty: differences between countries, whether reports of impact in Canada and the USA relate to T. minima, N. vaccinii or both

13. Potential impact in the PRA area

Will impacts be largely the same as in the current area of distribution? **Yes** /No

The potential impact was estimated to be similar to that in countries other than Australia (where T. minima occurs mostly in subtropical climatic conditions).

One critical issue for assessing potential impacts is whether *T. minima* would have a higher impact than *N. vaccinii*. There is no information on this from North America, but new recent alerts on *V. corymbosum* presumably relate to *T. minima*, and there are no such alerts regarding species attacked by *N. vaccinii*. In the EPPO region, *T. minima* would have an impact in commercial production, where North American *Vaccinium* species are cultivated, especially *V. corymbosum* and hybrids. The disease would be more severe in warmer areas with sufficient humidity, and in other areas would mostly present a problem for nurseries. As seen in other areas, the impact on evergreen *Vaccinium* may be higher. In areas where *Tsuga* occurs, this may increase the build-up of inoculum, spread and impact of *T. minima*.

T. minima could have impact on organic production. Highbush blueberry has been promoted as a niche culture with little phytopathological problems (e.g. in Switzerland) (W. Maier, pers. communication).

T. minima may cause some social impact through cosmetic damage on ornamental hosts such as *Rhododendron* and defoliation of *Vaccinium* plants in gardens. However, such impact is caused by many rusts on many plants.

If wild *Vaccinium* were attacked, impacts may potentially be very high if *T. minima* is more aggressive than *N. vaccinii*. Such high impacts are not currently observed for *N. vaccinii*, but *T. minima* is an exotic fungus that may behave differently where introduced. In that case, there may be very high environmental impact, and social impacts where populations utilize wild *Vaccinium* to generate an income.

Schrader and Maier (2015) stated that hybridization of *T. minima* with the native *N. vaccinii* cannot be ruled out *a priori*, potentially leading to new virulent types (referring to willow rusts in North America, for which hybridization with European willow rusts occured and a new species formed with broader host spectrum and stronger virulence - Newcombe et al. 2000). The presence of *Tsuga* hosts would probably be needed for hybridization to be possible, rendering this possibility less likely in the EPPO region.

Rating of the magnitude of potential impact	Very low ☐	Low ☐	Moderate ✓	High ☐	Very high ☐
Rating of uncertainty			Low ☐	Moderate ✓	High ☐

Uncertainties: differences between countries, susceptibility of wild Vaccinium, fungicides used in Vaccinium crops.

14. Identification of the endangered area

The areas more at risk would be those where evergreen *Vaccinium* are grown and *T. minima* may overwinter and continue its cycle outdoors in the absence of *Tsuga*, as well as areas of extensive cultivation of hosts under protected conditions. Areas with wet conditions during the growing season might be especially at risk. *T. minima* may also have a higher impact where *Tsuga* (e.g. private gardens and parks) and especially where it is frequent (i.e. close to plantations).

15. Overall assessment of risk

The risk of entry of *T. minima* into the EPPO region is mostly linked to the trade of *Vaccinium* plants for planting. *T. minima* is a serious pest in some countries. In the EPPO region, the disease has a limited distribution in the Netherlands and is under eradication in several others countries. *T. minima* would have impact on cultivated North American blueberries, which is an expanding crop in the EPPO region. It is likely to spread naturally and through the trade of *Vaccinium* plants for planting. Damage is expected to be more severe in areas with sufficient humidity and where evergreen *Vacciniums* are grown, while in general it would mostly present a problem for nurseries. In areas where *Tsuga* occurs, these may increase the build-up of inoculum, spread and impact of *T. minima*. The wild *Vaccinium* species in the EPPO region are currently not known to be hosts, but damage may be higher if they are. The Panel on Phytosanitary Measures (PPM) concluded that *T. minima* presents an unacceptable risk for the EPPO region, because it is still absent from a large part of the EPPO region, where it may be possible to prevent its introduction.

Stage 3. Pest risk management

16. Phytosanitary measures

The Panel on Phytosanitary Measures emphasized that eradication of rusts is very difficult, and that NPPOs should aim at preventing the introduction of the fungus. *T. minima* still has a very limited distribution at the scale of the EPPO region, and although it will spread naturally, such spread will be slow at the scale of the region, and phytosanitary measures have to be strengthened to prevent its introduction into other EPPO countries. Trade of plants for planting is a major pathway and large quantities are traded from the USA and also within the EPPO region.

16.1 Measures on individual pathways

The Panel on Phytosanitary Measures recommended measures focusing on the high risk pathway, i.e. *Vaccinium* plants for planting. Because *T. minima* has often been found in association with *V. corymbosum* and hybrids, measures on plants for planting of those, and possibly *V. angustifolium* and *V. ashei*, would be especially important. However, there is still an uncertainty about the host range. For *Vaccinium* fruit, even if the risk of entry if considered as very low, producers should be encouraged to not import bulk fruit to be repacked in their production units (or at least to manage any waste safely to avoid spread of spores).

Because of the difficulty in distinguishing *N. vaccinii* (species present in the EPPO region) and *T. minima*, some measures would require the identification of leaf rust to the species level, and others could apply to any leaf rust.

Countries may consider implementing measures relating to the transboundary movement of machinery in *Vaccinium* production (if any; i.e. disinfection). An ISPM is under development that may give guidance on this issue.

Possible pathways *(in order of importance))*	**Measures identified**
Vaccinium plants for planting (except seeds, tissue cultures, pollen)	PFA Or Grown under complete physical isolation Or Systems approach (inspection at place of production, fungicide treatments during production, dormant and free from leaves at import, consignment free from plant debris, inspection of the consignment) And packed in conditions preventing infestation during transport.

16.2 Eradication and containment

The first eradication attempt was successful in Tasmania but the second outbreak of the disease most likely could not be controlled because of the number of plants involved. In Germany, Belgium and Portugal, the pest is under eradication.

Eradication and containment of rusts are difficult especially because spores are readily transported by wind and contact. Several features of the fungus would complicate eradication:

- difficulty of early detection (Biosecurity Tasmania, 2014b) if the infection is only mild and/or incidence is low. This is especially relevant because millions of plants in large consignments have been shipped in recent years from North America to Europe, and it is likely that mild infections or a low incidence are overlooked in border controls or infections only become visible at a later stage with the growers.
- identification as *T. minima*. Because *N. vaccinii* occurs in Europe, detection of a "blueberry rust" may be attributed to *N. vaccinii*, and this may delay or hinder identification of *T. minima*. However, given current knowledge, it would be reasonable to assume *a priori* that a rust found on *V. corymbosum* or *V. angustifolium* is *T. minima,* unless proven otherwise. In addition molecular methods rapid identification of the pest.
- presence of other hosts and alternate host: if the fungus is able to infect native plants in the EPPO region (e.g. native Ericaceae it had never encountered in North America), this may ensure build up of populations and complicate eradication. If the alternate hosts (*Tsuga* spp.) are present in the vicinity, it could ensure the completion of the life cycle and facilitate build-up of the inoculum and diversity. Presence of hosts in private gardens, parks and in the wild would complicate eradication.
- if the rust is systemic as suggested by preliminary observations in the greenhouse (W.Maier, pers. comm.).

Eradication may be feasible if the fungus is detected indoors, especially if the outbreaks were detected early. It may be possible outdoors in areas where *Vaccinium corymbosum* , *V. ashei* and *V. angustifolium* are exotic and present only in cultivation, and where other hosts (e.g. *Rhododendron*) or *Tsuga* do not occur (i.e. ensuring that even if spores spread, they will not reach other hosts). However, in several areas of Europe *V. corymbosum* is also present as an invasive plant, and could thus sustain the survival of this rust fungus. Additionally, it is not known whether native *Vaccinium* or Ericaceae (or other plants) could serve as a host for *T. minima*. Eradication would be complicated in areas where outbreaks are found outdoors, where detection is late, and where there are other hosts in the wild. Details on eradication programmes that have been implemented in Tasmania and Victoria are given in Biosecurity Tasmania 2014a&b, Agriculture Victoria, 2016c.

The Panel on Phytosanitary Measures considered that it was not possible to detail eradication measures in this PRA.

17. Uncertainty

- whether *T. minima* can survive under harsh winter condition without its alternate hosts *Tsuga*
- whether systemic overwintering in *Vaccinium* plants may occur
- whether hybridization with *N. vaccinii* could occur, and consequences thereof
- whether other cultivated or wild species where the pest occurs or in the EPPO region could be hosts, and potential damage to these. This relates most likely to *Vaccinium* or other Ericaceae species.
- susceptibility of *V. corymbosum, V. angustifolium and V. ashei* varieties used in the EPPO region
- whether *T. minima* would be more severe than *N. vaccinii* on native hosts.
- whether fungicides would be available to control the fungus.
- distance of spread of spores and duration of spore survival

18. Remarks

The experts identified the following as possible further research:

- Testing of susceptibility of native *Vaccinium* species by greenhouse infection studies.
- Assessing the ability of *T. minima* to survive in buds or on stems

- Molecular phylogenetic analyses of some specimens used in Sato et al. (1993) or held in collections where the broad species concept was used, and additional sequencing of specimens collected on *V. corymbosum* to further investigate whether only *T. minima* or also *N. vaccinii* attack *V. corymbosum*.
- Determining viability of spores (whether 6 weeks as used in some countries is an appropriate estimate).
- Determining minimum wetness duration needed for infection and whether high relative humidity is sufficient for infection
- Quantifying the relationship of relative humidity to urediniospore production
- Determining distance of spread from a point source.

The experts considered that it would be useful to recommend that NPPOs of EPPO countries encourage the reporting of blueberry leaf rust outbreaks, in order to help early detection of *T. minima*. Information could be provided to stakeholders (especially nurseries, producers of *V. corymbosum*, *V. angustifolium*, *V. ashei* and hybrids, private persons through nurseries). Any leaf rust on at least *V. corymbosum*, *V. angustifolium* or *V. ashei* (and their hybrids) should be identified to the species level by sequencing, and preferably also on other hosts and potential hosts.

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Annex 1. Consideration of pest risk management options

The table below summarizes the consideration of possible measures for plants for planting (based on EPPO Standard PM 5/3). When a measure is considered appropriate, it is noted "yes", or "yes, in combination" if it should be combined with other measures in a systems approach. "No" indicates that a measure is not considered appropriate. A short justification is included.

Review of existing regulations: Western Australia (2017) regulates potential carriers of blueberry rust that have been grown, packed or used within 200 km of a detection of blueberry rust (such as host plants and parts, other than seed and dried fruit) and any agricultural equipment that has been used in association with those.
For plants: grown in post entry quarantine for a minimum of six (6) months, screened and found free from blueberry rust prior to release.

Option	**Host plants for planting (except seeds, tissue culture, pollen)**
Existing measures in EPPO countries	The current phytosanitary measures would not prevent the introduction of *T. minima*. See some current measures in Table 4
Options at the place of production	
Visual inspection at place of production	Yes, in combination. Regular inspections during the growing period will allow detection of the pest, although rust symptoms may not be visible at early stages of infection
Testing at place of production	Not relevant.
Treatment of crop	Yes, in combination. Fungicide sprays may be applied. However, they would not eliminate the pest completely. Applying fungicide may delay appearance of symptoms and make inspection less reliable. It is not clear if this would be relevant at all for plants for planting (nursery plants) of *Tsuga*.
Resistant cultivars	No. Some cultivars of *Vaccinium* are less susceptible, but there are no cultivars that are known to be fully resistant. There have been no trials to compare rust resistance in cultivars over different regions. It is also not known if there are strains or races of the pathogen that could overcome resistance. No information for Tsuga and other hosts.
Specified age of plant, growth stage or time of year of harvest	No. The rust may attack plants at any stage. Dormant plants without leaves are less likely to be infected but it can not be sure that they are free from the pest.
Produced in a certification scheme	Not relevant.
Growing under complete physical isolation	Yes. See EPPO Standard PM 5/8.
Possibility for pest-free production site, place of production, area?	Yes.
Pest free production site and pest free place of production	Yes, but only as complete physical isolation.
Pest-free area	Yes, following ISPM 4. The pest free area established on the basis of surveillance. The exporting country should provide surveillance data to demonstrate that the pest is absent from all or part of its territory and information on how pest freedom is maintained. For a country where the pest is present in part of the country, measures should be in

Option	Host plants for planting (except seeds, tissue culture, pollen)
	place to prevent that infected plants are moved into the pest free area. Delimiting surveys should be conducted to determine the exact pest distribution. For plants for planting with foliage, measures to prevent infestation during storage/transport should be implemented. To provide a buffer against the introduction of the rust into the area, the PFA should be separated from any infestation by 2 km. This distance is based on the likely spread of spores (see section 11) plus a security margin. In some situations, 1 km may be sufficient (e.g. depending on growing conditions).
Options on the consignment	
Visual inspection of consignment	Yes, in combination. Early or latent infection may not be discernible.
Testing of commodity	Not relevant
Treatment of the consignment	No. Fungicides may be applied, but they may not control the pest completely. It may delay the development of the disease, and thus hinder detection. Some fungicides have anti-sporulant activity.
Pest only on certain parts of plant/plant product, which can be removed	No. There is an uncertainty about whether the pest may overwinter in buds, and whether dormant plants may carry the fungus. Dead infected leaves may be present on the growing medium of potted plants
Prevention of infestation by packing/handling method	Yes, in combination, for some measures. Plants should be packed under conditions preventing infestation during transport.
Options in the country of import	
Post-entry quarantine	No for commercial consignments. Post-entry quarantine would apply only to a limited number of plants imported for research or breeding purposes.
Limited distribution of consignments in time and/or space or limited use	No. Plants for planting may be imported under physical isolation in the absence of other hosts, and subject to inspection, making sure that any outbreak is eradicated. However, this is difficult to control in practice. It is more feasible that such physical isolation and measures are applied before dispatch.
Only surveillance and eradication in the importing country	No. Early detection is difficult, and natural spread would complicate eradication. Import of infested plants would present a risk for any part of the EPPO region, as the pest may maintain itself even in the absence of *Tsuga*, and it is likely that some other hosts are present under other conditions (e.g. gardens, parks, wild).

Annex 2. Isefor data on imports of plants for planting into the EU

Because of the uncertainties regarding the distribution of the pathogen, countries in Table 2 (section 6) are also covered here.

Vaccinium

Year	Genus	Quantity (plants) Country
2000	Vaccinium	95895 USA
2001	Vaccinium	100 New Zealand, 98712 USA
2002	Vaccinium	1 Argentina, 1 China, 2 Japan, 69208 USA
2003	Vaccinium	600 South Africa, 35 USA
2004	Vaccinium	1598 USA
2006	V. corymbosum	771
2007	Vaccinium	1120 USA
2007	V. corymbosum	26801 USA
2008	V. corymbosum	1 USA
2009	V. corymbosum	7000 USA
2010	V. myrsinites	2 Canada
2010	Vaccinium	15 South Africa
2010	V. corymbosum	2200 USA

Other hosts or other Ericaeae (as plants or bonsais) (note: all Ericacea were extracted here, not only known hosts)

Genus	Year	Quantity Origin.country
Rhododendron	2000	328 Japan, 426 USA
	2001	7071 China, 527 Japan
	2002	4040 China, 2027 Japan, 26 NZ, 70 USA
	2004	4470 China
	2005	1910 Australia
	2006	4 China
	2009	3 Australia, 2750 China, 2 Japan
	2010	1 USA, 3605 China, 1108 Japan
	2011	7 China, 45 USA, 87 Japan
R. quinquefolium	2010	3 Japan
R. indicum	2010	5300 USA, 523 Japan
	2011	36 Japan
	2012	792 Japan
Azalea	2000	39400 USA
	2006	78600 China
Menziesia	2000	1 USA
Arbutus	2001	5300 USA
	2002	5300 USA
Arctous	2004	5340 South Africa

Enkianthus	2000	1 USA
	2001	2 Japan, 1 USA
	2002	1 Japan, 1 USA
	2006	134 USA
	2010	26 Japan
	2012	5 Japan
E. perulatus	2009	100 Japan
	2010	647 Japan
	2012	36 Japan
Erica	2002	50 Australia, 1000 China
	2009	6610 South Africa
Erica verticillata	2010	3 South Africa
Gaultheria	2000	1 USA
	2001	250 USA
	2002	3 Australia
Kalmia	2000	150 USA
	2002	3 USA
Leucothoe	2008	1000 USA
Oxydendrum	2000	500 USA
	2001	4800 USA
	2002	1017 USA
	2010	100 USA
Pieris	2000	2200 USA
	2002	50 Japan