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Bursaphelenchus xylophilus Pest Report to support ranking of EU candidate priority pests

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1. Introduction to the report

This document is one of the 28 Pest Reports produced by the EFSA Working Group on EU Priority Pests under task 3 of the mandate M-2017-0136. It supports the corresponding Pest Datasheet published together on Zenodo[1] and applies the methodology described in the Methodology Report published on the EFSA Journal (EFSA, 2019).

This Pest Report has five sections. In addition to this introduction, a conclusion and references, there are two key sections, sections 2 and 3.

Section 2 first summarises the relevant information on the pest related to its biology and taxonomy. The second part of Section 2 provides a review of the host range and the hosts present in the EU in order to select the hosts that will be evaluated in the expert elicitations on yield and quality losses. The third part of Section 2 identifies the area of potential distribution in the EU based on the pest's current distribution and assessments of the area where hosts are present, the climate is suitable for establishment and transient populations may be present. The fourth part of Section 2 assesses the extent to which the presence of the pest in the EU is likely to result in increased treatments of plant protection products. The fifth part of section 2 reviews additional potential effects due to increases in mycotoxin contamination or the transmission of pathogens.

In Section 3, the expert elicitations that assess potential yield losses, quality losses, the spread rate and the time to detection are described in detail. For each elicitation, the general and specific assumptions are outlined, the parameters to be estimated are selected, the question is defined, the evidence is reviewed and uncertainties are identified. The elicited values for the five quantiles are then given and compared to a fitted distribution both in a table and with graphs to show more clearly, for example, the magnitude and distribution of uncertainty. A short conclusion is then provided.

The report has two appendices. Appendix A contains a host list created by amalgamating the host lists in the EPPO Global Database (EPPO, online) and the CABI Crop Protection Compendium (CABI, 2018a). Appendix B provides a summary of the evidence used in the expert elicitations.

It should be noted that this report is based on information available up to the last day of the meeting[2] that the Priority Pests WG dedicated to the assessment of this specific pest. Therefore, more recent information has not been taken into account.

For *Bursaphelenchus xylophilus* the following documents were used as key references: EU REPHRAME project (REPHRAME, 2019); Pest Risk Assessment of the Pine Wood Nematode (PWN) *Bursaphelenchus xylophilus* in Norway (VKM, 2008), EPPO Pest Risk Assessment for *B. xylophilus* (Evans et al., 2009).

[1] Open-access repository developed under the European OpenAIRE program and operated by CERN, https://about.zenodo.org/

[2] The minutes of the Working Group on EU Priority Pests are available at http://www.efsa.europa.eu/sites/default/files/wgs/plant-health/wg-plh-EU_Priority_pests.pdf

2. The biology, ecology and distribution of the pest

2.1. Summary of the biology and taxonomy

Bursaphelenchus xylophilus is a single taxonomic entity. *B. xylophilus* (Pine Wood Nematode, PWN) is a microscopic roundworm with a phoretic relationship with cerambycid beetles, i.e. pine sawyers in the genus *Monochamus*. PWN is threatening pine forests worldwide by causing a severe hypersensitive response in infected trees, i.e. the Pine Wilt Disease (PWD). Pine species, which are susceptible to PWD and grow under warm and dry conditions may wilt and die from this disease in a few months and up to 2 years after infection. The nematode is endemic to North America where pine species are highly tolerant to PWD. The nematode has a short generation time. Under laboratory conditions on fungal cultures the generation time is 12 days (at 15°C), 6 days (at 20°C) and 3 days (at 30°C). Eggs take 26-32 hours to hatch at 25°C. The temperature threshold for development is 9.5°C (Evans et al., 1996; CABI, 2018a).

PWN has two different life-cycle phases:

- Propagative phase: characterised by rapid multiplication. The population is composed of males, females, eggs, four juvenile stages (JI-JIV) (Evans et al., 1996).
- Dispersal phase: Food shortage and adverse conditions induce the formation of the highly persistent resting stage JIII (Fig. 1 B). If conditions improve, this stage can moult to the propagative J4 (Fig. 1 C). The formation of JIII is also triggered by the pupation of cohabiting *Monochamus* spp. in wood. In spring this resting stage of the nematode is attracted to the wood surrounding the pupal chamber of the beetles. Here it develops into the dispersal stage (JIV) or “dauerlarva” (Fig. 1 D) which invades the pupal chamber and spreads out over the inner walls. After the eclosion of the adult beetle from the pupa, the JIV invades the tracheal system of the beetle (Mamiya, 1984). When the beetles fly out from the breeding material to feed on the thin bark of shoots and twigs, the JIV infect the feeding scars, moult to adults (Fig. 1 D), enter the propagative phase and spread rapidly in wood (Mamiya, 1984; Kuroda, 2008).

PWN has two types of life cycle based on its feeding behavior:

- Saprophytic life cycle: Here PWN feeds on the hyphae of various species of wood-inhabiting fungi. This is the normal life cycle of *B. xylophilus* in its natural habitat, where host and pest co-evolved with no significant damage to the host population.

<u>Pathogenic life cycle</u>: When the nematode comes in contact with susceptible pine species growing in warm and dry conditions this life cycle predominates. After invading the shoots and twigs through the feeding scars of its vector beetle, the nematodes multiply in the resin canals attacking the epithelial cells. The nematodes spread rapidly through wood at a rate of 150 cm per day (Kuroda,2008). An early sign of infection is a reduction in oleoresin flow. Needles become chlorotic and wilt so rapidly that the red brown needles will remain on the trees. In hot regions, where mean summer temperatures exceed 20°C infected pine trees may die in 30-40 days after infestation potentially harbouring millions of nematodes inside the trunk, branches and roots. In some northern locations the dying of trees is less rapid and may happen two years after infection and with lower nematode densities in wood. This type of symptom expression is known as biennial disease development (Mamiya, 1988).

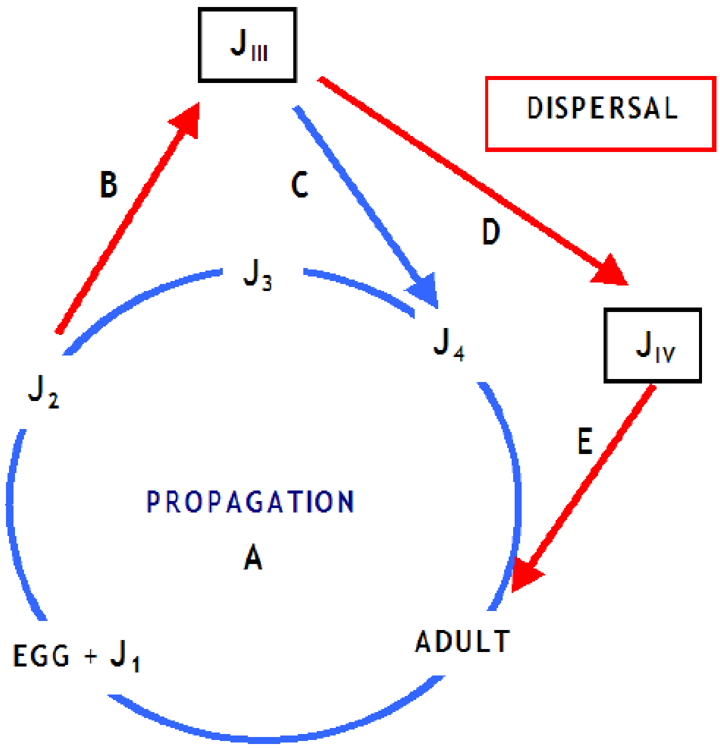

Figure 1 Pine Wood Nematode (PWN) *Bursaphelenchus xylophilus* life strategy. A. Propagative phase (blue). B, D and& E. Dispersal phase (red). B. Induction of spreading and resting stage JIII. C. Reversion to propagative J4. D. Induction of phoretic dispersal stage JIV. E. Moult to adult in feeding wound or oviposition scar made by *Monochamus* spp. (From VKM, 2008).

The vector

Pinewood nematode “dauerlarvae” are transmitted to healthy trees through the feeding scars produced by adult cerambycids of the genus *Monochamus* (Family Cerambycidae, subfamily Lamiinae) (EFSA, 2012). This genus, commonly known as sawyers or pine sawyer beetles, comprises more than 160 species distributed worldwide in different environments. All species indigenous to temperate regions attack plants of Pinaceae family, focusing on individuals stressed or recently killed (EFSA, 2012).

Maturation feeding by the vector results in primary transmission to the shoots of the trees. Beetle females oviposit in the branches or trunks of stressed, dying or recently died trees. During oviposition “dauerlarvae” remaining in the tracheal system of the beetles leave the insect to invade the oviposition scars. This is the secondary transmission, by which PWN may be present in a dying tree without being the cause of tree death. Eggs hatch in 4-12 days according to the temperature. Pupal stages last for up to 19 days, whereas 6-8 days may pass between eclosion and adult emergence. Complete development (from oviposition to adult emergence) takes 8-12 weeks (Evans et al., 1996). Ten days after emergence, the female is capable of depositing eggs, living up to 83 days and being capable of laying a total of 40-215 eggs. *M. alternatus* usually has 1 generation/year (Evans et al., 1996).

Table 1 lists the *Monochamus* species known to be vectors for PWN (EFSA, 2012). The most studied *Monochamus* species are *M. alternatus*, *M. gallo*provincialis and *M. carolinensis*. Additional information may be found in: CABI, 2018a—d.

Table 1: List of *Monochamus* species from coniferous trees, known to be vectors of PWN or considered to be potential vectors (EFSA, 2012).

Species	Country (region)	Hosts
America		
M. carolinensis	United States (central and eastern seaboard; 26 states), Mexico, Canada (New Brunswick, Ontario, Quebec)	*Pinus*
M. clamator	Canada (British Columbia)	*Pinus contorta, Pseudotsuga menziesii*
M. scutellatus	United States (35 states), Mexico, Canada (widespread)	*Abies, Larix, Picea, Pinus, Pseudotsuga menziesii,Tsuga*
M. titillator	United States (31 states), Canada (Ontario)	*Abies, Picea, Pinus*
M. mutator	United States (Minnesota), Canada (six provinces)	*Pinus*
M. obtusus	United States, Canada (four states in western British Columbia)	*Abies, Pinus, Pseudotsuga menziesii*
M. notatus	United States, Canada (10 provinces)	*Pinus strobes, Picea glauca, Pinus monticola, Pseudotsuga menziesii*
M. marmorator	United States (19 states), Canada (five provinces)	*Abies, Picea*
Asia		
M. alternatus	China (20 provinces), Japan (widespread), Republic of Korea (Pusan area), Laos, Taiwan, Vietnam	*Abies, Cedrus, Larix, Picea, Pinus*
M. nitens	Japan	*Pinus*
Europe/Asia		
M. saltuarius	China (four provinces), Japan, Europe	*Abies, Larix, Picea, Pinus, Sciadopitys, Tsuga,*
M. rosenmuelleri (=*M. urussovi*) (*)	China (three provinces), Korea, Japan, Europe	*Abies, Betula, Larix, Picea, Pinus*
M. sutor (*)	China (five provinces), Siberia, Mongolia, Korea, Japan, Europe	*Larix, Picea, Pinus,*
Europe/North Africa		
M. galloprovincialis	Europe, Africa (Algeria, Morocco, Tunisia)	*Pinus, Picea*
M. sartor (*)	Europe	*Abies, Picea, Pinus,*

2.2. Host plants

2.2.1. List of hosts

The *Pinus* genus represents the main host group for PWN. Other Coniferae (*Abies*, *Juniperus, Chamaecyparis, Picea*, *Larix*, *Cedrus, Thuja* and *Pseudotsuga*) may act as hosts and reservoirs, with lower amounts of damage (Evans et al., 1996 and 2009; EPPO, 2014). In addition to these species, the *Monochamus* vectors may also attack other conifers such as *Cryptomeria* and sometimes *Tsuga* (EFSA, 2012), but it is uncertain whether these genera are hosts for PWN.

Appendix A provides the full list of hosts.

2.2.2. Selection of hosts for the evaluation

Although the main host group is the *Pinus* genus, differences in susceptibility of Pinus species native or planted in Europe are reported: according to Menéndez-Gutiérrez et al. (2018) i) *P. sylvestris* is highly-susceptible, ii) *P. radiata* and *P. pinaster* susceptible, iii) *P. canariensis*, *P. halepensis*, *P. nigra*, *P. pinea* and *P. taeda*, non- to slightly susceptible.

The host status of *P. mugo* and *P. cembra* is less well documented, while *P. halepensis*, *P. brutia* and *P. pinea* are clearly minor hosts:

- Mamiya (1983) lists *P. halepensis* and *P. brutia* as resistant, while Evans et al. (1996) identified the same species as intermediate hosts.
- Mamiya (1983), Kishi (1995) and Evans et al. (1996) considered *P. mugo* to be susceptible hosts of PWN since they could be killed by natural infection.
- Since the host status of *P. pinea* is unclear, it can be considered as an inferior host compared to all the other species.

In conclusion, the assessment of the impact has been conducted on the main PWN hosts among the *Pinus* species native or planted as exotics in the EU: *P. sylvestris*, *P. radiata* and *P. pinaster*. All are susceptible to pine wilt as well as supporting the mycophagous phase of the PWN life cycle.

The roles of other Coniferous species have not been quantified in the impact assessment.

2.2.3. Conclusions on the hosts selected for the evaluation

The hosts on which the impact is assessed are susceptible hosts that would be killed by the PWN. The assessment considers commercial plantations of the three main PWN hosts among the *Pinus* species in the EU (*P. pinaster, P. radiata, P. sylvestris*). The assessment of impact does not take into account the potential losses on other ornamental *Pinus* species.

2.3. Area of potential distribution

2.3.1. Area of current distribution

Figure 2 provides an overview of the current area of distribution of the pest. EU outbreaks occurred in 1999 near Setúbal, Portugal and in 2008, 2010, 2012, 2014 and 2018 in Spain (EPPO, online).

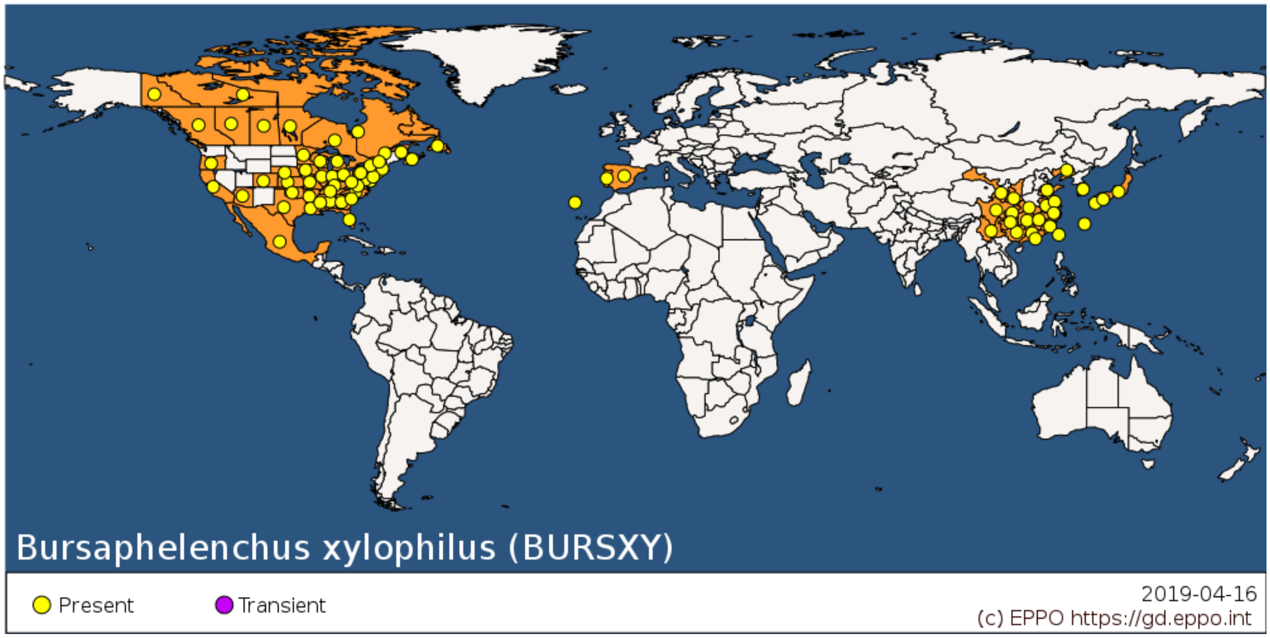

Figure 2 Distribution map of *Bursaphelenchus xylophilus* from the EPPO Global Database accessed 16/04/2019.

2.3.2. Area of potential establishment

For the purposes of this analysis, it is assumed that PWN is present throughout the distribution of suitable host plants in Europe. It is, therefore, important to differentiate between those climatic zones that will result in rapid wilt expression (the situation typical in Japan) in susceptible hosts and those areas where delayed expression or no expression is expected when nematodes are introduced to the tree by *Monochamus* spp. maturation feeding.

A process model for determining likelihood of wilt expression was developed in the EU REPHRAME project (www.rephrame.eu) and described by Gruffudd et al. (2016). The model simulates how a host tree responds to the presence of nematodes introduced through maturation feeding by *Monochamus* spp. vectors. It incorporates components for water flow through the tree linked to photosynthesis and the amount of energy allocated to either growth (no nematode stress) or defence (presence of nematode as an antagonist). Input data are daily (or interpolated daily from monthly climate data) time steps for temperature, rainfall, sunlight interception, soil water, soil and canopy evaporation and transpiration for local soil and climate for a given tree species.

Outputs from the model provide a measure of the likelihood and timing of pine wilt expression with, essentially, three potential scenarios: rapid wilt (in the same year as nematode infestation), delayed wilt (one or possibly two years later) and no wilt (the tree does not succumb to the nematode). Using the worst case of climate in recent years (the record high temperatures recorded in 2010) the predicted wilt, delayed wilt and no wilt distributions across Europe are shown in the Figure below.

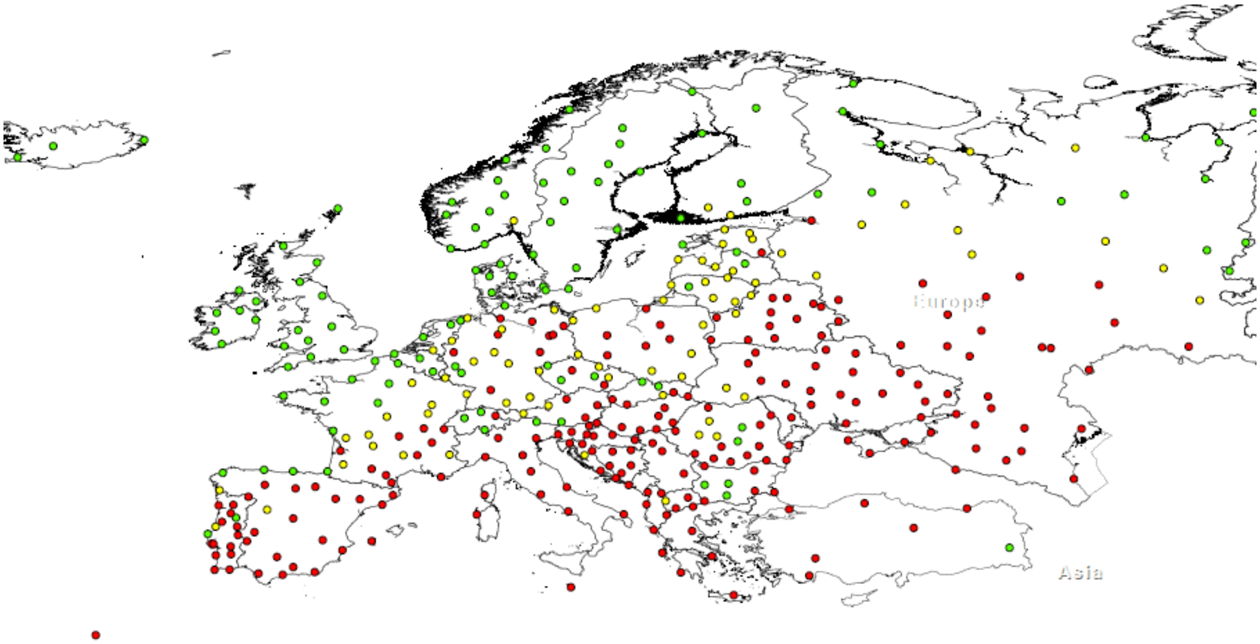

Figure 3 Pine wilt disease expression in Europe for 2010, a year of record high temperatures, based on the process model described by Gruffudd et al. (2016). The model outputs have been summarised as: ● rapid wilt expression, ● delayed wilt expression and ● no wilt expression.

It can be seen that some parts of Europe will remain free of pine wilt expression, even though the nematode can survive in susceptible host trees through the saprophytic phase of its cycle. There is also a substantial zone (with the current climate scenario) where there are likely to be 1 or 2 year delays in wilt expression and, ultimately, tree death.

While the full model requires complex input parameters, Gruffudd et al. (2016) describe methods for generating approximate outputs using simplified parameters, including geographic position (longitude and latitude data entered into a formula provided) or mean summer temperature for a location.

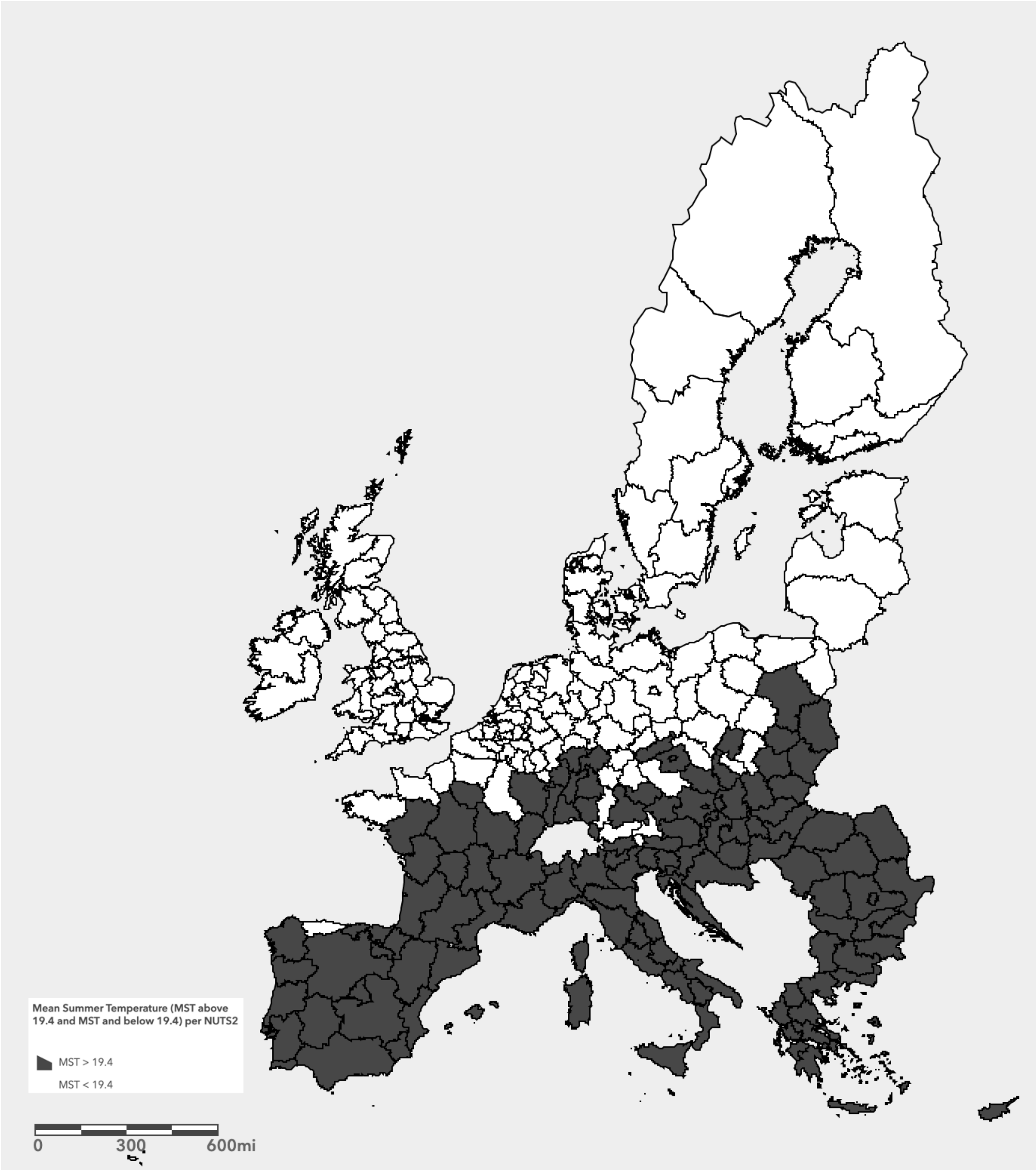

Figure 4 The potential distribution of the pest in the EU NUTS2 regions based on the scenarios established for assessing the impacts of the pest by the EFSA Working Group on EU Priority Pests (EFSA, 2019). This link provides an online interactive version of the map that can be used to explore the data further: https://arcg.is/1O8C8T (MST - mean summer temperature).

2.3.3. Transient populations

Bursaphelenchus xylophilusi is not expected to form transient populations in the EU (for "transient" see the definition in EFSA, 2019).

2.3.4. Conclusions on the area of potential distribution

The area of potential distribution is based on the assumption that host plants are available throughout Europe and the availability of vectors does not represent a limiting factor for the area of potential establishment of PWN. Two zones were identified: a Northern zone where PWN infestations are not likely to cause plant death except under specific climatic circumstances and a Southern zone where PWN infestations are likely to cause plant death.

2.4. Expected change in the use of plant protection products

It has not proved possible to control *B. xylophilus* spread once introduced into a tree. Control strategies therefore rely on a combination of cultural practices, removing dead/dying trees from a forest in order to avoid the spreading of secondary infections, and applying (even prophylactic) chemical insecticides to control vector beetles.

Kobayashi (1988) listed as widely practiced preventive applications of nematicides and insecticides, and spraying, burning and chipping of infested trees.

Due to the fact that no effective treatments with plant protection products (PPPs) are currently available to control this pathogen, the most suitable PPP indicator is Case "A" and the category is "0" based on Table 2.

Table 2: Expected changes in the use of Plant Protection Products (PPPs) following *Bursaphelenchus xylophilus* establishment in the EU in relation to four cases (A-D) and three level score (0-2) for the expected change in the use of PPPs

Expected change in the use of PPPs	Case	PPPs indicator
PPPs effective against the pest are not available/feasible in the EU	**A**	**0**
PPPs applied against other pests in the risk assessment area are also effective against the pest, without increasing the amount/number of treatments	B	0
PPPs applied against other pests in the risk assessment area are also effective against the pest but only if the amount/number of treatments is increased	C	1
A significant increase in the use of PPPs is not sufficient to control the pest: only new integrated strategies combining different tactics are likely to be effective	D	2

2.5. Additional potential effects

2.5.1. Mycotoxins

The species is not known to be related to problems caused by mycotoxins.

2.5.2. Capacity to transmit pathogens

The species is not known to vector any plant pathogens.

3. Expert Knowledge Elicitation report

3.1. Yield and quality losses

3.1.1. Structured expert judgement

3.1.1.1. Generic scenario assumptions

All the generic scenario assumptions common to the assessments of all the priority pests are listed in the section 2.4.1.1 of the Methodology Report (EFSA, 2019).

3.1.1.2. Specific scenario assumptions

- The area of potential establishment is the whole of the EU because conifer trees and associated *Monochamus* species are widespread, except for the UK and Ireland due to the absence of vectors.
- Susceptible hosts are living trees that would be killed by the PWN. The assessment considers commercial plantations of the main *Pinus* species hosts in the EU (*P. pinaster, P. radiata, P. sylvestris*) and does not take into account the potential losses to other ornamental *Pinus* species which are less widely grown.
- PWN leading to tree death is driven by a combination of temperature and soil moisture parameters. Some parts of the EU (Northern areas) are not likely to suffer damages due to PWN according to Gruffudd et al., 2016.
- The model results by Gruffudd et al. (2016) have been used to stratify the EU territory into two zones: a Northern zone in which PWN infestations are not likely to cause plant death, unless under specific climatic circumstances; a Southern zone in which PWN infestations are likely to cause plant death. The assessment uses the model outputs to divide the area in two zones.
- Yield losses are estimated separately for the two zones.
- *Pinus* timber production cycle and natural regeneration would remain important throughout the EU even in the Southern area where tree mortality due to PWN occurs.
- There is a uniform age distribution of *Pinus* trees, from very young to end of rotation (45-120 years), in the area of potential establishment.
- The capacity of the vector to transmit PWN is assessed throughout the area of potential distribution, spatial variability in the abundance is based on the availability of resources for feeding and reproduction with consequences on the spatial variability of transmission.

3.1.1.3. Selection of the parameter(s) estimated

Only yield losses based on percentage mortality have been assessed. Quality losses have not been assessed because infested trees or parts of trees will only be used for low value products and will therefore count as total losses.

3.1.1.4. Defined question(s)

What is the percentage yield loss in forest stands in the Southern zone under the scenario assumptions in the area of the EU under assessment for *Bursaphelenchus xylophilus*, as defined in the Pest Report?

What is the percentage yield loss in forest stands in the Northern zone under the scenario assumptions in the area of the EU under assessment for *Bursaphelenchus xylophilus*, as defined in the Pest Report?

3.1.1.5. Evidence selected

The experts reviewed the evidence obtained from the literature (see Table B.1 in Appendix B) selecting the data and references used as the key evidence for the EKE on impact. Some general points were made:

- "Drying-out" symptoms (e.g. wilting and reduced oleoresin exudation) appear 3 weeks after infestation. Trees die in 30-40 days.
- When susceptible conifer species are grown under stressful environmental conditions (e.g. high temperatures and low soil moisture), the nematodes - introduced by maturation feeding - can survive and move through the tree, ultimately leading to xylem cavitation and PWD.
- Massive mortality of native pine trees has been recorded in Japan and to a lesser, but still serious, extent in China and Taiwan, Korea, and also Portugal. In all such cases, the existing, native species of *Monochamus* in each country has taken the role of the vector.
- Japan spent tens of millions of dollars to control PWN annually; Portugal spent almost 24 million euros (2001-2009) to control/eradicate PWN; for the same reasons, Spain spent 344 thousand euros in 2009 and almost 3 million euros in 2010 (Evans et al., 2009).
- PWN attacks favour secondary impacts by other pests that can produce a qualitative damage.
- The *Monochamus* vector species are native to Europe and any damage they cause has not been included in the assessment
- As noted in section 1.2.1, if *B. xylophilus* larvae are introduced to *P. sylvestris*, *P. nigra*, *P. pinaster* or *P. radiata* trees growing in Europe during feeding by *Monochamus* spp. Three wilt disease scenarios are possible: (i) rapid wilt (tree mortality in the same year as nematode infestation), (ii) delayed wilt (tree mortality one to two years later) or (iii) no wilt (the tree does not succumb to the nematode). The quality of the timber from trees that have died under scenarios (i) and (ii) is similar to that from uninfected trees harvested at the same age. There is also no loss in quality under scenario 3. Although secondary fungal infections and insect attack can occur as a result of scars caused by *Monochamus* feeding, such damage is unrelated to the presence of *B. xylophilus*. As noted in section 1.2, coniferous trees in genera other than *Pinus* can act as reservoirs for *B. xylophilus* but the presence of the nematodes does not affect timber yield or quality.
- Since losses are only linked to the reduction in potential volume (i.e. yield) arising from the early death of the tree before reaching its full rotation, quality losses have not been estimated for *B. xylophilus*.
- Mamiya, 1988: the paper provides the percentage of infestation linked to the final yield loss for one of the prefectures observed
- The PHRAME project provides an accumulation of the total losses where 100% is not reached

Type of host	Climatic conditions	Consequences	Additional conditions influencing the impact
On PWN susceptible species	Unfavourable conditions: cool and wet climate	no damage	
	Favourable conditions: gradient of dry and warm conditions	tree killed: survival from weeks to 3 years	Secondary attack by fungi and borer insects Distance in time between pest attack and harvesting
On PWN non-susceptible species		no damage	

3.1.1.6. *Uncertainties identified*

- very limited information on the impact is available from literature
- no clear evidence for classifying host susceptibility to PWN is available for *P. cembra*, *P. mugo*, *P. pinea* and *P. nigra* (EFSA, 2013; Menéndez-Gutiérrez et al., 2018)
- Variability due to the timing of PWN infection in relation to the timing of felling the tree: the closer together they are, the lower the yield loss.
- Although 2 regions for symptoms expression have been identified in the EU, there could be favourable years for symptoms expression also in Northern EU
- The level of damage is strongly affected by vectors presence and density, and the spatial and temporal dynamics of vectors abundance across EU is not known

The effect of removal of wilting plants without identification of the causal agent could lead to an underestimation of the current impact

3.1.2. Elicited values for yield losses on *Pinus* plantations in the Southern zone

What is the percentage yield loss in forest stands in the Southern zone under the scenario assumptions in the area of the EU under assessment for *B. xylophilus*, as defined in the Pest Report?

The five elicited values on yield loss on *Pinus* plantations in the Southern zone on which the group agreed are reported in the table below.

Table 3: The 5 elicited values on yield loss (%) on *Pinus* plantations in Southern zone

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	3%	17%	25%	35%	65%

3.1.2.1. *Justification for the elicited values for yield loss on Pinus plantations in Southern zone*

Reasoning for a scenario which would lead to high yield loss (99th percentile / upper limit)

The upper value of yield loss in the Southern zone is mainly justified by the following points:

- High vector populations
- The tree population attacked is not close to harvest
- In most of the cases conditions are favourable for infestation but not all of them would result in yield loss

Reasoning for a scenario which would lead to low yield loss (1st percentile / lower limit)

The lower value of yield loss in the Southern zone is mainly justified by the following points:

- low vector populations
- dead trees are replaced
- The tree population attacked is old enough to be close to harvest
- Limiting effect of altitude and proximity to coasts (e.g. Atlantic effect in Portugal)

Reasoning for a central scenario equally likely to over- or underestimate the yield loss (50th percentile / median)

The median value of yield loss is due to the likelihood of conditions being favorable for infestation, and to the fact that, in the presence of an infestation, the management of infected trees and their removal is difficult. In Portugal, for example, the removal of infected plants was very difficult due to the scattered ownership of affected land.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The precision is mainly affected by the management of the affected trees (identification and removal of infected trees, which in some locations is extremely difficult) as a factor which is more relevant than the presence of vectors.

3.1.2.2. Estimation of the uncertainty distribution for yield loss on Pinus plantations in the Southern zone

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 4: Fitted values of the uncertainty distribution on the yield loss (%) on *Pinus* plantations in the Southern zone

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	3%					17%		25%		35%					65%
Fitted distribution	4%	6%	8%	11%	14%	17%	20%	25%	31%	35%	39%	44%	50%	55%	61%

Fitted distribution: BetaGeneral(2.8622,7.8794,0,1), @RISK7.5

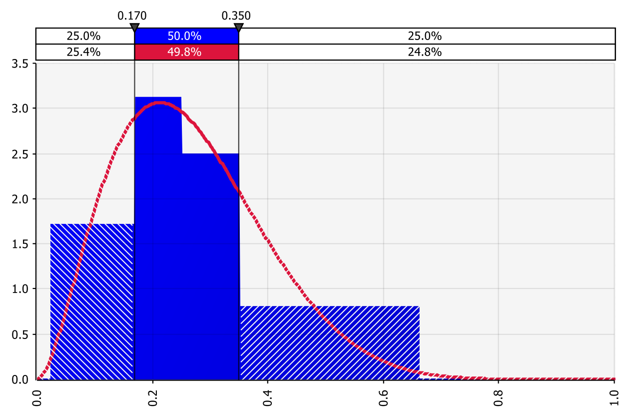

Figure 5 Comparison of judged values (histogram in blue) and fitted distribution (red line) for yield loss on *Pinus* plantations in the Southern zone.

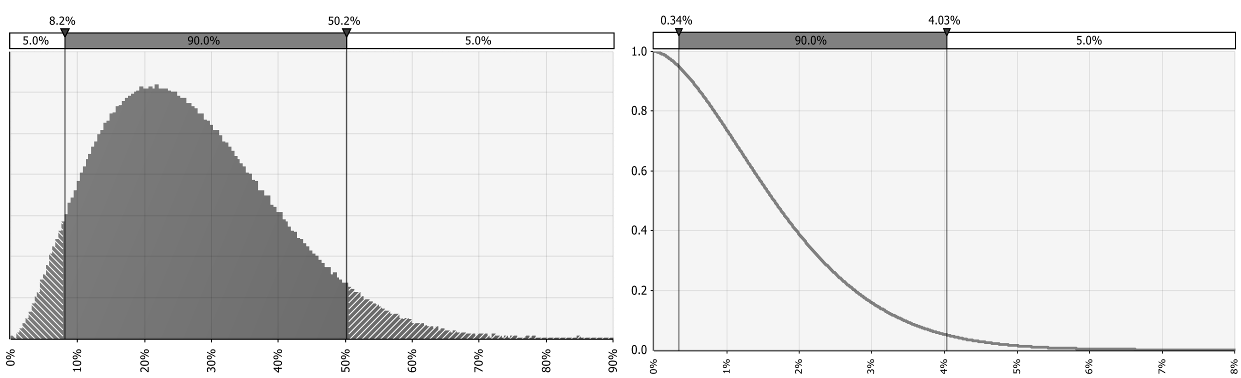

Figure 6 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for yield loss on *Pinus* plantations in the Southern zone.

3.1.3. Elicited values for yield losses on *Pinus* plantations in the Northern zone

What is the percentage yield loss in forest stands in the Northern zone under the scenario assumptions in the area of the EU under assessment for *B. xylophilus*, as defined in the Pest Report?

The five elicited values on yield loss on *Pinus* plantations in the Northern zone on which the group agreed are reported in the table below.

Table 5: The 5 elicited values on yield loss (%) on *Pinus* plantations in the Northern zone

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	0.3%	0.9%	1.7%	2.5%	5%

3.1.3.1. Justification for the elicited values for yield loss on Pinus plantations in the Northern zone

Reasoning for a scenario which would lead to high yield loss (99th percentile / upper limit)

The upper value of yield loss in the Northern zone is mainly justified by the following points:

- Effect of low temperatures on the mortality rates observed on young trees in experimental conditions (Braasch, 2000)
- Assumptions of the revised model are all driven by real life observations; the underlying assumptions did not change
- Favourable conditions come unfrequently

Reasoning for a scenario which would lead to low yield loss (1st percentile / lower limit)

The lower value of yield loss in the Northern zone is mainly justified by the following points:

- The total absence of losses is excluded
- Even in Japan there are climatic situations where losses have never been observed, even so, the climatic variability in the Northern zone does not allow complete damage to be excluded.

Reasoning for a central scenario equally likely to over- or underestimate the yield loss (50th percentile / median)

The median value of yield loss is influenced by field observations and by the fact that favourable climatic conditions would remain rare events and would only rarely appear in consecutive years.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The precision is mainly affected by climate variability.

The upper value is more of an outline but there is a good confidence in the median as favourable conditions would remain infrequent.

3.1.3.2. Estimation of the uncertainty distribution for yield loss on *Pinus* plantations in the Northern zone

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 6: Fitted values of the uncertainty distribution on the yield loss (%) on *Pinus* plantations in the Northern zone

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	0.3%					0.9%		1.7%		2.5%					5%
Fitted distribution	0.1%	0.2%	0.3%	0.5%	0.7%	1.0%	1.2%	1.7%	2.2%	2.5%	2.9%	3.4%	4.0%	4.6%	5.2%

Fitted distribution: Weibull(1.6422,0.020669), @RISK7.5

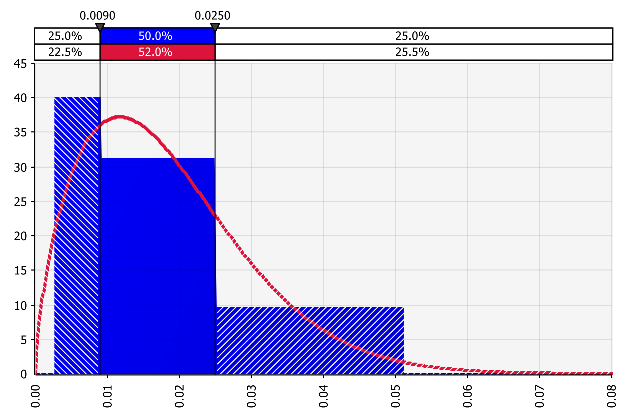

Figure 7 Comparison of judged values (histogram in blue) and fitted distribution (red line) for yield loss on *Pinus* plantations in the Northern zone.

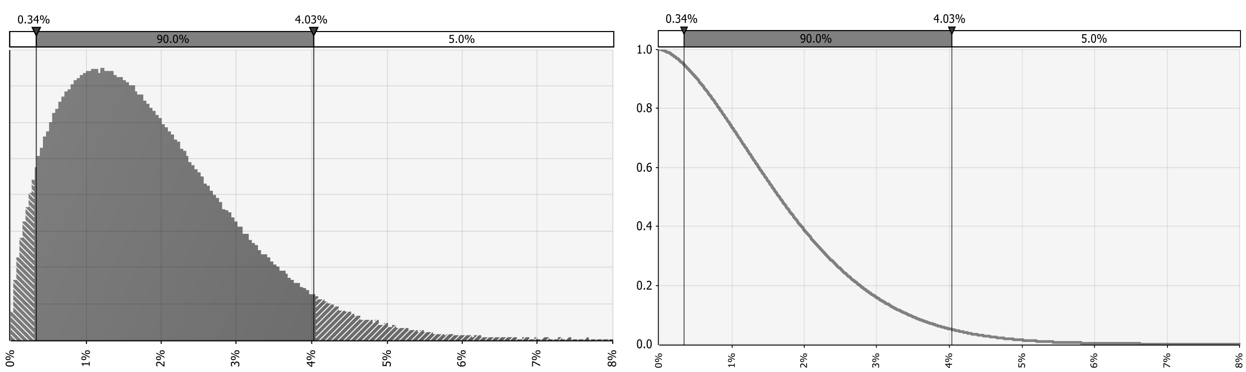

Figure 8 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for yield loss on *Pinus* plantations in the Northern zone.

3.1.4. Conclusions on yield and quality losses

Based on the general and specific scenario considered in this assessment, the percentage yield losses based on percentage mortality is estimated to be:

- 25% (with a 95% uncertainty range of 6-55%) on *Pinus* plantations in the Southern zone
- 2% (with a 95% uncertainty range of 0.2-5%) on *Pinus* plantations in the Northern zone

Only yield losses based on percentage mortality have been assessed. Quality losses have not been assessed because infested trees or parts of trees will only be used for low value products and will therefore count as total losses.

3.2. Spread rate

3.2.1. Structured expert judgement

3.2.1.1. Generic scenario assumptions

All the generic scenario assumptions common to the assessments of all the priority pests are listed in the section 2.4.2.1 of the Methodology Report (EFSA, 2019).

3.2.1.2. Specific scenario assumptions

- Vector dispersal is a biological trait depending on the distribution of the host plants, scattered host plant distribution facilitates the dispersal rate and the length of the flight events. Damaged and stressed trees are more prone to vector attacks. Therefore, the estimation is based on conditions supporting the highest frequency and length of dispersal events: scattered host distribution and a limited availability of stressed and damaged trees.
- The contribution of the movement of the PWN in the plant and between plants is considered to play a negligible role in spread compared to vector dispersal
- All the *Monochamus* species in the EU are assumed to have the same vectorial capacity and dispersal rate
- The spread rate is considered to be the same throughout the EU

3.2.1.3. Selection of the parameter(s) estimated

The spread rate has been assessed as the number of metres per year.

3.2.1.4. Defined question(s)

What is the spread rate in 1 year for an isolated focus within this scenario based on average European conditions? (units: m/year)

3.2.1.5. Evidence selected

The experts reviewed the evidence obtained from the literature (see Table B.2 in Appendix B) selecting the data and references used as the key evidence for the EKE on spread rate.

Some general points were made:

- A good recent summary is given by Akbulut and Stamps (2011). Without their vectors, PWN can move from one infested tree to another theoretically (but very unlikely) by: root transmission, soli/water transmission, wood to wood contact, migration from chips or other infested material in contact with roots, soil and root grafting. However, these vector-less transmission pathways have never been confirmed under field conditions (Evans et al., 2009). The peak of *Monochamus* flying activity is reached 5 days after emergence. *Monochamus* beetles usually infest neighbouring trees in highly dense forest. Human assisted spread, including trade commodities occure with plants for planting (including bonsai), cut branches of host species, wood, particle wood and waste wood of host species, coniferous wood packaging material, isolated bark of host species (Evans et al., 2009). Cerambycids rarely attack young trees (< 7 years) (EPPO, 2014). It is reasonable to consider the flying distance of cerambycids vectors to be around 3 km/flight season.
- Low temperatures reduce the number of nematodes and the host plants remaining symptomless (Evans et al., 2009). In addition, the pest is capable of establishing in trees without symptom expression and living both in a saprophytic and pathogenic phase (Evans et al., 2009).
- the experimental estimation of the flight distance of the vectors available from literature is based on single flight events. The spread of PWD is usually higher than the vector flight distance because it is estimated as the total distance from repeated flight events related to several egg laying episodes in one year.
- The total distance flown over the vector lifespan is consistent with the disease spread rate.

3.2.1.6. Uncertainties identified

- pattern of host distribution
- contribution of local human assisted spread not related to the movement of plant material

3.2.2. Elicited values for the spread rate

What is the spread rate in 1 year for an isolated focus within this scenario based on average European conditions? (units: m/year)

The five elicited values on spread rate on which the group agreed are reported in the table below.

Table 7: The 5 elicited values on spread rate (m/y)

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	100	2,000	5,000	7,000	17,000

3.2.2.1. Justification for the elicited values of the spread rate

Reasoning for a scenario which would lead to wide spread (99th percentile / upper limit)

The upper value takes into account the extreme situation where the strongest flyer moves mainly in one direction looking for a suitable host to lay eggs (stressed trees).

Reasoning for a scenario, which would lead to limited spread (1st percentile / lower limit)

The lower value of spread rate is justified by the conditions where the vector doesn't need to fly (suitable hosts are available close by).

Reasoning for a central scenario, equally likely to over- or underestimate the spread (50th percentile / median)

The median value of PWN spread is the combination of the medium flight capacity with a reduction factor due to the rarity of the nematode in the initial invasion phase.

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The precision is given by the fact that the vector's behavior is driven by the need to find trees for breeding, which can be easily available without long distance flights.

3.2.2.2. *Estimation of the uncertainty distribution for the spread rate*

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 8: Fitted values of the uncertainty distribution on the spread rate (m/y)

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	100					2,000		5,000		7,000					17,000
Fitted distribution	166	339	587	1,027	1,572	2,240	2,923	4,432	6,337	7,591	9,264	11,256	13,807	16,228	19,278

Fitted distribution: Weibull(1.2882,5891), @RISK7.5

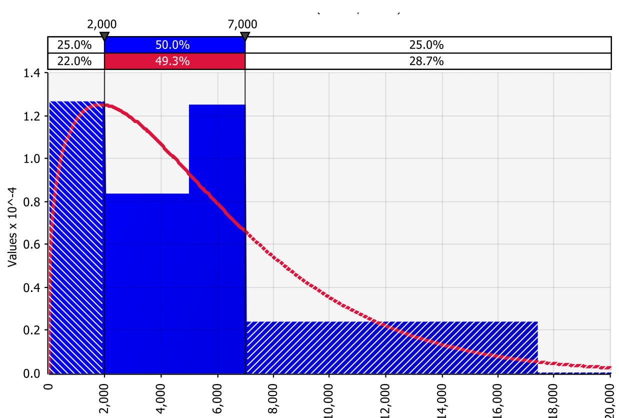

Figure 9 Comparison of judged values (histogram in blue) and fitted distribution (red line) for spread rate.

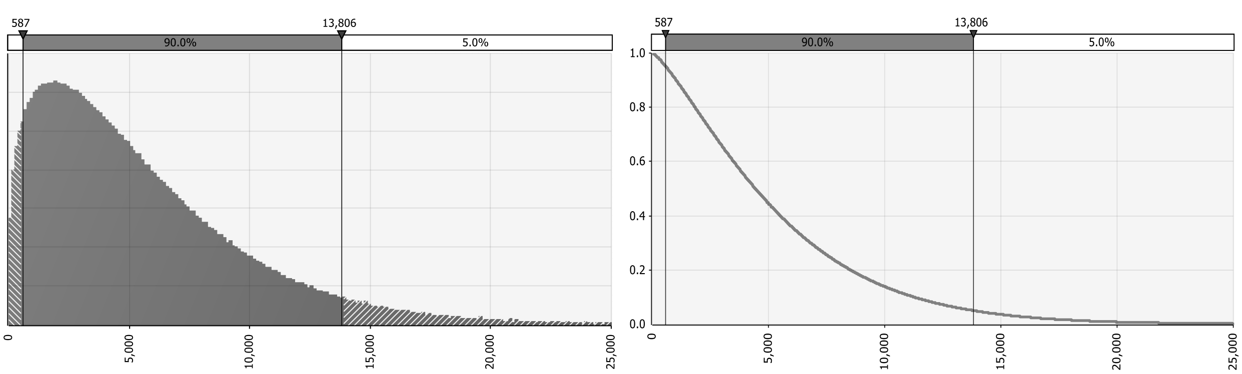

Figure 10 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for spread rate.

3.2.3. Conclusions on the spread rate

Based on the general and specific scenarios considered in this assessment, the maximum distance expected to be covered in one year by *B. xylophilus* is around 5000 m (with a 95% uncertainty range of 339 – 16,230 m).

3.3. Time to detection

3.3.1. Structured expert judgement

3.3.1.1. Generic scenario assumptions

All the generic scenario assumptions common to the assessments of all the priority pests are listed in the section 2.4.2.1 of the Methodology Report (EFSA, 2019).

3.3.1.2. Specific scenario assumptions

- The time for detection takes into account the different conditions of symptom expression in the Northern and Southern zones.

3.3.1.3. Selection of the parameter(s) estimated

The time for detection has been assessed as the number of months between the first event of pest transfer to a suitable host and its detection.

3.3.1.4. Defined question(s)

What is the time between the event of pest transfer to a suitable host and its first detection within this scenario based on average European conditions? (unit: months)

3.3.1.5. Evidence selected

The experts reviewed the evidence obtained from the literature (see Table B.3 in Appendix B) selecting the data and references used as the key evidence for the EKE on spread rate. A few general points were made:

- survey activity in EU specific to PWN is regularly conducted following official protocols
- pheromone traps for the vectors are available

3.3.1.6. Uncertainties identified

- survey protocols focus on breeding material
- inconsistency of application of EU protocols at national level
- pheromone traps and trap logs are not used in all the MSs as they are not specified in the EU protocol
- visual symptoms are not diagnostic although they increase the probability of detection

3.3.2. Elicited values for the time to detection

What is the time between the event of pest transfer to a suitable host and its first detection within this scenario based on average European conditions? (unit: months)

The five elicited values on time to detection on which the group agreed are reported in the table below.

Table 9: The 5 elicited values on time to detection (months)

Percentile	**1%**	**25%**	**50%**	**75%**	**99%**
Expert elicitation	10	84	120	170	240

3.3.2.1. Justification for the elicited values of the time to detection

Reasoning for a scenario which would lead to high time for detection (99th percentile / upper limit)

The upper value is the average of the worst cases in the Southern zone and in the Northern zone.

Reasoning for a scenario which would lead to short time for detection (1st percentile / lower limit)

Since the lower value of fast detection represents the average at EU level it includes conditions of symptom absence as in the Northern zone. The experience of PWN time to detection in Portugal and Spain has been taken into account.

Reasoning for a central scenario, equally likely to over- or underestimate the time for detection (50th percentile / median)

The median value is related to the efficiency of the currently applied detection practices. Detection methods are destructive and in many cases are not applicable (e.g. trees located in private gardens).

Reasoning for the precision of the judgement describing the remaining uncertainties (1st and 3rd quartile / interquartile range)

The precision is mainly driven by the difficulty of detection balanced by the regular survey activity conducted in the EU on PWN.

3.3.2.2. Estimation of the uncertainty distribution for the time to detection

The comparison between the fitted values of the uncertainty distribution and the values agreed by the group of experts is reported in the table below.

Table 10: Fitted values of the uncertainty distribution on the time to detection (months)

Percentile	1%	2.5%	5%	10%	17%	25%	33%	50%	67%	75%	83%	90%	95%	97.5%	99%
Expert elicitation	10					84		120		170					240
Fitted distribution	19	29	39	54	68	83	97	122	149	165	185	206	231	253	278

Fitted distribution: Weibull(2.2998,143.32), @RISK7.5

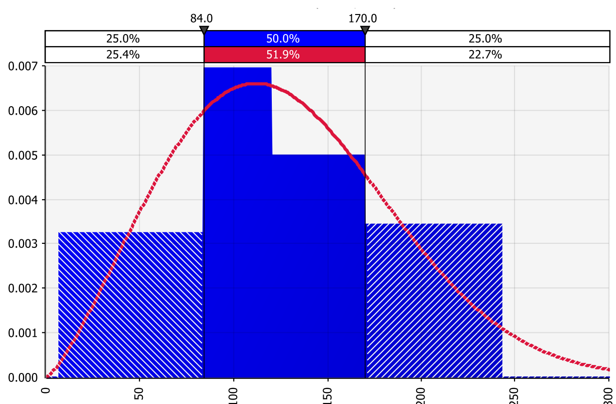

Figure 11 Comparison of judged values (histogram in blue) and fitted distribution (red line) for time to detection.

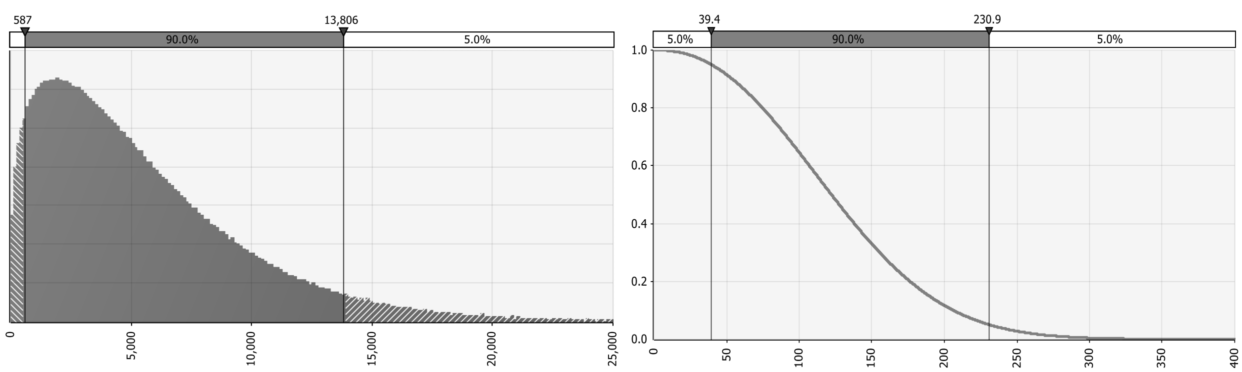

Figure 12 Fitted density function to describe the uncertainties with 90% uncertainty interval (left) and fitted descending distribution function showing the likelihood (y-axis) that a given proportion (x-axis) maybe exceeded (right) for time to detection.

3.3.3. Conclusions on the time to detection

Based on the general and specific scenarios considered in this assessment, the time between the event of pest transfer to a suitable host and its detection is estimated to be 120 months (with a 95% uncertainty range of 29 to 253 months).

4. Conclusions

Hosts selection

The hosts on which the impact is assessed are susceptible hosts that would be killed by the PWN. The assessment considers commercial plantations of the three main PWN hosts among the *Pinus* species in the EU (*P. pinaster, P. radiata, P. sylvestris*). The assessment of impact does not take into account the potential losses on other ornamental *Pinus* species.

Area of potential distribution

The area of potential distribution is based on the assumption that host plants are available throughout Europe and the availability of vectors does not represent a limiting factor for the area of potential establishment of PWN. Two zones were identified: a Northern zone where PWN infestations are not likely to cause plant death except under specific climatic circumstances and a Southern zone where PWN infestations are likely to cause plant death.

Expected change in the use of plant protection products

Due to the fact that no effective treatments with plant protection products (PPPs) are currently available to control this pathogen, the most suitable PPP indicator is Case “A” and the category is “0”.

Yield and quality losses

Based on the general and specific scenario considered in this assessment, the percentage yield losses based on percentage mortality is estimated to be:

- 25% (with a 95% uncertainty range of 6-55%) on *Pinus* plantations in the Southern zone
- 2% (with a 95% uncertainty range of 0.2-5%) on *Pinus* plantations in the Northern zone

Only yield losses based on percentage mortality have been assessed. Quality losses have not been assessed because infested trees or parts of trees will be only be used for low value products and will therefore count as total losses.

Spread rate

Based on the general and specific scenarios considered in this assessment, the maximum distance expected to be covered in one year by *B. xylophilus* is around 5000 m (with a 95% uncertainty range of 339 – 16,230 m).

Time for detection after entry

Based on the general and specific scenarios considered in this assessment, the time between the event of pest transfer to a suitable host and its detection is estimated to be 120 months (with a 95% uncertainty range of 29 to 253 months).

5. References

Akbulut S and Linit MJ, 1999. Flight performance of *Monochamus carolinensis* (Coleoptera: Cerambycidae) with respect to nematode phoresis and beetle characteristics. Environmental Entomology, 28, 1014-1020.

Akbulut S and Stamps WT, 2011. Insect vectors of the pinewood nematode: a review of the biology and ecology of *Monochamus* species. Forest Pathology, published online on 20 July 2011, 11pp.

Bergdahl DR and Halik S, 2003. Persistence of the pine wood nematode in asymptomatic Scots pines. Nematology Monographs and Perspectives, 1, 177–185.

Braasch H, 2000. Influence of temperature and water supply on mortality of 3-year-old pines inoculated with *Bursaphelenchus xylophilus* and *B. mucronatus*. Nachrichtenblatt des Deutschen Pflanzenschutzdienste, 52, 244-249.

Burgermeister W, Braasch H, Metge K, Gu J, Schroder T and Woldt E, 2009. ITS-RFLP analysis, an efficient tool for identification of *Bursaphelenchus* species. Nematology 11, 649–668.

CABI (Centre for Agriculture and Bioscience International), 2018a. Datasheet report for *Bursaphelenchus xylophilus* (pine wilt nematode). Crop Protection Compendium. Last modified 28 September 2018. Available online: https://www.cabi.org/cpc/datasheet/10448

CABI (Centre for Agriculture and Bioscience International), 2018b. Datasheet report for *Monochamus sutor* (small white-marmorated longicorn). Crop Protection Compendium. Last modified 27 September 2018. Available online: https://www.cabi.org/cpc/datasheet/34735

CABI (Centre for Agriculture and Bioscience International), 2018c. Datasheet report for *Monochamus galloprovincialis* (pine sawyer). Crop Protection Compendium. Last modified 16 November 2018. Available online: https://www.cabi.org/cpc/datasheet/34722

CABI (Centre for Agriculture and Bioscience International), 2018d. Datasheet report for *Monochamus saltuarius* (Japanese pine sawyer). Crop Protection Compendium. Last modified 16 November 2018. Available online: https://www.cabi.org/cpc/datasheet/34733

Campadelli G and Dindo ML, 1994. *Monochamus galloprovincialis* (Oliv.) (Coleoptera Cerambycidae) in S. Vitale pine forest. Informatore Fitopatologico, 44, 31-34.

Castagnone C, Abad P and Castagnone-Sereno P, 2005. Satellite DNA-based species specific identification of single individuals of the pinewood nematode *Bursaphelenchus xylophilus* (Nematoda: Aphelenchoididae). European Journal of Plant Pathology 112, 191– 193.

Cherepanov AI, 1983. Cerambycidae of Northern Asia. New Delhi, India: Oxonian Press PVT Ltd. [English translation, 1990.]

Cherepanov AI, 1990. Cerambycidae of northern Asia. Volume 3, Lamiinae, Part I. New Delhi, India: Amerind Publishing Company Pvt. Ltd. [English translation of Russian original.]

EFSA PLH Panel (EFSA Panel on Plant Health), 2012. Scientific Opinion on the phytosanitary risk associated with some coniferous species and genera for the spread of pine wood nematode. EFSA Journal 2012;10(1):2553. [87 pp.] doi:10.2903/j.efsa.2012.2553.

EFSA PLH Panel (EFSA Panel on Plant Health), 2013. Scientific Opinion on comments provided by Portugal on the phytosanitary risk associated with *Pinus pinea* for the spread of pine wood nematode. EFSA Journal 2013;11(4):3163, 37 pp. doi:10.2903/j.efsa.2013.3163.

EFSA (European Food Safety Authority), Baker R, Gilioli G, Behring C, Candiani D, Gogin A, Kaluski T, Kinkar M, Mosbach-Schulz O, Neri FM, Siligato R, Stancanelli G and Tramontini S, 2019. Scientific report on the methodology applied by EFSA to provide a quantitative assessment of pest-related criteria required to rank candidate priority pests as defined by Regulation (EU) 2016/2031. EFSA Journal 2019;17(5):5731, 64 pp. https://doi.org/10.2903/j.efsa.2019.5731

Enda N and Igarashi M, 1988. The development in relation to temperature of *Monochamus saltuarius* Gebler (Coleoptera, Cerambycidae) on artificial diets. Transactions of the 40th Annual Meeting of Kanto Branch of the Japanese Forestry Society, 181-182.

EPPO (European and Mediterranean Plant Protection Organization), online. EPPO Global Database. Available online: https://gd.eppo.int/ [Accessed: 17 May 2019]

EPPO (European and Mediterranean Plant Protection Organization), 2013. PM 7/4 (3) *Bursaphelenchus xylophilus*. Bulletin OEPP/EPPO Bulletin, 43, 105–118.

EPPO (European and Mediterranean Plant Protection Organization), 2014. PM 8/2 (2) Coniferae. Bulletin OEPP/EPPO Bulletin, 44, 403–440.

Etxebeste I, Sanchez-Husillos E, Alvarez G, Mas i Gisbert H and Pajares J, 2016. Dispersal of *Monochamus galloprovincialis* (Col.: Cerambycidae) as recorded by mark-release-recapture using pheromone traps. Journal of Applied Entomology, 140, 485–499.

Evans HF, 2007. Plant Health Risk And Monitoring Evaluation (PHRAME) final report. PHRAME final report and conclusions. Available online: https://www.forestresearch.gov.uk/research/plant-health-risk-and-monitoring-evaluation-phrame/phrame-final-report-and-conclusions/

Evans HF, Kulinich O, Magnusson C, Robinet C and Schroeder T, 2009. Report of a pest risk analysis for *Bursaphelenchus xylophilus*. EPPO (European and Mediterranean Plant Protection Organization). 17 pp. Available online: file:///C:/Users/pretist/Downloads/pra_rep_BURSXY.pdf

Evans HF, McNamara DG, Braash H, Chadoeuf J and Magnusson C, 1996. Pest Risk Analysis (PRA) for the territories of the European Union (as PRA area) on *Bursaphelenchus xylophilus* and its vectors in the genus Monochamus. Bulletin OEPP/EPPO Bulletin 26, 199-249.

Evans, H. 2015. REPHRAME Final report: Development of improved methods for detection, control and eradication of pine wood nematode in support of EU Plant Health policy. 57 pp. Available online: http://www.rephrame.eu/uploads/rephrame_final_report_summary.pdf [Accessed: 20/05/2019].

Francois C, Castagnone C, Boonham N, Tomlinson J, Lawson R, Hockland S, Quill J, Vieira P, Mota M and Castagnone-Sereno P, 2007. Satellite DNA as a target for TaqMan real-time PCR detection of the pinewood nematode, *Bursaphelenchus xylophilus*. Molecular Plant Pathology 8, 803–809.

Fujioka H, 1993. A report on the habitat of *Monochamus alternatus* Hope in Akita prefecture. Bulletin of the Akita Prefecture Forest Technology Center, 2, 40–56.

FVO (Food and Veterinary Office), 2001. Report of a mission carried out in Portugal from 8/10/2001 to 11/10 2001 in order to verify the implementation of Commission Decision 2001/218/EC and to assess the eradication programme for *Bursaphelenchus xylophilus*. Brussels, Health & Consumer Protection Directorate-General, DG(SANCO)/3404/2001-MR Final: 21 pp.

Gruffudd HR, Jenkins TAR and Evans HF, 2016. Using an evapo-transpiration model (ETpN) to predict the risk and expression of symptoms of pine wilt disease (PWD) across Europe. Biological Invasion, 18, 1–18. doi: 10.1007/s10530-016-1173-7.

Ido N and Kobayashi K, 1977. Dispersal of *Monochamus alternatus*. In: Studies on the control of pine wilt disease. Secretariat Agriculture, Forestry and Fisheries Research Council, Ministry of Agriculture, Forestry and Fisheries, Tokyo, 87-88. (In Japanese, cited in Togashi and Shigesada, 2006)

Jikumaru S and Togashi K, 1996. Effect of temperature on the post-diapause development of *Monochamus saltuarius* (Gebler) (Coleoptera: Cerambycidae). Applied Entomology and Zoology, 31, 145-148.

Jikumaru S, Togashi K, Taketsune A and Takahashi F, 1994. Oviposition biology of *Monochamus saltuarius* (Coleoptera: Cerambycidae) at a constant temperature. Applied Entomology and Zoology, 29, 555-561.

Kawabata K, 1979. Migration of the pine sawyer among small islands. Transactions of the 32nd Annual Meeting of Kyushu Branch of the Japanese Forestry Society, 281-282 (In Japanese).

Kishi Y, 1980. Mortality of pine trees by *Bursaphelenchus lignicolus* (Nematoda: Aphelenchoididae) in Ibaraki Prefecture and its control. Bulletin of Ibaraki Prefecture Forest Experiment Station, 11, 1-83.

Kishi Y, 1995. Pine Wood Nematode and the Japanese Pine Sawyer. Thomas Company Limited.

Kobayashi F, 1988. The Japanese Pine Sawyer. In: Berryman AA, ed. Dynamics of Forest Insect Populations. New York, USA: Plenum, 431-454.

Kobayashi F, Yamane A and Ikeda T, 1984. The Japanese pine sawyer beetle as a vector of pine wilt disease. Annual Review of Entomology, 29, 115–135.

Kuroda K, 2008. Physiological incidences related to symptom development and wilting mechanism. In: Zhao BG, Futai K, Sutherland JR and Takeuchi Y. (Eds.) Pine Wilt Disease. Springer. pp. 204-222.

Linit M and Akbulut S, 2003. Pine wood nematode phoresis: the impact on *Monochamus carolinensis* life functions. Nematology Monographs & Perspectives, 1, 227-237.

Malek RB and Appleby JE, 1984. Epidemiology of pine wilt in Illinois. Plant Disease 68, 180-186.

Mamiya Y and Kiyohara T, 1972. Description of *Bursaphelenchus lignicolus* n.sp. (Nematoda: Aphelenchoididae) from pine wood and histopathology of nematode-infested trees. Nematologica, 18, 120-124.

Mamiya Y, 1983. Pathology of pine wilt disease caused by *Bursaphelenchus xylophilus*. Annual Review of Phytopathology, 21, 201-220.

Mamiya Y, 1984. The Pine Wood Nematode. In: W.R.Nickle (ed.). Plant and Insect Nematodes. Marcel Dekker Inc, New York, USA. pp. 589-626.

Mamiya Y, 1988. History of pine wilt disease in Japan. Journal of Nematology, 20, 219-226.

Menéndez-Gutiérrez M, Alonso M, Jiménez E, Toval G, Mansilla P, Abelleira A, Abelleira-Sanmartín A and Díaz R, 2018. Interspecific variation of constitutive chemical compounds in *Pinus* spp. xylem and susceptibility to pinewood nematode (*Bursaphelenchus xylophilus*). European Journal of Plant Pathology, 150, 939–953.

Nakayama Y, Jikumaru S and Togashi K, 1998. Reproductive traits and diel activity of adult *Monochamus saltuarius* (Coleoptera: Cerambycidae) at two different temperatures. Journal of Forest Research, 3,61-65.

Naves PM, de Sousa EM and Quartau JA, 2006. Feeding and oviposition preferences of *Monochamus galloprovincialis* for certain conifers under laboratory conditions. Entomologia Experimentalis et Applicata, 120, 99–104.

Nickle WR, Golden AM, Mamiya Y and Wergin WP, 1981. On the taxonomy and morphology of the pine wood nematode, *Bursaphelenchus xylophilus* (Steiner & Buhrer 1934) Nickle 1970. Journal of Nematology, 13, 385-392.

Ogawa S and Hagiwara Y, 1980. Expansion of the pine infestation caused by pine wood nematodes. Shinrin Boeki, Forest Pests 29, 115-117.

Osada Y, Yamakita T, Shoda-Kagaya E, Liebhold AM and Yamanaka T, 2018. Disentangling the drivers of invasion spread in a vector-borne tree disease. Journal of Animal Ecology, 87, 1512-1524.

Polozhentzev PA, 1926. Forest Pests of the Buzuluk Forest in the Samara Government. Forester, 2.

Putz J, Vorwagner EM and Hoch G, 2016. Flight performance of *Monochamus sartor* and Monochamus sutor, potential vectors of the pine wood nematode. Forestry Journal, 62, 195–201.

REPHRAME, online. Pests, forests and climate change - latest research develops new ways of protecting Europe's woodlands. Available online: www.rephrame.eu [Accessed: 17/05/2019]

Robinet C, Roques A, Pan H, Fang G, Ye J, Zhang Y and Sun J, 2009. Role of Human-Mediated Dispersal in the Spread of the Pinewood Nematode in China. PLoS ONE, 4, e4646. doi:10.1371/journal.pone.0004646

Shibata E, 1986. Dispersal movement of the adult Japanese pine sawyer, *Monochamus alternatus* Hope (Coleoptera : Cerambycidae) in a young pine forest. Applied Entomology and Zoology, 21, 184-186.

Sokanovskii B, 1929. Notes on Forest Pests in the Government of Vladimir. Plant Protection, 6, 521- 526.

Takasu F, Yamamoto N, Kawasaki K, Togashi K, Kishi Y and Shigesada N, 2000. Modeling the expansion of an introduced tree disease. Biological Invasions, 2, 141–150.

Takizawa Y, 1983. Life history of *Monochamus saltuarius* Gebler. Transactions of the 35th Annual Meeting of Tohoku Branch of the Japanese Forestry Society, 145-146.

Togashi K and Shigesada N, 2006. Spread of the pinewood nematode vectored by the Japanese pine sawyer: modeling and analytical approaches. Population Ecology, 48, 271–283

Togashi K, 1990. A field experiment on dispersal of newly emerged adults of *Monochamus alternatus* (Coleoptera: Cerambycidae). Researches on Population Ecology, 32, 1–13.

Togashi K, 2008. Vector-Nematode Relationships and Epidemiology in Pine Wilt Disease. In: B.G. Zhao, K. Futai, J.R. Sutherland & Y. Takeuchi (Eds.), Pine Wilt Disease. pp. 162–183. Dordrecht, the Netherlands: Springer.

Togashi K, Jikumaru S, Taketsune A and Takahashi F, 1994. Termination of larval diapause in *Monochamus saltuarius* (Coleoptera: Cerambycidae) under natural conditions. Journal of the Japanese Forestry Society, 76, 30-34.

USDA (United States Department of Agriculture) Forest Service, 1991. Pest risk assessment of the importation of larch from Siberia and the Soviet Far East. Miscellaneous Publication No1495, pp. 263.

VKM (Vitenskapskomiteen for mat og miljø), 2008. Pest risk assessment of the Pine Wood Nematode (PWN) *Bursaphelenchus xylophilus* in Norway - Part 1. Opinion of the Panel on plant health of the Norwegian Scientific Committee for Food Safety.

Zhang J, Zhang R and Chen J, 2007. Species and their dispersal ability of *Monochamus* as vectors to transmit *Bursaphelenchus xylophilus*. Journal of Zhejiang Forestry College, 24, 350-356.

Appendix A – CABI/EPPO host list

The following list, defined in the Methodology Report (EFSA, 2019) as the full list of host plants, is compiled merging the information from the most recent PRAs, the CABI Crop Protection Compendium and the EPPO Global Database. Hosts from the CABI list classified as 'Unknown', as well as hosts from the EPPO list classified as 'Alternate', 'Artificial', or 'Incidental' have been excluded from the list.

Genus	**Species ephitet**
Abies	
Abies	*amabilis*
Abies	*balsamea*
Abies	*firma*
Abies	*grandis*
Abies	*sachalinensis*
Cedrus	
Cedrus	*atlantica*
Cedrus	*deodara*
Larix	
Larix	*decidua*
Larix	*kaempferi*
Larix	*laricina*
Larix	*occidentalis*
Picea	*abies*
Picea	*engelmannii*
Picea	*glauca*
Picea	*jezoensis*
Picea	*mariana*
Picea	*pungens*
Picea	*rubens*
Picea	*sitchensis*
Pinus	
Pinus	*armandii*
Pinus	*ayacahuite*
Pinus	*banksiana*
Pinus	*brutia*
Pinus	*bungeana*
Pinus	*caribaea*
Pinus	*contorta*
Pinus	*densiflora*
Pinus	*echinata*
Pinus	*elliottii*
Pinus	*halepensis*
Pinus	*hartwegii*
Pinus	*jeffreyi*
Pinus	*koraiensis*
Pinus	*lambertiana*
Pinus	*leiophylla*
Pinus	*luchuensis*
Pinus	*massoniana*

Pinus	*monticola*
Pinus	*mugo*
Pinus	*nigra*
Pinus	*oocarpa*
Pinus	*palustris*
Pinus	*pinaster*
Pinus	*pinea*
Pinus	*ponderosa*
Pinus	*pungens*
Pinus	*radiata*
Pinus	*resinosa*
Pinus	*strobiformis*
Pinus	*strobus*
Pinus	*sylvestris*
Pinus	*tabuliformis*
Pinus	*taeda*
Pinus	*thunbergii*
Pinus	*wallichiana*
Pinus	*yunnanensis*
Pseudotsuga	
Pseudotsuga	*menziesii*
Tsuga	
Xanthocyparis	*nootkatensis*

Appendix B – Evidence tables

B.1 Summary on the evidence supporting the elicitation of yield and quality losses

Susceptibility	**Infestation**	**Symptoms**	**Impact**	**Additional information**	**Reference**	**Uncertainties**
	Incidence	***Severity***	***Losses***			
			arrived in 1971, by 1979 it was present in the whole area. Mortality of affected pine trees from less than 1% (of dominant trees over 5 m high) to over 50%.	Ibaraki Prefecture, Japan	Kishi, 1980	
	tree mortality increases very slowly in stands with 1% or less mortality, but infection increased suddenly in those stands with 2-9% mortality.				Kobayashi, 1988	It is not clear whether the report refers to year mortality
			number of trees killed in 1 year is usually two to seven times those killed the previous year		Kobayashi, 1988, citing Ogawa and Hagiwara, 1980	The rate of increase of the disease is too high
			Annual loss of pine trees in Japan due to PWN (x1,000 m^3) 1942: 475 1946: 938 1948: 1246 1979, 2425 (the heaviest loss) 1980, 2140 1981: 2073 1985: 1279		Mamiya, 1988	% of losses not provided
	65% of 56,000 ha of pine forests affected by the disease		742,000 m^3 of timber (= 10% of the total volume of growing stock) lost in 1 year A forest without any control activities was destroyed within 4 years.	1978 Ibaraki prefecture, Japan	Mamiya, 1988	

			130,000 m^3 of pine trees (= 2% of the total volume of growing stock) lost from the late 1970s	1979 Tottori prefecture, Japan	Mamiya, 1988	
Pinus sylvestris			mortality 0 at 15 °C 70% at 20 °C, 70-100% at 25 °C and 30 °C	three-year-old plants inoculated with two variants of PWN (US 15 and US I 0)	Braasch, 2000	
			90% of infested trees will die in the Lisbon area, and are more likely to do so in the year following infestation. 40% of infested trees will die in the Bragança region and are more likely to do so in the year of infestation, depending on the timing of high transpiration and the flushing period of trees.	Simulated values of the likelihood of host mortality after inoculation of susceptible pine trees in Portugal	Evans, 2007	No recent information coming from real observations available to be compared with the simulation results

B.2 Summary on the evidence supporting the elicitation of the spread rate

Spread	**Additional information**	**Reference**	**Uncertainty**
2-15 km/year	Rate of PWD spread in Japan	Takasu et al, 2000; Togashi and Shigesada, 2006	Combination of beetle flight and human-assisted local movement of infested wood
From 2–3 km/year to 9–10 and 3–15 km/year	The rate of spread of PWD's range over pine stands determined in several areas by mapping the expanding population front of disease incidence over 9 years	Togashi, 2008	
7.5 km/year	Rate of PWD spread in China	Robinet et al,. 2009	Combination of beetle flight and human-assisted local movement of infested wood
111-339 km/year	strongly correlated with factors such as human population density and transport routes, national movement of untreated WPM, host wood and plants for planting	Robinet et al,. 2009	Modelling estimation based on human assisted dispersal for long distances
average 800m max 3.3 km	*Monochamus*	Kobayashi et al., 1984 citing	

		Kawabata, 1979.	
Normal radius < 2km Occasionally > 5km	Dispersal by contaminated adult beetles	Kobayashi, 1988	
3 km/flight season (May to end October)	*Monochamus vectors (M. galloprovincialis, M. sutor, M. sartor, M. urussovi, M. saltuarius and M. impluviatus)*	Evans et al., 2009	Conclusion based on reports
4.2 km/year from historical invasion records for PWD 1.82 km/year using mark–recapture experiments with sawyers		Takasu et al., 2000	
Max 2.4 km	*M. alternatus*	Ido and Kobayashi, 1977	75,5% of the beetles recaptured within 100 metre
3.3 km/flight across open sea	*M. alternatus*	Kawabata, 1979	
Max 100 metres	*M. alternatus*	Ogawa and Hagiwara, 1980	
10-50 m/flight	*M. alternatus*	Shibata, 1986	
Average 10–20 m per week Dispersal would range from 50 to 260 m	*M. alternatus* beetle	Togashi, 1990	Assuming an average field lifespan of 7 weeks
2 km/flight	*M. alternatus*	Fujioka, 1993	
1.8 km/experiment period in average	*M. alternatus*	Takasu et al., 2000	
10 km/ 115 minutes	female *M. carolinensis* beetles	Akbulut and Linit, 1999	
2.3 km/flight with a low nematode load (<10000): 2274 m with a high nematode load (>10000): 1484 m	*M. carolinensis* flight performance with the use of a flight mill	Linit and Akbulut, 2003	
Total distance flown over the adult lifespan: 15.6 km, on average, for males, and 16.3 km for females maximum flight distance 62.7 km (for a male) Half of the tested population covered total flight distances exceeding 11.4 km. The average speed was similar in males and females, at about 1.4 m/s or 5 km/h.	flight mill *M. galloprovincialis* no significant difference between sexes for 77% adults	Evans, 2015	

between 250–532 m and 2344–3495 m depending on the replicate and choice of model	*M. galloprovincialis* dispersal under continuous pine stands	Etxebeste et al., 2016	
Max 1,300 metres (laboratory tests) Max 800 metres (field observation)	*M. saltuarius*	Zhang et al.,2007	
The maximum distance flown by in a single flight: 3,136.7 m. Mean distances (per beetle) per flight: from 694.6 m in females to 872.5 m in males In 75% of all individual flights flew less than 1 km; only 3.7% flew distances longer than 2 km. The mean cumulative distance travelled throughout the lifespan: 7.5 km.	Flight mill tests *M. sartor*	Putz et al., 2016	
The maximum distance per flight: 5,556.5 m Mean distances from 1,653.6 m in females to 1178.3 m in males.	Flight mill tests The smaller *M. sutor* beetles flew faster and longer distances than *M sartor.*	Putz et al., 2016	
males travelled 810 ± 97 m and females 689 ± 82 m. flight speed of the large M. sartor was slower than for M. sutor Nevertheless, this species is also able to travel more than 500 m in an individual flight.	*M. sartor*	Evans, 2015	
males and females covered distances of 1272 ± 348 m and 2008 ± 510 m, respectively, in individual flight events.	*M. sutor* longer distances than *M sartor.*	Evans, 2015	
Estimated rate of spread of • nonzero sawyer abundance 3.14 km/year • high sawyer abundance 2.13 km/year • low PWD infection 2.57 km/year • high PWD 3.09 km/year average sawyer dispersal distance 6.609 km/year		Osada et al., 2018	

B.3 Summary on the evidence supporting the elicitation of the time to detection

Category of factors	case	Evidence	Additional information	Reference	Uncertainties
Detection methods	Visual symptoms	Needles wilting/ yellowing and reduced oleoresin exudation	Symptoms appear 3 weeks after infestation. Holes of 10-15 cm help to detect the reduction in oleoresin production	Evans et al., 1996; Mamiya, 1983; Malek and Appleby, 1984	The pest is capable of living saprophytically without evident symptoms
Detection methods	Visual symptoms	Death	Infested trees die 30-40 days after infestation	Evans et al., 1996	No method may distinguish with visual inspection between trees dying from PWD and those dying because of other reasons (e.g. wind/ fire damage)
Detection methods	PWN morphological identification	Extraction from wood or vectors		EPPO, 2013	Required: preparation of good quality microscope slides, access to a high-powered microscope and considerable experience in nematode taxonomy
Detection methods	ITS RFLP PCR	used for differentiating *B. xylophilus* from 44 other *Bursaphelenchus* species	used in the EPPO region	Burgermeister et al., 2009	
Detection methods	satellite DNA-based PCR technology	a species-specific test to identify *B. xylophilus*	used in the EPPO region	Castagnone et al., 2005	
Detection methods	real time PCR test	targeting satellite DNA; an adaptation of this method is utilised on wood extracts	used in the EPPO region	Francois et al., 2007	
Detection methods	LAMP			EPPO, 2013	
Biology of the pathogen	Pest life cycle	latency in disease expression in some cooler areas: nematode development and reproduction is highly dependent on temperature		Gruffudd et al., 2016	

Biology of the pathogen	Latency period	Under normal climatic conditions 10% of the deaths occurred in spring, 10% in summer, 50% in autumn and 30% in winter. When high temperatures occurred in the summer, most deaths occurred in the summer and autumn.	Ibaraki Prefecture, Japan	Kishi, 1980	
Biology of the pathogen	Latency period	In inoculated pines B. xylophilus persisted for 6 years and subsequently up to 13 years. Many plants appeared healthy. In some of them, the nematode survived for about 2 years following the death of the host tree.	Study on 20 year old Bx inoculated Scots pines Vermont, USA	Gruffudd et al., 2016	
Biology of the pathogen	Pest life cycle	*B. xylophilus* reproduces in 12 days (15°C)/ 6 days (20°C)/ 3 days (30°C).		Evans et al., 1996	
Biology of the pathogen	Pest life cycle	Eggs hatch in 26-32 hours at 25°C		Evans et al., 1996	
Biology of the pathogen	Pest life cycle	Temperature threshold for development is 9.5°C		Evans et al., 1996	
Biology of the pathogen	Pest dimension	Female length: 0.45-0.61 mm		Nickle et al., 1981	
Biology of the pathogen	Pest dimension			Nickle et al., 1981	
Biology of the pathogen	Pest dimension	length: Female 0.71- 1.01 mm Male 0.52-0.6 mm	Japan Measurements done on specimens in formalin	Mamiya and Kiyohara, 1972	
Biology of the pathogen	Transfer capacity	83 % of the individuals of the vector *M. galloprovincialis* were carrying larval instars of the PWN		EFSA, 2012	
Biology of the vectors	Vector life cycle	Eggs hatch in 4-12 days according to the temperature		Evans et al., 1996	
Biology of the vectors	Vector life cycle	Pupal stages last for up to 19 days, whereas 6-8 days may pass between eclosion and emergence		Evans et al., 1996	
Biology of the vectors	Vector life cycle	Complete development (ovoposition -> adult emergence) takes 8-12 weeks		Evans et al., 1996	

Biology of the vectors	Vector life cycle	10 days after emergence, the female is capable of depositing eggs		Evans et al., 1996	
Biology of the vectors	Vector life cycle	Maximum number of laid eggs/female: 40-215		Evans et al., 1996	
Biology of the vectors	Vector life cycle	Generations/year: 1 (in Europe)		Evans et al., 1996	It could be longer in northern/colder climates.
Biology of the vectors	Vector life cycle	Lifespan: up to 83 days		Evans et al., 1996	
Biology of the vectors	Vector dimension	Adults of *Monochamus* are 15-30 m long		Evans et al., 1996	
Biology of the vectors	Vector Reproduction	Oviposition: Highest number was laid on *P. sylvestris,* followed by *P. halepensis* and *P. pinaster*, then *P. radiata.* The lowest number of eggs was laid on *P. pinea* and *P. menziesii*, none were laid on *C. lusitanica.* Emergence rate**:** No difference was found between *P. halepensis*, *P. pinaster, P. radiata* and *P. sylvestris.* No adults emerged from *P. pinea* or *P. menziesii*.		EFSA, 2012; Naves et al., 2006	Naves *et al.* (2006) conclude that *P. pinea*, *P. menziesii* and *C. lusitanica* are not adequate hosts for *M. galloprovincialis* and that the breeding success in *P. pinaster* indicates that it is the most suitable host.
Biology of the vectors	Vector life cycle	<u>*M. saltuarius*</u> embryonic development: 7-8 days at 25°C	*M. saltuarius*	Takizawa, 1983	
Biology of the vectors	Vector life cycle	<u>*M. saltuarius*</u> emergence of post-diapause larvae: 243.9 day degrees and 10.1°C	*M. saltuarius*	Jikumaru and Togashi, 1996	
Biology of the vectors	Vector life cycle	<u>*M. saltuarius* lifespan</u>: 3-80 days (average of 47.8 days) under constant conditions of 25°C, 90-100% RH and a photoperiod of 12L-12D	*M. saltuarius*	Jikumaru et al., 1994	
Biology of the vectors	Vector life cycle	<u>*M. saltuarius*</u> pupal stage: 8/9 days at 23°C	*M. saltuarius*	Enda and Igarashi, 1988	
Biology of the vectors	Vector life cycle	<u>*M. saltuarius* sexual maturation</u> <u>Males</u>: 2-18 days at 20°C or 0-16 days at 25°C <u>Females</u>: 7-36 days at 20°C or 5-24 days at 25°C	*M. saltuarius*	Nakayama et al., 1998	
Biology of the vectors	Vector life cycle	<u>*M. saltuarius*</u> lifetime fecundity: 0-172 eggs (mean 69.7 eggs) under constant conditions	*M. saltuarius*	Jikumaru et al., 1994	

		of 25°C, 90-100% RH and a photoperiod of 12L-12D			
Biology of the vectors	Vector dimension	*M. saltuarius* eggs: white, almost parallel-sided. 3-3.5 mm long and 0.8-1.2 mm wide	*M. saltuarius*	Cherepanov, 1983	
Biology of the vectors	Vector dimension	*M. saltuarius* larva: cylindrical and elongate with an oval head and no legs. Length: 20-28 mm. Width: 3.5-4 mm	*M. saltuarius*	Togashi et al., 1994	
Biology of the vectors	Vector dimension	*M. saltuarius* pupa. Length: 14-20 mm. Width: 4.5-4.8 mm.	*M. saltuarius*	Cherepanov, 1983	
Biology of the vectors	Vector dimension	*M. saltuarius* adult. Length: 11-20 mm.	*M. saltuarius*	Cherepanov, 1983	
Biology of the vectors	Vector dimension	*M sutor* eggs. Length: 3.8 mm. Width: 0.8 mm.	*M. sutor*	Cherepanov, 1990	
Biology of the vectors	Vector dimension	*M sutor* larvae. Length: 35-40 mm. Width: 4.1-4.7 mm.	*M. sutor*	Cherepanov, 1990	
Biology of the vectors	Vector dimension	*M sutor* adults. Length: 15-26 mm.	*M. sutor*	Cherepanov, 1990	
Biology of the vectors	Vector Reproduction	*M sutor* females lay 50 eggs, in groups of 1-6 eggs	*M. sutor*	USDA Forest Service, 1991	
Biology of the vectors	Vector dimension	*M. galloprovincialis* eggs: white, 4 mm long and 1 mm wide	*M. galloprovincialis*	CABI, 2018c	
Biology of the vectors	Vector dimension	*M. galloprovincialis* adult: 12-26 mm long	*M. galloprovincialis*	CABI, 2018c	
Biology of the vectors	Vector Reproduction	*M galloprovincialis* females lay 11 to 24 eggs	*M. galloprovincialis*	CABI, 2018c	
Biology of the vectors	Vector life cycle	*M. galloprovincialis* larvae hatch in 7-15 days and live under the bark	*M. galloprovincialis*	CABI, 2018c	
Biology of the vectors	Vector life cycle	*M. galloprovincialis* larvae development takes 14-19 days	*M. galloprovincialis*	Campadelli and Dindo, 1994	
Biology of the vectors	Vector life cycle	*M. galloprovincialis* may take 6-8 days from eclosion (adults emerging from pupa) and reaching the surface of the host/exiting through the bark	*M. galloprovincialis*	CABI, 2018c	

Biology of the vectors	Vector life cycle	*M. galloprovincialis* females have a maturation-feeding period lasting up to 18 days	*M. galloprovincialis*	CABI, 2018c	
Biology of the vectors	Vector life cycle	*M. galloprovincialis* females can oviposit for 62 days after mating	*M. galloprovincialis*	Campadelli and Dindo, 1994	
Biology of the vectors	Vector life cycle	*M. galloprovincialis* male lifespan: 74 days	*M. galloprovincialis*	FVO, 2001	
Biology of the vectors	Vector life cycle	*M. galloprovincialis* female lifespan: 84 days	*M. galloprovincialis*	FVO, 2001	
Biology of the vectors	Vector life cycle	*M. galloprovincialis* years/generation: 1 (Southern Europe) 2 (Northern Europe)	*M. galloprovincialis*	CABI, 2018c	
Biology of the vectors	Flying behaviour	Mass adult flights can be seen from mid-May to mid-June, July or even up to September/October	*M. galloprovincialis*	Sokanovskii, 1929; Polozhentzev, 1926	Variation according to geographic distribution and environmental conditions
Biology of the vectors	Flying behaviour	Mortality first noticed to nearby trees, then gradually spreads from this centre. Most dead trees within 700 m but 1 at 2.5 km.	*M. alternatus*		
Host conditions during the period of potential detection	Host size	Scots pine trees harbouring populations of PWN remained asymptomatic for up to 11 years after inoculation		Bergdahl and Halik, 2003	