

Pest Risk Assessment for Dutch elm disease



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DESCRIPTION

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Abstract	<p>Dutch elm disease (DED) is a fungal disease that causes high mortality of elms. DED and its vector beetles are widely present in most of the countries in the Northern Hemisphere, but they are not known to be present in Finland.</p> <p>DED is a major risk to plant health in Finland. DED and its vectors are moderately likely to enter Finland by natural spread aided by hitchhiking, because they are present in areas close to Finland. Entry via other pathways is much less likely, mainly due to the low volume of trade of untreated wood and plants for planting. DED and its vectors could likely establish in the southern parts of the country, since they currently occur in similar climatic conditions in other countries. DED could cause massive environmental damage as natural elm groves are critically endangered habitats in Finland. The economic consequences to the owners of mature elms could also be significant.</p> <p>Eradication or containment of DED could be possible if strict measures were taken as the patchy distribution of elms would limit the spread of the disease.</p> <p>The most important source of uncertainty in this assessment is the lack of information regarding the amount of elm in fuel wood, wood waste and wood chips imported to Finland.</p>
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KUVAILULEHTI

Julkaisija	Elintarviketurvallisuusvirasto Evira
Julkaisun nimi	Hollanninjalavataudin riskinarvio
Tekijät	Salla Hannunen, Mariela Marinova-Todorova
Tiivistelmä	<p>Hollanninjalavatauti on vakava jalavien sienitauti. Tautia ja sitä levittäviä kaarnakuoriaisia esiintyy laajasti lähes kaikissa pohjoisen pallopuoliskon maissa. Suomessa niitä ei tiedetä esiintyvän.</p> <p>Hollanninjalavatauti on vakava uhka Suomen kasvinterveydelle. Tauti ja sen vektorit voivat levitä Suomeen luontaisesti tai liikenteen mukana melko todennäköisesti, koska niitä esiintyy Suomen lähialueilla. Leviäminen puutavaran tai taimien mukana on epätodennäköistä, koska käsittelemätöntä jalavan puutavaraa ja taimia ei juurikaan tuoda Suomeen. Tauti ja vektorit pystyisivät todennäköisesti asettumaan ainakin eteläisimpään Suomeen, sillä niitä esiintyy muualla vastaavassa ilmastossa. Taudilla voisi olla erittäin vakavia ympäristövaikutuksia, koska jalavalehdot ovat Suomessa äärimmäisen uhanalaisia. Tauti voisi myös aiheuttaa merkittäviä taloudellisia vahinkoja istutettujen jalavien omistajille.</p> <p>Taudin hävittäminen tai sen leviämisen rajoittaminen olisi useissa tilanteissa mahdollista, sillä jalavien harvalukuisuus ja populaatioiden eristyneisyys rajoittaisi taudin leviämistä Suomessa.</p> <p>Tärkein arvion epävarmuutta aiheuttava seikka on se, ettei jalavan yleisyydestä Suomeen tuotavassa polttopuussa, puujätteessä ja hakkeessa ole tietoa.</p>
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Författare	Salla Hannunen, Mariela Marinova-Todorova
Resumé	<p>Holländsk almsjuka är en farlig svampsjukdom hos almar. Sjukdomen och de barkborrar som sprider den förekommer i stor utsträckning på norra halvklotet, men det finns inga belägg för att de skulle förekomma i Finland.</p> <p>Holländsk almsjuka är ett allvarligt hot mot växthälsan i Finland. Eftersom sjukdomen och dess vektorer förekommer i Finlands närområden, kan de med rätt stor sannolikhet spridas till Finland naturligt eller med transportmedel. Spridning till Finland med trävaror eller plantor är osannolik, då importen av obehandlade almträvaror och almplantor är mycket liten. Sjukdomen och vektorerna skulle sannolikt kunna etablera sig åtminstone i sydligaste Finland, eftersom de förekommer under liknande klimatförhållanden på annat håll. Sjukdomen skulle kunna ha mycket allvarliga miljökonsekvenser eftersom almlundarna i Finland är ytterst hotade. De ekonomiska skadorna för ägare av planterade almar skulle också kunna bli betydande.</p> <p>I många fall kunde det vara möjligt att utrota eller begränsa sjukdomens spridning tack vare almarnas fåtalighet och populationernas isolering i Finland.</p> <p>Den största källan till osäkerhet i bedömningen är att uppgifter saknas gällande mängden alm i brännved, träavfall och träflis som importerats till Finland.</p>
Utgivningsdatum	Juli 2016
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PRA SCHEME

This PRA follows the Decision-support scheme for quarantine pests of the European and Mediterranean Plant Protection Organization (EPPO 2011). The questions for natural spread aided by hitchhiking (Section B, Pathway 3) have been slightly modified to better fit the assessed pathway. The likelihood of the factors affecting the risk is rated as very unlikely, unlikely, moderately likely, likely or very likely. Uncertainty of the assessments is rated as low, medium or high.

STAGE 1: INITIATION

1.01 - Give the reason for performing the PRA

This PRA has been performed because Dutch elm disease (DED) may pose a threat to Finland. DED is a serious pest in its present range. It is present in all other European countries, but it is not known to be present in the PRA area. However, in the current phytosanitary legislation there are no measures targeted at preventing the entry and establishment of the pest in the PRA area.

1.02a - Name of the pest

Ophiostoma ulmi (Buisman) Nannf.

Synonyms: *Ceratocystis ulmi* (Buisman) C.Moreau, *Ceratostomella ulmi* Buisman, *Graphium ulmi* M.B.Schwartz, *Pesotum ulmi* (Schwarz) Crane & Schoknecht

Common names: Dutch elm disease (English), hollanninjalavansurma (Finnish), hollanninjalavatauti (Finnish), non-aggressive subgroup

Ophiostoma novo-ulmi* subsp. *novo-ulmi Brasier & Kirk

Synonyms: *Ophiostoma novo-ulmi* Eurasian (EAN) race

Common names: Dutch elm disease (English), jalavansurma (Finnish), hollanninjalavatauti (Finnish), aggressive subgroup

Ophiostoma novo-ulmi* subsp. *americana Brasier & Kirk

Synonyms: *Ophiostoma novo-ulmi* North American (NAN) race

Common names: Dutch elm disease (English), hollanninjalavatauti (Finnish), aggressive subgroup

1.02b - Indicate the type of the pest

Fungus or fungus-like.

1.02d - Indicate the taxonomic position

Domain: Eukaryota

Kingdom: Fungi

Phylum: Ascomycota

Subphylum: Pezizomycotina

Class: Sordariomycetes

Subclass: Sordariomycetidae

Order: Ophiostomatales

Family: Ophiostomataceae

Genus: *Ophiostoma*

Species: *O. ulmi* (Buisman) Nannf. 1934 and *O. novo-ulmi* Brasier 1991

Subspecies: *O. novo-ulmi* subsp. *novo-ulmi* Brasier & Kirk and *O. novo-ulmi* subsp. *americana* Brasier & Kirk

1.03 - Clearly define the PRA area

The PRA area is Finland.

1.04 - Does a relevant earlier PRA exist?

There is no relevant earlier PRA available.

1.06 - Specify all host plant species. Indicate the ones which are present in the PRA area.

Host plants of *Ophiostoma ulmi* and *O. novo-ulmi* are species belonging to the genus *Ulmus* and *Zelkova carpinifolia*. The main host species are *Ulmus alata*, *U. americana*, *U. glabra*, *U. laevis*, *U. minor*, *U. procera*, *U. pumila*, *U. rubra*, *U. serotina*, *U. thomasii* and *Zelkova carpinifolia* (CABI 2015 a, b).

Of these *U. americana*, *U. glabra* (including 'Camperdownii', 'Exoniensis' and 'Pendula'), *U. 'Hollandica'*, *U. laevis* (f. *laevis* and f. *simplicidens*), *U. minor* ('Hoersholmiensis') and *U. pumila* are present in the PRA area. *U. glabra* and *U. laevis* occur naturally and as planted ornamental trees. The other species occur only as ornamental plants in urban areas and in private gardens (Hämet-Ahti et al. 1992; Lampinen & Lahti 2016).

U. americana, *U. glabra* and *U. laevis* are highly susceptible to DED (Stipes & Campana 1981; Webber 2000; Solla et al. 2005; Ghelardini & Santini 2009), *U. minor* has some resistance, and *U. pumila* is resistant to DED (Stipes & Campana 1981).

1.07 - Specify the pest distribution

Table 1. The distribution of *O. ulmi* and *O. novo-ulmi*.

	<i>Ophiostoma novo-ulmi</i>	<i>Ophiostoma ulmi</i>
ASIA		
Armenia	Brasier (1991)	Brasier (1991)
Azerbaijan	Brasier (1991)	Brasier (1991)
Georgia (Republic of)	Brasier (1991)	Brasier (1991)
India	-	Gibbs (1978)
Iran	Brasier & Kirk (2001)	Brasier & Kirk (2001)
Japan	Masuya et al. (2010)	Masuya et al. (2010)
Kazakhstan	Brasier & Kirk (2001)	-
Tajikistan	-	EPPO (2014)
Turkey	Brasier & Kirk (2001)	Brasier & Kirk (2001)
Uzbekistan	Brasier & Kirk (2001)	Gibbs (1978)
NORTH AMERICA		
Canada	Brasier & Kirk (2001)	Gibbs (1978), Temple et al. (2006)
USA	Brasier & Kirk (2001)	Brasier & Kirk (2001)
EUROPE		
Albania	Brasier & Kirk (2001)	-
Austria	Kirisits & Konrad (2004)	Kirisits & Konrad (2004)
Belarus	-	Brasier (1991)
Belgium	Brasier & Kirk (2001)	Gibbs (1978)
Bosnia-Herzegovina	Brasier & Kirk (2001)	-
Bulgaria	Stoyanov (2004)	Gibbs (1978)
Croatia	Brasier & Kirk (2001)	Brasier & Kirk (2001)
Czech Republic	Dvorac et al. (2007)	Dvorac et al. (2007)
Czechoslovakia (former)	Brasier (1991)	EPPO (2014)
Denmark	Brasier & Kirk (2001)	Gibbs (1978)
Estonia	-	EPPO (2014)
France	Brasier & Kirk (2010)	Gibbs (1978)
Germany	Brasier & Kirk (2001)	Gibbs (1978)
Greece	Brasier & Kirk (2001)	EPPO (1991)
Hungary	Brasier & Kirk (2001)	EPPO (1999)
Ireland	Brasier & Kirk (2001)	Brasier & Kirk (2001)
Italy	Brasier & Kirk (2001)	Brasier & Kirk (2001)
Latvia	-	EPPO (2013)
Lithuania	-	EPPO (2014)
Luxembourg	EPPO (2014)	EPPO (2014)
Macedonia	FRA (2010)	FRA (2010)
Moldova	Brasier & Kirk (2001)	Gibbs (1978)
Netherlands	Brasier & Kirk (2001)	Gibbs (1978)
Norway	Brasier & Kirk (2010)	Gibbs (1978)
Poland	Brasier & Kirk (2001)	Brasier & Kirk (2001)
Portugal	Brasier & Kirk (2001)	Brasier & Kirk (2001)
Romania	Brasier & Kirk (2001)	Brasier & Kirk (2001)

Russian Federation	Brasier & Kirk (2001)	Gibbs (1978)
San Marino	Brasier & Kirk (2001)	-
Serbia	Brasier & Kirk (2001)	Brasier & Kirk (2001)
Slovakia	Brasier & Kirk (2001)	-
Slovenia	Brasier & Kirk (2001)	Brasier (1991)
Spain	Brasier & Kirk (2001)	EPPO (2014)
Balearic Islands	Rotger & Casado (1996)	Rotger & Casado (1996)
Sweden	Brasier & Kirk (2010)	Gibbs (1978)
Switzerland	Gibbs (1978)	EPPO (2014)
UK	Brasier & Kirk (2001)	Gibbs (1978)
Ukraine	Brasier & Kirk (2010)	Gibbs (1978)
Yugoslavia (former)	Brasier (1991)	Brasier (1991)
OCEANIA		
New Zealand	EPPO (2000)	MPI Biosecurity New Zealand (2008)

It is possible that *O. novo-ulmi* has replaced *O. ulmi* in most of the current distribution area of DED (Brasier 1991, 1996, Brasier & Kirk 2010). Since the latest records for *O. novo-ulmi* date from 2013, it seems that the pathogen is still expanding its range.

STAGE 2: PEST RISK ASSESSMENT

Section A: Pest categorization

1.08 - Does the name you have given for the organism correspond to a single taxonomic entity which can be adequately distinguished from other entities of the same rank?

Yes. *O. ulmi*, *O. novo-ulmi* subsp. *novo-ulmi* and *O. novo-ulmi* subsp. *americana* are single taxonomic entities. Previously *O. novo-ulmi* was divided into two races, Eurasian (EAN) and North American (NAN), but based on their morphological, behavioral and molecular differences, Brasier & Kirk (2001) designated them as two subspecies, *O. novo-ulmi* subsp. *novo-ulmi* (former EAN) and *O. novo-ulmi* subsp. *americana* (former NAN). Detailed information on the differences between the three taxa is provided in Brasier (1991) and Brasier & Kirk (2001).

1.10 - Is the organism in its area of current distribution a known pest of plants or plant products?

Yes. DED has caused serious damage in the area of its current distribution where it is killing mature elm trees. There have been two DED pandemics, of which the first was caused by *Ophiostoma ulmi*. It started in Europe at the beginning of the 20th century and spread to North America. The second (current) pandemic started in the 1940s. It is caused by the more aggressive *O. novo-ulmi*, and it has killed millions of elms in the Northern Hemisphere (Gibbs 1978; Brasier 1990; Brasier 1991; Brasier 1996; Brasier & Buck 2001; Brasier & Kirk 2001; D'Arcy 2000; Webber 2000; Harwood et al. 2011; Potter et al. 2011).

1.12 - Does the pest occur in the PRA area?

The pathogens are not known to be present in the PRA area. However, their absence has not been confirmed by an official survey. *O. ulmi* was introduced into the PRA area in the 1960s, but it was successfully eradicated (Hintikka 1974).

Scolytus mali which is considered to be a potential vector for DED (Stipes & Campana 1981; Webber 2004) is present in the PRA area (Lekander et al. 1977; Voolma et al. 2004). No other vector species are known to be present in the PRA area. However, their absence has not been confirmed by an official survey.

1.14 - Does at least one host-plant species occur in the PRA area?

Yes. *U. americana*, *U. glabra* (including 'Camperdownii', 'Exoniensis' and 'Pendula'), *U. 'Hollandica'*, *U. laevis* (f. *laevis* and f. *simplicidens*), *U. minor* ('Hoersholmensis') and *U. pumila* are present in the PRA area (Hämet-Ahti et al. 1992). Two of the major host plants, *U. glabra* and *U. laevis* occur naturally in the PRA area (Lampinen & Lahti 2016), and they are also the most commonly planted *Ulmus* species in urban areas. The other host species grow only as ornamental plants in urban areas and private gardens. (See Appendix 1 for distribution maps of the most common *Ulmus* species in Finland.)

1.15a - Is transmission by a vector the only means by which the pest can spread naturally?

The pathogen is transported to new host plants mainly by its vectors, i.e. elm bark beetles from the genus *Scolytus* and *Hylurgopinus* (Stipes & Campana 1981). However, over short distances the pathogens can also spread naturally through root grafts (Stipes & Campana 1981). According to D'Arcy (2000) large elms growing within seven meters of each other have almost 100% chance of becoming infected through root grafts, but the likelihood is lower if the trees are at least thirteen meters apart. There is no evidence for dispersal by any other natural means, such as dispersal by wind. (See Appendix 2 for more information about the vector species.)

1.16 - Does the known area of current distribution of the pest include ecoclimatic conditions comparable with those of the PRA area or sufficiently similar for the pest to survive and thrive?

Yes. Heikkinen et al. (2012) compared the climatic conditions in Finland with those in the pathogens' current area of distribution in North America and Sweden and concluded that the climatic conditions in Finland are suitable for DED. Also based on the climatic classification of Köppen-Geiger the climate in some areas of the pest's current distribution is similar to the climate in the PRA area. This is true especially for Canada and the countries neighboring the PRA area, i.e. Estonia, Russia and Sweden. The northernmost occurrence of DED in Sweden is in the city Falun (60.6°N), which is roughly at the same latitude as Turku (60.4°N) in the PRA area.

The climatic conditions in parts of the PRA area are likely to be suitable also for the vectors of DED. In Sweden *S. laevis* is found as far north as the province of Dalarna,

and *S. triarmatus* and *S. multistriatus* occur up to the province of Uppland (Lindelöw 2015). In Russia *S. scolytus* and *S. multistriatus* have been found in Vyborg in 2014, only about 30 km from the PRA area (Stcherbakova & Mandelshtam 2014, Mandelshtam 2015).

1.17 - With specific reference to the plants which occur in the PRA area, and the damage or loss caused by the pest in its area of current distribution, could the pest cause significant damage or loss to plants or other negative economic impacts (on the environment, on society, on export markets) through the effect on plant health in the PRA area?

Yes. DED has caused significant damage in its area of current distribution (Gibbs 1978; Gibbs et al. 1994; Brasier 1996; Allen & Humble 2002; Kirisits & Konrad 2004; González-Ruiz et al. 2006; Harwood et al. 2011). Hence, it is possible that DED could cause significant damage in the PRA area to naturally occurring *Ulmus* trees, nursery production and elms planted as ornamentals in urban areas and private gardens.

1.18 - Conclusions of the pest categorization

DED could present a phytosanitary risk to the PRA area because:

- DED has caused serious damage in its current area of distribution where it is killing mature elm trees.
- Susceptible host species are present in the PRA area.
- The ecoclimatic conditions in some areas of the pest's current distribution are similar to those in the PRA area.
- DED is established in most countries in the Northern Hemisphere and it continues to spread and cause losses of susceptible *Ulmus* trees.
- Some of the vectors of DED are present in the countries neighboring the PRA area.
- *O. ulmi* was introduced into the PRA area in the 1960s, although it was eradicated soon after.
- In the current phytosanitary legislation there are no measures targeted at preventing the entry and establishment of DED in the PRA area.

Section B: Probability of entry of a pest

2.01a - Describe the relevant pathways and make a note of any obvious pathways that are impossible and record the reasons

Possible pathways

1. Wood and wood packaging material (WPM) of *Ulmus* spp. originating from where DED occurs
2. Plants for planting of *Ulmus* spp. originating from where DED occurs
3. Natural spread aided by hitchhiking on vehicles

Pathways considered very unlikely and not considered further

1. Cut branches of *Ulmus* spp. originating from where DED occurs
Cut branches of *Ulmus* spp. are not traded.
2. Isolated bark of *Ulmus* spp. originating from where DED occurs
Isolated bark is not traded.
3. Soil and other growing media originating from where DED occurs
The pathogens causing DED may be present in soil in remnants of diseased roots. It is unlikely that such soil would be traded as growing medium.

2.01b - List the relevant pathways that will be considered for entry and/or management

- Wood and wood packaging material (WPM) of *Ulmus* spp. originating from where DED occurs
- Plants for planting of *Ulmus* spp. originating from where DED occurs
- Natural spread aided by hitchhiking on vehicles

Pathway 1: Wood and wood packaging material (WPM) of *Ulmus* spp. originating from where DED occurs

2.03 - How likely is the pest to be associated with the pathway at the points of origin taking into account the biology of the pest?

The pathogens

O. ulmi and *O. novo-ulmi* can be present in the wood of 1) living trees that have been infected via maturation feeding of the vectors or by root grafts from nearby trees, 2) dead or weakened trees that have been infected via breeding of the vectors, and 3) logs that have been infected via breeding of the vectors (Stipes & Campana 1981).

In susceptible trees that have been infected via feeding of the vectors or through root grafts, the pathogens are present in the sapwood (Stipes & Campana 1981; Webber & Brasier 1984). Therefore, the pathogens can be present in wood and WPM, with and without bark obtained from such trees.

In resistant trees that have been infected via feeding of the vectors or through root grafts, the pathogens are likely to be restricted close to the area of the original infection (Stipes & Campana 1981; Dickison 2000; Gheraldini & Santini 2009). Since the vectors prefer to feed on twigs in the upper periphery of the crown (Webber & Brasier 1984) the pathogens are unlikely to be present in round or sawn wood or in WPM obtained from such trees.

In trees and in logs that have been infected via breeding of the vectors, the pathogens are present in the vectors' breeding galleries in the bark and outer sapwood (Webber & Brasier 1984; Webber 2000). The pathogens can be present in wood and WPM, with and without bark obtained from such trees.

Logs are likely to get infected by the pathogens because the vectors are attracted to fresh logs for breeding (Stipes & Campana 1981). Both susceptible and resistant trees may become infected after cutting (Stipes & Campana 1981).

The vectors

The vectors of DED breed in dead and severely weakened trees and in logs. The adult females lay eggs in or under the bark where the larvae and pupae develop (Rudinsky 1962; Webber 1990; Webber 2000). Consequently, all life stages can be present in wood and WPM with bark. Some *Scolytus* larvae bore their pupal chambers in outer sapwood (Webber & Brasier 1984, Webber 1990) and therefore pupae may be present also in wood and WPM without bark. Vectors are very unlikely to be present in wood obtained from healthy trees since they use such trees only for maturation feeding (Stipes & Campana 1981). Such trees may, however, be colonized by the vectors after logging.

Use of infected wood

Healthy wood that has been infected after logging is a likely source of infected wood since such wood does not show symptoms of DED, e.g. internal vascular browning (Stipes & Campana 1981). Symptomatic wood is not likely to be used for round or sawn wood because the quality of such wood is poor. Wood showing symptoms may, however, be used for fuel wood. WPM is usually prepared from low grade wood (Allen & Humble 2002), and therefore wood infected by the pathogens and the vectors may be used for WPM.

Infected trees that don't show clear symptoms of DED may be used for wood or WPM. Yet, it is not clear how likely a source of infected material such trees are. This is because symptoms tend to develop very quickly, within weeks, if the pathogen spreads throughout the tree (Moreau 1982; Phillips & Burdekin 1985). On the other hand, if the infection is localized close to the original site of the infection the pathogens are not likely to be present in wood.

Prevalence of the pathogen

DED is widely distributed in most of the countries in the Northern Hemisphere (Gibbs 1978; Brasier 1991; Brasier 2000; Brasier & Buck 2001; Brasier & Kirk 2001). Due to the devastating effect of the disease mature susceptible elm trees that could be used for wood and WPM are rare in the areas where DED is present (Brasier & Buck 2001; Kirisits & Konrad 2004; Collin & Bozzano 2015). Still, the disease persists and is able to cause epidemics once the elm population has recovered (Birch et al. 1981). And more importantly, as long as the disease is present, resistant trees can be infected after logging.

Conclusions

The pathogens can be present in wood and WPM, with and without bark. The vectors can be present in wood and WPM with bark, but only pupae can be present in material without bark. Logs infected after cutting are a likely source of wood and WPM infested with the pathogens and the vectors. In areas where DED is present, even logs from resistant trees may become infected with the pathogens and the vectors after the trees have been cut. WPM is usually prepared from low grade wood and therefore wood infected by the pathogens and the vectors may be used for WPM.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Likelihood	Uncertainty	Likelihood	Uncertainty
Wood with bark	very likely	low	very likely	low
Wood without bark	very likely	low	very unlikely	low
WPM	very likely	low	likely	low

2.04 - How likely is the pest to be associated with the pathway at the points of origin taking into account *current management conditions*?

Removal of dead trees and branches

In urban areas DED is managed by removing diseased trees and branches. If such methods were applied in forestry they might have some impact on the vector populations and on the prevalence of DED. However, it is unlikely that such methods could be applied effectively on a forestry scale.

Use of resistant elm trees

In resistant trees the pathogens are likely to be restricted close to the area of the original infection in the upper periphery of the crown (Stipes & Campana 1981). Hence, the pathogens are unlikely to be present in wood obtained from such trees. However, wood from resistant trees may be infected after logging, by vectors which are attracted to logs for breeding (Stipes & Campana 1981).

DED can be managed by using resistant elm trees, but we do not know how common this is in forestry. If resistant trees are used, it will decrease the prevalence of DED. It will also decrease the density of the vector populations since there are less dead elms available for breeding sites. However, use of resistant varieties is not likely to eliminate the pathogen or the vector population since trees that have died from other reasons can act as reservoirs for the pathogens and the vectors. Also, logs left in the forest may sustain the vector and pathogen populations.

Debarking

Debarking does not eliminate the pathogens since they are also present in the sapwood (Stipes & Campana 1981; Webber & Brasier 1984). Debarking eliminates most of the vectors, but not all since 1) debarked wood may have large enough remnants of bark to support the vectors (which are only 0.6–7 mm long, depending on the species and life stage), and 2) some vectors bore their pupal chambers also into the outer sapwood (Webber & Brasier 1984; Webber 1990).

Chipping

Chipping has no effect on the likelihood of the pathogens being associated with wood. Chipping eliminates some vectors, but not all since eggs, larvae and pupae are small enough (0.6–7 mm long depending on the life stage and species) to survive the chipping process. This is because chips may be rather large, more than ten centimeters in one direction and 1–4 cm in the other directions (McCullough et al. 2007). Consequently, vectors may be present in wood chips with bark. If the chips are produced from debarked wood or from wood without bark, vectors are much less likely to be associated with the product.

Kiln drying

Prior to kiln drying, elm wood is air-dried until its moisture content is about 20–25%. According to Suninen (2015) who is an expert on the hard wood import industry, this takes a couple of months for 26 mm thick sawn wood, whereas for thicker lumber longer times are needed. After that the wood is dried in a kiln for two to three weeks at an increasing temperature. The recommended kiln drying schedules for elms are such that the dry-bulb air temperature during the second-to last stage of the process is 50, 60, 65.5 or 71 °C, and during the last stage 60, 71 or 82 °C, depending on the elm species and thickness of the wood (Boone et al. 1988). The lowest temperature schedules are the British standard schedules for *U. glabra*, *U. hollandica* and *U. procera*.

Temperatures over 61 °C for more than 30 minutes have been shown to be lethal to *O. ulmi* and *O. novo-ulmi* (Ramsfield et al. 2010). Therefore most kiln drying schedules are very likely to eliminate the pathogens although the temperatures inside the wood are somewhat lower than the air temperature in the kiln. Also the British standard schedules for the European elm species may eliminate the pathogens since the last two stages of the process are likely to take much longer than 30 minutes. All the kiln drying schedules are likely to eliminate the vectors since even short periods at 50–55 °C are lethal to bark beetle larvae (Rudinsky 1962).

ISPM 15

The international standard on phytosanitary measures regulating WPM in international trade, i.e. ISPM 15 (IPPC 2013) requires that WPM has to be manufactured from debarked wood that has been heat treated or fumigated with methyl bromide. The ISPM 15 requirements apply only to WPM entering the PRA area from non-EU countries, not to WPM moving in intra-EU trade.

Debarking must be done so that the remaining pieces of bark are a) less than 3 cm in width (regardless of the length) or b) greater than 3 cm in width, with the total surface area of an individual piece less than 50 cm². Heat treatment must be such that a minimum temperature of 56 °C is achieved throughout the wood for at least 30 minutes. Methyl bromide fumigation must be done according to specific requirements laid down in the standard.

Debarking according to the ISPM 15 requirements does not eliminate the pathogens since they are present also in the sapwood (Stipes & Campana 1981; Webber & Brasier 1984). Debarking eliminates most vectors, but not all since 1) WPM may have large enough remnants of bark to support the vectors (which are only 0.6–7 mm long, depending on the species and life stage), and 2) some vectors also bore their pupal chambers into the outer sapwood (Webber & Brasier 1984; Webber 1990).

Heat treatment performed according to the ISPM 15 requirements (56 °C for 30 min) has been shown not to be completely effective against *O. novo-ulmi* although it seems to eliminate the pathogens in most cases (Ramsfield et al. 2010). The heat treatment is likely to eliminate the vectors since even short periods of 50–55 °C are lethal to bark beetle larvae (Rudinsky 1962). However, some Scolytidae species have been found to be able to infest and develop in heat treated logs and boards that have residual bark (Haack & Petrice 2009).

Methyl bromide fumigation (32 and 33 g/m³ for 48 hours) has been shown to kill most of the pathogens and their vectors, but not to eliminate them completely (Berisford et al. 1980; Hanula & Berisford 1982). We were not able to judge, if the conditions in these experiments fall below or exceed the ISPM 15 requirements since details, such as temperatures during the experiments, are not given in the publications.

Conclusions

Debarking has no effect on the pathogens, but it will decrease the vectors' likelihood of being present in wood or WPM. Similarly, chipping has no effect on the pathogens, but it will decrease the vectors' likelihood of being present in the wood. Most kiln drying schedules are very likely to eliminate both the pathogens and the vectors. However, it is somewhat uncertain if the British standard kiln drying schedules for the European elm species will eliminate the pathogens. The ISPM 15 requirements eliminate most of the pathogens, but they are not 100% effective. The requirements are likely to be effective against the vectors, but WPM with bark may be colonized after it has been heat treated. (The ISPM 15 requirements do not apply to intra-EU trade, and violations of the ISPM 15 standard are possible.)

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Likelihood	Uncertainty	Likelihood	Uncertainty
Debarked wood	very likely	low	unlikely	low
Chipped wood with bark	very likely	low	likely	low
Kiln dried wood	very unlikely	medium	very unlikely	low
WPM treated according to ISPM 15 requirements	unlikely	low	unlikely	low

2.05 - Consider the volume of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this volume will support entry?

There are no statistics available on the movement of elm wood or WPM into Finland, and therefore the assessment has to be based on expert knowledge and deduction from the trade statistics of other tree species.

Wood in the rough

There are no statistics available on the trade of elm wood in the rough into Finland. In the combined customs nomenclature elm is reported on the same code with several other non-coniferous plant species (CN code 44039995). The amount of trade of this group into Finland in 2010–2014 was about 300 000–460 000 m³ annually (Finnish Customs 2015). However, only a very small proportion, if any, of this is likely to be elm (Suninen 2015).

If there was trade of elm wood in the rough to Finland, its volume would very likely be much less than that of oak wood in the rough (Suninen 2015). The amount of oak wood in the rough (CN code 440391) traded to Finland in 2010–2014 was about 0–130 000 kg annually (Finnish Customs 2015). At the maximum this is equal to about 171 m³ (assuming wood density of 760 kg/m³), and hence it could fit into

about five standard 20' containers. This amount would be enough to enable the entry of the pathogens and the vectors, yet it would not make entry likely.

Individual elm logs could sometimes end up in consignments of birch imported to Finland, yet this is considered very unlikely as the consignments originate from areas and biotypes where elm is not present or is very rare (Kivelä 2016; Lyykorpi 2016).

Fuel wood and wood waste

The amount of fuel wood (CN code 44011000) traded to Finland during the years 2010–2014 was about 21 000–95 000 tons annually (Finnish Customs 2015). Most of it came from Russia (43–59%) and Latvia (22–53%). The amount of not agglomerated wood waste, excluding sawdust (CN code 44013980), traded to Finland in 2010–2014 was about 178 000–193 000 tons annually (Finnish Customs 2015), and that of sawdust (CN code 44013930) was about 77 000–94 000 tons annually (Finnish Customs 2015). Most of both wood waste (80–96%) and saw dust (93–99%) was imported from Russia.

Although elm can be used for firewood probably only a very small proportion of the fuel wood traded to Finland is elm. This is because elm is not one of the common tree species in the areas from where fuel wood is traded to Finland. This is true also for wood waste. However, since DED is currently spreading in Russia, in areas close to Finland (Serebriiskiy 2014), it may become increasingly likely that elms infected by DED and its vectors end up also in fuel wood and wood waste consignments exported to Finland.

Private persons may transport elm fire wood to Finland from areas where DED and its vectors are present. For example, persons who live in Finland and have summer houses in Sweden or Estonia could bring infected wood to Finland. In the USA campers are known to move significant amounts of firewood between different states (Jacobi et al. 2011). However, there is no information about the frequency of such activity in the Nordic-Baltic area.

Wood chips

The amount of deciduous wood chips (CN code 44012200) traded to Finland in 2010–2014 was about 279 000–495 000 tons annually (Finnish Customs 2015). Most of it (61–99%) was imported from Russia, and most of it is birch intended to be used for pulp production (Islander 2015).

Wood chips for energy production may contain elm, but only a small proportion of the chips is likely to be elm wood. However, since DED is currently spreading in Russia, in areas close to Finland (Serebriiskiy 2014), it may become increasingly likely that elms infected by DED and its vectors end up in wood chip consignments imported for energy production.

Sawn wood

According to Suninen (2015), elm wood is traded to Finland only as kiln dried sawn wood, and the volume of import is very low, only about 1–3% of that of oak sawn wood. The volume of oak sawn wood (CN code 440791) traded to Finland varied between 5 420–10 266 m³ in 2010–2014 (Finnish Customs 2015), which means that

the volume of the elm trade would be about 160–310 m³ per year. This amount would fit into 4–9 standard 20' containers. If the pathogens or the vectors could be present in kiln dried sawn wood, the amount of trade would enable entry, but it would not make it likely.

WPM

The amount of the WPM entering Finland has been estimated to be at least 131 million kg annually (Hannunen et al. 2014). However, only a small proportion of this is likely to be elm wood since good quality elm wood is valuable, and it is unlikely to be used as WPM. However, symptomatic, low quality elm wood may be used as WPM. Consequently, some elm WPM may enter Finland annually, but the amount is expected to be so low that it is unlikely to support the entry of the pathogens or the vectors.

Conclusions

The amount of elm wood and WPM entering Finland is expected to be very low. Although there are no statistics about the elm wood trade to Finland the uncertainty of the assessment is considered low for wood in the rough and sawn wood, since expert knowledge supports the assessment. For fuel wood, the uncertainty is rated high because there is no information about the volume of firewood transported by private persons. For wood waste and wood chips the uncertainty is rated medium because DED is currently spreading in Russia in areas close to Finland. For WPM the uncertainty is considered medium because it is not known how commonly infected wood is used for WPM in the EU.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Likelihood	Uncertainty	Likelihood	Uncertainty
Wood in the rough	very unlikely	low	very unlikely	low
Fuel wood	unlikely	high	unlikely	high
Wood waste and wood chips	very unlikely	medium	very unlikely	medium
Sawn wood	very unlikely	low	very unlikely	low
WPM	very unlikely	medium	very unlikely	medium

2.06 - Consider the frequency of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this frequency will support entry?

Movement of consignments, which may contain elm wood, to Finland may be regular. For example fuel wood, wood waste, non-coniferous wood chips, and wood in the rough, of the group in which elm wood is reported in the combined customs nomenclature, are traded to Finland throughout the year (Finnish Customs 2015). However, since the amount of elm wood and WPM entering Finland is expected to be very low (See point 2.05) the frequency of movement is expected to be very low.

Although there are no statistics about the elm wood trade to Finland or about the movement of elm WPM the uncertainty of the assessment is considered low for wood in the rough and sawn wood since expert knowledge supports the assessment.

For fuel wood, the uncertainty is rated high because there is no information about the volume of firewood transported by private persons. For wood waste and wood chips the uncertainty is rated medium because DED is currently spreading in Russia, in areas close to Finland, which may increase the likelihood of infected wood ending up in the consignments. For WPM the uncertainty is considered medium because it is not known how commonly infected wood is used for WPM in the EU.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Likelihood	Uncertainty	Likelihood	Uncertainty
Wood in the rough	very unlikely	low	very unlikely	low
Fuel wood	unlikely	high	unlikely	high
Wood waste and wood chips	very unlikely	medium	very unlikely	medium
Sawn wood	very unlikely	low	very unlikely	low
WPM	very unlikely	medium	very unlikely	medium

2.07 - How likely is the pest to survive during transport or storage?

Conditions during transport and storage

Wood normally needs to be transported and stored in temperature and humidity conditions which keep its moisture content relatively stable. Hence, conditions during transport and storage of wood are not likely to adversely affect the survival of the pathogens or the vectors. The temperature and humidity conditions during transport and storage of WPM accompanying different kinds of consignments depend on the requirement for the consignments. Even if these conditions are not always optimal for the pathogens and the vectors, in most cases they are not likely to adversely affect the survival of the pathogens or the vectors.

Wood with bark

Since the pathogens live in the bark or in the sapwood (Webber & Brasier 1984), and the vectors' eggs, larvae and pupae live in and under the bark (Rudinsky 1962; Stipes & Campana 1981; Webber & Brasier 1984) the conditions in wood with bark are likely to favor their survival during transport and storage. This is supported by the fact that colonized cut trees are known to act as reservoirs of the pathogens (Stipes & Campana 1981). Also, the pathogens are believed to have been introduced from Europe to North America and vice versa in untreated timbers (Gibbs 1978).

Wood without bark

The pathogens are likely to survive during transport and storage in wood without bark since the pathogens are present in the sapwood of trees that have been infected via maturation feeding of the vectors (Webber & Brasier 1984). The vectors are very unlikely to survive the transport and storage in wood without bark since lack of protection would expose them to desiccation. Nevertheless, they could survive the transport and storage in debarked wood that has large enough remnants of bark. Eggs and larvae are likely to need large remnants to complete their development since the length of the larval galleries of *S. scolytus* and *S. multistriatus* is about 12–73 mm (EPPO 1983). However, even small remnants of bark could enable the survival

and development of pupae which are less than 10 mm long. (We did not find information about the length of the pupae but according to EPPO (1983) fully developed larvae are about 3.5–7 mm long.)

Wood chips

The pathogens are likely to survive in wood chips during transport and storage since the environmental conditions are similar to those in round wood, at least in parts of the consignments. Vectors can survive only in wood chips with bark. In addition, the vectors' probability of survival is determined by the size of the chips. At least a part of the chips are likely to be large enough for the vectors to complete their development since the chips are frequently more than ten centimeters in one direction and 1–4 cm in the other directions (McCullough et al. 2007). Survival is less likely for eggs and larvae since the larval galleries of *S. scolytus* and *S. multistriatus* are 12–73 cm long (EPPO 1983). Pupae may survive even in small chips since they are less than 10 mm long.

WPM

The pathogens are likely to survive in WPM during transport and storage even if the WPM does not have bark since in trees that have been infected via maturation feeding of the vectors, the pathogens are present in the sapwood (Webber & Brasier 1984). The vectors may survive in WPM that has large enough remnants of bark. Eggs and larvae are likely to need large remnants to complete their development since the length of the larval galleries of *S. scolytus* and *S. multistriatus* is about 12–73 mm (EPPO 1983). However, even small remnants of bark could enable the survival and development of pupae which are less than 10 mm long. The debarking requirement of the ISPM 15 decreases the vectors' probability of survival since only relatively small pieces of bark are allowed to be present (IPPC 2013).

Conclusions

The pathogens can survive transport and storage both in wood with and wood without bark, in wood chips, and in WPM. The vectors can survive in wood with bark and, to a lesser extent, in debarked wood and WPM, but not in wood without bark. In wood chips the vectors can survive only if the chips are made of wood with bark and if the chips are large enough.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Likelihood	Uncertainty	Likelihood	Uncertainty
Wood with bark	very likely	low	very likely	low
Wood without bark	very likely	low	very unlikely	low
Debarked wood	very likely	low	moderately likely	low
Wood chips with bark	very likely	low	moderately likely	low
WPM	very likely	low	moderately likely	low

2.08 - How likely is the pest to multiply/increase in prevalence during transport or storage?

The optimum growth temperature is 20–22 °C for *O. novo-ulmi* and 27–33 °C for *O. ulmi*, and the maximum temperatures for growth are 32–33 °C for *O. novo-ulmi* and 35 °C for *O. ulmi* (Brasier 1991). Yet, the pathogens can multiply in the host plant in a variety of temperatures as it sporulates heavily during most of the period of larval development (Webber & Brassier 1984). Therefore the conditions during transport and storage are likely to be suitable for the pathogens to multiply within the host plants.

To increase in prevalence during transport and storage the pathogens need a vector to transport them to new logs. In principle this may be possible since in nature adult beetles emerge when the air temperature is about 17.5 °C and start to fly when the temperature reaches 20 °C (Fransen 1939). However, increase in prevalence during transport and storage is limited by the fact that the vectors have only 1–2 generations per year (Stipes & Campana 1981).

Wood with bark

If a new vector generation emerges from wood with bark it may transport the pathogen to new logs during transport and storage. This is possible because maturation feeding in living trees is not an obligatory part of the vectors' life cycle (Birch et al. 1981; Webber 2000). Although trees that have been dead for more than a few weeks are not considered ideal for breeding (Stipes & Campana 1981), the bark of dead trees is considered to remain suitable for breeding for up to two years (Gibbs et al. 1994). Since bark that has already been used for breeding is not suitable for further breeding (Stipes & Campana 1981) the newly emerged beetles are likely to colonize uninfected logs, which will lead to an increase in the prevalence of the pathogens and the vectors.

Wood without bark

Since the vectors cannot complete their life cycle in wood without bark the pathogens cannot increase in prevalence in such consignments. However, in debarked wood that has large enough remnants of bark, the vectors may complete their development and transport the pathogens to new logs. Eggs and larvae are likely to need rather large remnants of bark to complete their development since the length of the larval galleries of *S. scolytus* and *S. multistriatus* is about 12–73 mm (EPPO 1983). However, even small remnants could enable the development of pupae which are less than 10 mm long. (We did not find information about the length of the pupae but according to EPPO (1983) fully developed larvae are about 3.5–7 mm long.)

Wood chips

The vectors may be able to complete their development in wood chips with bark, and the newly emerged adults may lay eggs in new pieces of wood in the consignment, resulting in an increase in the prevalence of the pathogens and the vectors. However, this is considered to be very unlikely since the vectors would be able to search for chips suitable for breeding effectively only on the surface of the consignment.

WPM

If WPM has large enough remnants of bark to allow vectors to complete their life cycle, the new generation of vectors may colonize and transport the pathogens to new WPM. This may be possible even if the WPM has been heat treated according to ISPM 15 since some Scolytidae species have been found to be able to infest and develop in heat treated logs and boards which have residual bark (Haack & Petrice 2009).

Conclusions

In wood, wood chips and WPM with large enough pieces of bark the pathogens and the vectors may, in principle, be able to increase in prevalence during transport and storage because new vectors may emerge and transport the pathogens to new pieces of wood. Still, this is considered very unlikely since the vectors have only 1–2 generations per year. In consignments without bark, vectors cannot survive and transport the pathogens to new pieces of wood.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Likelihood	Uncertainty	Likelihood	Uncertainty
Wood	very unlikely	low	very unlikely	low
Wood chips with bark	very unlikely	low	very unlikely	low
WPM	very unlikely	low	very unlikely	low

2.09 - Under current inspection procedures how likely is the pest to enter the PRA area undetected?

Regulatory status and inspections

Neither the pathogens nor their vectors are regulated in the Council Directive 2000/29/EC, and no phytosanitary certificate is required for wood of *Ulmus* imported into the EU. Hence no import inspections, market inspections or official surveys, which could affect the probability of entry of the pathogens or the vectors into the PRA area in wood, are carried out.

A small proportion of WPM entering Finland from outside the EU is inspected by the customs and plant health officials for compliance with ISPM 15. In addition, WPM accompanying consignments of specified commodities originating in China is inspected, at specified minimum frequencies (15% or 90%), based on the Commission decision 2013/92/EU. In these inspections symptoms of DED or the vectors might be observed. However, the inspections cover only a minute proportion of the WPM entering Finland from outside the EU, and the WPM entering Finland from other EU member states is not inspected at all (except WPM from Portugal). Detection of live vector insects in the ISPM 15 labeled WPM would result in an import ban of the consignment in question, but since DED is not a regulated pest no measures would be taken if its symptoms were observed on WPM.

Detectability of the pathogens

The pathogens cause discoloration of the outer rings of wood (Stipes & Campana 1981), which can be detected in the cross section of the logs. However, logs that have been infected after cutting do not show these symptoms since the pathogens are

present only in the vectors' galleries and in the bark (Webber et al. 1987). In wood without bark the vectors' feeding galleries may be visible, and their presence indicates that the pathogens may be present in the wood too. However, in no case can identification of the pathogen be done reliably based on symptoms, instead it requires laboratory testing (D'Arcy 2000).

Detectability of the vectors

The vector insects are unlikely to be detected in inspections since they live in and under the bark, and the relevant life stages (eggs, larvae and pupae) are only 0.6–7 mm long depending on the life stage and species (EPPO 1983). The vectors' entrance holes are visible in the bark, but they are likely to remain undetected since they are only 1 mm in diameter (EPPO 1983).

Interceptions

According to the Europhyt notification system, the pathogens have not been intercepted in wood or WPM in the EU in the period 1999–2014. This is not surprising since the pathogens are not regulated in the EU. Scolytidae have been intercepted in the EU 35 times from WPM in the period 1999–2015. However, the beetles have not been identified to genera or species level, and thus it is not possible to know if any of the interceptions were vectors of DED. In New Zealand *S. multistriatus* and *S. scolytus* have been intercepted in WPM 40 times between 1948 and 2000 (Gadgil et al. 2000).

Conclusions

Since there are currently no official inspections carried out on wood of *Ulmus* the pathogens and the vectors would be very likely to remain undetected in the current inspections. The inspections carried out on WPM are far too sporadic to affect the probability of entry of the pests.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Likelihood	Uncertainty	Likelihood	Uncertainty
Wood	very likely	low	very likely	low
WPM	very likely	low	very likely	low

2.10 - How likely is the pest to be able to transfer from the pathway to a suitable host or habitat?

Occurrence of the vectors

The pathogens need a vector insect to transmit them from wood to living trees in the PRA area. Therefore, transmission is possible only if vectors are already present in the PRA area, or if vectors are introduced in the same consignment with the pathogens.

One potential vector species, *S. mali* (Stipes & Campana 1981; Webber 2004) is currently present in Finland (Lekander et al. 1977; Voolma et al. 2004). However, it is not clear if it could, under normal circumstances, act as a DED vector. This is because we found only one record on *S. mali* associated with DED (Pechuman 1938). It reports a case where the population of *S. mali* first increased due to an ample supply of dead apple trees, which are its preferred hosts. Later, when the dead apple trees were no longer suitable for breeding, the beetles were forced to breed on other host species, including elms.

It seems that elms are not preferred hosts for *S. mali* in the PRA area either, since it has never been reported on elm in the PRA area (Siitonen 2015), in the other Nordic countries (ArtDatabanken 2015), or in the St Petersburg area, where both *S. mali* and elms are present (Mandelstam 2015). Furthermore, *S. mali* seems to be very rare in Finland since it has been found only in three sites, Turku, Siuntio and Vantaa (Lekander et al. 1977; Siitonen 2015). However, reliable conclusions about the distribution and size of the population cannot be made based on these findings since the magnitude of survey efforts is not known.

Dispersal capacity of the vectors

After emerging from the wood the adult vectors need to fly to suitable host plants to feed and to breed. Bark beetles may disperse over long distance by drifting downstream with the wind (Byers 1995; Byers 2000). Short distance movement is directed by olfactory cues from the host trees and aggregation pheromones of conspecifics (Wood 1982; Byers 1995; Byers 1996).

Birch et al. (1981) found *S. multistriatus* in pheromone traps that were more than 8 km from the nearest elm trees. Anderbrant & Schlyter (1987) found *S. laevis* and *S. scolytus* in pheromone traps that were 1–2 km away from the elm forest edge, although the number of beetles was higher in the traps closer to the edge (20–300 m). In a mark recapture study, carried out in an elm forest, *Hylurgopinus rufipes* were captured in traps 1 km from the release point (Pines & Westwood 2008). Due to the experimental designs used, these distances represent distances frequently dispersed by the species, not the maximum dispersal distances possible. In conclusion, it seems that the vectors frequently disperse at least a few kilometers from the emergence site, and if host plants are not present, they may be able to disperse for at least 8 kilometers.

Distribution of host plants

The likelihood of a vector finding a suitable host plant in the PRA area varies a lot depending on the geographical location since elms occur only in parts of the country. (See Appendix 1, Figures A1 and A2 for distribution maps of the host plants in Finland.)

Naturally occurring *Ulmus* spp. are very rare in the PRA area. Both *U. glabra* and *U. laevis* are classified as threatened vulnerable species in the PRA area (Rassi et al. 2010). The total area of *U. glabra* groves is about 50–100 ha, of which about 3 ha is on the Åland islands (Raunio et al. 2008). The average size of the groves is 0.5–2 ha, and in addition there are scattered solitary trees (Raunio et al. 2008). The groves are located on the southwestern coast and archipelago, in the Lohja area and in Häme. The northernmost solitary trees are found in North Savo, North Karelia and Central Finland (Raunio et al. 2008).

The largest natural occurrences of *U. laevis* are located in Häme, along the coasts of Vanajavesi, Pyhäjärvi and Kulovesi, where there are about 2300 trees altogether (Wiksten 2015). The total area of *U. laevis* groves is less than 50 ha, of which about 10 ha is on the Åland islands (Raunio et al. 2008). The average size of the groves is 0.5–3 ha (Raunio et al. 2008). In addition there are about 80 trees in Lohja, and some individual trees in, e.g. Hauho, Pälkäne, Hyvinkää, Heinola, Porvoo and Tammissaari (Wiksten 2015).

There are at least 11 780 elms planted in parks and along roads in cities in Finland. The number of ornamental elms is the highest in Helsinki (3069), Turku (2069), Espoo (1633) and Lappeenranta (>1000). (For more details see Appendix 1, Table A1.) In addition to the planted trees there are also numerous naturally regenerated elms in the cities. Some elms are planted in private gardens, but there is no information about the number or location of such trees.

Some of the vector species are reported to have host plants also in genera that are very common in the PRA area, such as *Acer*, *Alnus*, and *Salix* (Wood & Bright 1992; See Appendix 2, Table A3). However, it is not clear whether the beetles have been observed to breed and complete their development on the plants, or if they have just been observed to feed on them. There is some indication that the latter might be true since Fransén (1939) reports that *S. scolytus* was not able to complete its life cycle on all the hosts listed by Wood & Bright (1992). In Finland's neighboring countries DED vectors have never been found on those plants (Mandelstam 2015, Lindelöw 2015).

If the vectors are also able to utilize species that are common in Finland, their probability of transfer to a suitable host will be greatly improved. However, this does not improve the probability with which the pathogens can transfer to suitable host plants. On the contrary, it may decrease the probability since the vectors would probably be more likely to feed and breed on the common hosts than to search for the very rare elm trees.

Entry points and final destinations

If elm wood or WPM that can support entry of the pathogens and the vectors was traded to Finland, it would arrive at harbors, by rail, or via roads from Russia, Sweden or Norway. The harbors on the southern coast, and the road and rail connections from Russia are located in an area where host plants are present, and therefore transfer of the pathogens and the vectors to suitable host plants would be possible during transport within the PRA area.

If elm wood that can support entry of the pathogens and the vectors (i.e. untreated wood with bark) was traded to Finland, it would most likely be transported to sawmills. Most of the Finnish sawmills use Finnish wood, and are therefore located in forested areas. There are plenty of sawmills also in the areas where elms are present (Finnish Sawmills Association 2015). Yet, we don't know if any of these mills would be a potential importer of untreated elm wood with bark. Also, we don't know if there are elms close enough to the sawmills to enable transfer of the vectors and the pathogens to host trees.

Possible final destinations of potentially infected elm WPM are numerous, and they are located in all parts of the country often in urban areas. Therefore, transfer to a suitable habitat from infected WPM is probably slightly more likely than transfer from wood.

Conclusions

At present, the pathogens are very unlikely to transfer to suitable hosts since the only possible vector species that is present in Finland (*S. mali*) is unlikely to act as a vector.

If wood or WPM that can support entry of the pathogens and the vectors would be traded to Finland, it could arrive to an area where elms are present. However, since the number of elms in Finland is low and their distribution is scattered the vectors arriving in wood would be unlikely to find a suitable host. Those arriving in WPM are considered slightly more likely to find suitable hosts since WPM commonly arrives in urban areas. For the vectors the uncertainty is considered medium since it is not clear if the vectors could breed also on some tree species other than elms.

	<i>O. ulmi</i> s.l. without vectors		Vectors of <i>O. ulmi</i> s.l.	
	Likelihood	Uncertainty	Likelihood	Uncertainty
Wood	very unlikely	low	unlikely	medium
WPM	very unlikely	low	moderately likely	medium

2.11 - The probability of entry for the pathway should be described

At the moment the probability of entry of the pathogens and the vectors in wood is considered to be very unlikely, with medium uncertainty. This is mainly because the volume of trade of untreated elm wood to Finland was assessed to be very unlikely to support entry. If, however, there was trade of untreated elm wood with bark to the PRA area, the probability would be either moderately likely, likely or even very likely, depending on the type of commodity and amount of the trade. The uncertainty of the assessment is considered medium since it is not known how often elm is present in fuel wood, wood waste or wood chips imported from Russia, where DED and its vectors are currently spreading.

The probability of entry of the pathogens and the vectors in WPM is considered very unlikely, with medium uncertainty. This is mainly because the ISPM 15 requirements are expected to be effective against the pathogens and the vectors, and because the volume of elm WPM moving in intra EU-trade, for which the ISPM 15 requirements do not apply, is expected to be very small. The uncertainty of the assessment is considered medium because it is not known how commonly infected elm wood is used for WPM in the EU.

Pathway 2: Plants for planting of *Ulmus* spp. originating from where DED occurs

2.03 - How likely is the pest to be associated with the pathway at the points of origin taking into account the biology of the pest?

The pathogens

O. ulmi and *O. novo-ulmi* can be present in plants for planting that have been infected 1) during maturation feeding or 2) breeding of the vector insects, 3) via root grafts from nearby trees (Stipes & Campana 1981), or 4) via contaminated pruning tools (Opgenorth et al. 1983).

All these mechanisms of infection are considered, at most, moderately likely. This is because 1) a principal vector, *S. scolytus* has been shown to prefer to feed on large trees rather than on small ones (Webber 2004), 2) the vectors breed only on dead or severely weakened trees or branches (Stipes & Campana 1981), 3) the time the plants spend in the nursery is probably too short for root grafts to be formed, and 4) if infections in nurseries are rare, due to the aforementioned reasons, pruning tools are unlikely to be contaminated.

The vectors

The vectors of DED are unlikely to be present in healthy living trees because most of the species can use such trees only for maturation feeding (Stipes & Campana 1981). The vectors breed only in plants that have dead branches with bark thick enough to protect the offspring (Rudinsky 1962; Santini 2015). However, the small vector species, such as *S. pygmaeus*, can develop under rather thin bark (Izhevsky et al. 2005), and in fact *S. pygmaeus* is assumed to have been introduced to St Petersburg with plants for planting (Stcherbakova & Mandelshtam 2014).

Use of infected plants for planting

Symptomatic trees are not likely to be used as plants for planting since they are of too poor quality to be traded. Infected susceptible trees that do not show extensive symptoms may be used, but it is unlikely because symptoms tend to develop very quickly, within weeks (Moreau 1982; Phillips & Burdekin 1985), and small trees can be killed within one year (Stipes & Campana 1981). Infected resistant trees may be used as plants for planting because the trees are not likely to show clear symptoms (Stipes & Campana 1981).

Prevalence of the pathogen

DED is widely distributed in most of the countries in the Northern Hemisphere (Gibbs 1978; Brasier 1991; Brasier 2000; Brasier & Buck 2001; Brasier & Kirk 2001), and the prevalence of DED in areas of its current distribution is likely to be so high that the pathogens can be present in plants for planting.

Conclusions

The pathogens and the vectors can be associated with the pathway, but that is only considered moderately likely. This is because 1) at least some the vector species (*S. scolytus*) prefer large trees for feeding, 2) the vectors can breed only in dead or severely weakened trunks or branches, and 3) dead or severely weakened plants for planting are unlikely to be traded. The uncertainty of the assessment is considered medium because we don't know how likely the vectors are to feed or breed on small nursery trees.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
moderately likely	medium	moderately likely	medium

2.04 - How likely is the pest to be associated with the pathway at the points of origin taking into account current management conditions?

Cultural practices

Cultural pest management practices (such as use of proper plant materials, proper fertilization, watering and pruning, preventative disease and insect control, strict hygiene, eliminating dead or severely weakened elm trees and unhealthy branches, and preventing root grafts) may significantly decrease the probability of nursery trees becoming infected with the pathogens and colonized by the vectors (Stipes & Campana 1981; Ward & Kaiser 2012). Such practices will reduce the sources of infection, protect the trees from the vectors, and reduce plant stress, and hence make the plants less susceptible to the pathogens. Yet, such measures are not likely to be completely effective, especially if there are elm trees in the surroundings of the nursery.

Use of resistant trees

Resistant *Ulmus* varieties are able to heal the disease by themselves (Stipes & Campana 1981; Dickison 2000; Gheraldini & Santini 2009), but resistance does not prevent trees from becoming infected and acting as a pathway of introduction for the pathogens and the vectors.

Conclusions

Use of resistant *Ulmus* varieties and appropriate cultural practices can decrease the likelihood with which plants for planting become infected with the pathogens and colonized by the vectors. However, these measures are not considered to be effective enough to render the association unlikely. The uncertainty of the assessment is considered medium because we don't know how likely the vectors are to feed or breed on small nursery trees.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
moderately likely	medium	moderately likely	medium

2.05 - Consider the volume of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this volume will support entry?

There are no statistics available on the trade of elm plants for planting to Finland, and therefore the assessment has to be based on expert knowledge and deduction from other assessments.

According to Jyri Uimonen (2015a), who is a special extension officer in the Finnish associations for horticulture and nursery producers (Puutarhaliitto ry and Taimistoviljelijät ry), the number of *Ulmus* plants for planting traded to Finland annually is very small. He estimates that the total number of elm plants used annually in Finland is between several hundreds and some thousands (but less than 10 000), and that at least 99% of the used elms are domestic. If these estimates are correct, it means that only 1–100 elm trees are traded to Finland from other countries annually.

The city of Helsinki, which is probably the largest user of elm trees in Finland, planted 854 elm trees in the period 2000–2005 (Tegel 2010), which is about 140 elms annually. The origin of the trees is unknown, but most of them are likely to be domestic.

The number of broad leaved trees traded to Finnish garden centers from abroad has been estimated to be about 10 500 plants annually, which is about 1.4% of the foreign plant trade of garden centers (Hannunen et al. 2014). The number of landscaping plants traded to Finland by nurseries has been estimated to be about 1.5 million plants per year (Hannunen et al. 2014). If the proportion of broad leaved trees in the nurseries’ trade were the same as in that of the garden centers (i.e. 1.4%), the total number of non-coniferous ornamental trees traded to Finland from abroad would be about 12 600 plants annually (10 500 by garden centers and 2 100 by nurseries). It is not known how large a proportion of these are elms, but if the proportion was, say, 1% that would mean that only about 130 elm trees were traded to Finland annually.

All the above deductions suggest that the number of elm plants for planting traded to Finland is low. It may be high enough to support entry of the pathogens or the vectors, but not high enough to make invasions likely.

Conclusions

The volume of trade of elm plants for planting to Finland is expected to be very low. Although there are no official statistics to support the assessment, the uncertainty of the assessment is considered low since the numbers of elm trees used annually is known to be low, and since most of the used elms are known to be domestic.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
unlikely	low	unlikely	low

2.06 - Consider the frequency of movement along the pathway (for periods when the pest is likely to be associated with it): how likely is it that this frequency will support entry?

There is no information about the frequency of the trade of elm plants for planting to Finland. Yet even if there was trade every year, the volume of trade is so low (only a couple of hundred plants per year at the maximum) that it will not make entry of the pathogens or the vectors likely.

Conclusions

Although the trade of elm plants for planting may be annual, the trade flow is not expected to favor entry of the pathogens or the vectors.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
unlikely	low	unlikely	low

2.07 - How likely is the pest to survive during transport or storage?

Elm plants for planting traded to Finland are normally transported and stored as root balled or potted plants, which may be dormant or in the growth stage. The plants are transported in early spring (March, April), in late autumn (September, October), or in between, using either regular or refrigerated trucks. In Finland the plants may be stored in cold temperatures (-2 °C) or in the field at ambient temperatures. Transportation from Northern and Central Europe takes only a couple of days (Uimonen 2015b).

The conditions during transport and storage are not likely to adversely affect the survival of the pathogens or the vectors since they also withstand low temperatures. In laboratory conditions the pathogen can be stored at -10 to -15 °C (Stipes & Campana 1981), and vector larvae (*S. scolytus*) have been shown to survive sub-zero treatments and to pupate and reach the adult stage after the treatments (Barson 1974).

Conclusions

The pathogens and the vectors can survive the transport and storage in plants for planting.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
very likely	low	very likely	low

2.08 - How likely is the pest to multiply/increase in prevalence during transport or storage?

The conditions during transport and storage may be such that the pathogens can multiply in the plants. (See point 2.07 for information about the conditions during transport and storage, and Pathway 1 point 2.08 for details about the conditions required for multiplication.) However, to increase in prevalence the pathogens need a vector to transport them to new plants.

The vectors may, in some cases, be able to move to new host plants to oviposit during transport and storage. Yet, the increase in prevalence is very unlikely since a new vector generation emerges twice a year, in late spring and late summer (Stipes & Campana 1981), while transport normally takes only a couple of days. (For more details see Pathway 1, point 2.08.)

Conclusions

The pathogens and the vectors are very unlikely to increase in prevalence during transport and storage of plants for planting.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
very unlikely	low	very unlikely	low

2.09 - Under current inspection procedures, how likely is the pest to enter the PRA area undetected?

Regulatory status and official inspections

Neither the pathogens nor their vectors are regulated in the Council Directive 2000/29/EC. Nevertheless, all consignments of plants for planting imported from outside the EU need to be accompanied by a Phytosanitary Certificate, and they will be subject to an official import inspection upon arrival. However, plants for planting marketed to Finland from other EU member states are very unlikely to be subject to an inspection.

Detectability of the pathogens

The pathogens cause crown discoloration and wilting, yellowing and drying of the leaves (Stipes & Campana 1981), which can be detected in inspections. However, resistant plants or plants which have been infected very recently do not always show clear symptoms. In any case, the pathogens cannot be identified visually since similar symptoms may be caused by various reasons. Instead, identification of the pathogens requires laboratory testing (D'Arcy 2000).

Detectability of the vectors

The vector insects are unlikely to be detected during inspections since they live in and under the bark, and the relevant life stages (eggs, larvae and pupae) are only 0.6–7 mm long depending on the life stage and species (EPP0 1983). The vectors' entrance holes are visible in the bark, but they are likely to remain undetected since they are only 1 mm in diameter (EPP0 1983).

Interceptions

According to the Europhyt notification system DED pathogens or Scolytidae beetles have not been intercepted in plants for planting in the EU during 1999–2014. This is not surprising since the pathogens are not regulated in the EU.

Conclusions

Infected plants for planting would be very likely to remain undetected in inspections since only a minute proportion of the plants traded from other EU member states are subject to inspections.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
very likely	low	very likely	low

2.10 - How likely is the pest to be able to transfer from the pathway to a suitable host or habitat?

Dispersal of the pathogens via root grafts

The pathogens may transfer from susceptible infected plants to nearby trees via root grafts (Stipes & Campana 1981). Still, this is considered unlikely because susceptible infected plants are likely to die before forming root anastomosis within 1-2 years. (The time needed for root grafts to form depends on the size of the trees and the

distance between them. We don't know how long it takes in a typical situation, but we expect the distance between newly planted trees to be large enough to prevent anastomosis during the first years after planting.)

In infected but resistant plants for planting the pathogens are likely to be restricted close to the original infection site (Stipes and Campana 1981, Dickison 2000, Gheraldini and Santini 2009). This is likely to prevent the pathogens from transferring via root grafts to nearby trees.

Occurrence of the vectors

The pathogens need a vector insect to transfer them from plants for planting to trees in the PRA area. Therefore transfer is possible only if vectors are already present in the PRA area or if vectors are introduced in the same consignment with the pathogens.

One potential vector species, *S. mali* (Stipes & Campana 1981; Webber 2004) is currently present in Finland (Lekander et al. 1977; Voolma et al. 2004). However, it is not clear if it could, under normal circumstances, act as a DED vector. Also, *S. mali* seems to be very rare in Finland, and it seems that elms are not its preferred hosts. (For more details see Pathway 1 point 2.10.)

Dispersal capacity of the vectors

It seems that the vectors frequently disperse at least a few kilometers from the emergence site, and if host plants are not present, they may be able to disperse for at least 8 kilometers. (For details see Pathway 1 point 2.10.) Short range movement is directed by olfactory cues from the host trees and aggregation pheromones of conspecifics (Wood 1982; Byers 1995; Byers 1996), which assist in dispersal through areas of low host plant density.

Distribution of host plants

The likelihood with which a vector can find a suitable host plant in the PRA area varies a lot depending on the geographical location since elms occur only in parts of the country. (See Appendix 1, Figures A1 and A2 for distribution maps of the host plants in Finland.)

Naturally occurring *Ulmus* spp. are very rare in the PRA area (For more details see Pathway 1, point 2.10), but in Finnish cities there are at least 11 780 elm trees planted in parks and along roads. The number of ornamental elms is the highest in Helsinki (3 069), Turku (2 069), Espoo (1 633) and Lappeenranta (>1 000). (For more details see Appendix 1, Table A1.) In addition to the planted trees there are also numerous naturally regenerated elm trees in the cities. Some elms are also planted in private gardens, but there is no information about the number or location of such trees.

Some of the vector species may have host plants also in genera that are very common in the PRA area, such as *Acer*, *Alnus*, and *Salix*. (For more details see Pathway 1, point 2.10 and Appendix 2, Table A3.) If the vectors are also able to utilize species that are common in Finland, their probability of transfer to a suitable host is greatly improved. However, this does not improve the probability with which the pathogens are transferred to a suitable host plant. On the contrary, it may decrease

the probability since the vectors would probably be more likely to feed and breed on the common hosts than to search for the more rare elm trees.

Entry points and final destinations

Elm plants for planting traded to Finland arrive in nurseries and will eventually be planted in suitable environments, mostly in urban areas in locations where other host plants are likely to be present nearby.

Conclusions

At present, the pathogens are very unlikely to transfer from plants for planting to new elm plants unless vectors are introduced in the same consignment. If plants for planting infected with both *O. ulmi* s.l. and its vector would enter Finland, they would be likely to arrive in an environment where other elms are present. In that case the vectors would be likely to transfer the pathogens to new host plants.

<i>O. ulmi</i> s.l. without vectors		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
very unlikely	low	likely	low

2.11 - The probability of entry for the pathway should be described

At the moment the probability of entry of the pathogens and the vectors in plants for planting is considered to be unlikely, with low uncertainty. This is due to the low volume of trade of elm plants for planting, and the lack of vectors in the PRA area. If however there was regular trade of plants for planting to the PRA area, and especially if vectors were introduced to the PRA area, the probability could be moderately likely.

Pathway 3: Natural spread aided by hitchhiking on vehicles

2.03 - How likely is the pest to be able to spread naturally or by hitchhiking on vehicles from its present area of distribution to the PRA area taking into account the biology of the pest?

The distribution of the pathogens in the neighboring countries

The pathogens are present in all of the PRA area’s neighboring countries (Russia, Estonia, Sweden and Norway). The closest occurrences are in St Petersburg, in Russia, less than 160 km from the Finnish border (Serebritskiy 2014), and on the northern coast of Estonia, about 100 km from the Finnish coast (Voolma 2015). In Sweden the pathogens are present as far north as the city Falun (Lindelöw 2015). The distance from the Swedish to the Finnish coast is about 200 km or more, but the shortest distance between forested Swedish islands and forested Åland islands is only about 40 km.

The distribution of the vectors in the neighboring countries

The vectors are present in all of the PRA area's neighboring countries (Russia, Estonia, Sweden and Norway). The closest occurrence is in Vyborg, in Russia, less than 30 km from the Finnish border (Stcherbakova & Mandelshtam 2014). In Estonia the closest occurrence is the northern coast of the country (Voolma et al. 2000), and in Sweden the vectors appear as far north as in Dalarna (Lindelöw 2015).

Barriers for spread from the neighboring countries

The Gulf of Finland and the Gulf of Bothnia are likely to hinder the spread of the pathogens and the vectors from Estonia and Sweden. However, there does not seem to be a clear gap in the occurrence of elm trees that would prevent the pathogens or the vectors from spreading via land from Russia to Finland. Elms are present throughout the southeastern coast of Finland where the distance between separate elm patches is about 10-15 km, and the easternmost patches are about 5 km from the Finnish-Russian border (Lampinen & Lahti 2016; SYKE 2015). On the Russian side of the border the known distribution of elms along the coast between St Petersburg and Vyborg is similar to that on the Finnish southeastern coast, i.e. the distance between separate elm patches is about 10-15 km (Hiitonen 1946; Hulten 1950). Also, between Vyborg and the Finnish border the distribution between documented patches is similar, except that the closest documented presence of elms is about 25 km from the Finnish border (Hiitonen 1946). However, there may well be undocumented elm patches closer to the border, since the only source of information we were able to find (i.e. Hiitonen 1946) is from the 1940's.

Dispersal capacity of the pathogens

The dispersal capacity of the pathogens depends on the dispersal capacity of the vectors since transmission by vectors is their only means for medium and long range dispersal (Stipes & Campana 1981). Over short distances the pathogens can spread naturally also via root grafts (Stipes & Campana 1981). There is no evidence for dispersal by any other natural means, such as dispersal by wind.

Dispersal capacity of the vectors

It seems that the vectors frequently disperse at least a few kilometers from the emergence site, and if host plants are not present, they may be able to disperse for at least 8 kilometers. (For details see Pathway 1 point 2.10.) Short range movement is directed by olfactory cues from the host trees and aggregation pheromones of conspecifics (Wood 1982; Byers 1995; Byers 1996), which assist in dispersal through areas of low host plant density.

The dispersal capacity of the vectors is limited by the fact that they disperse only as adult beetles while searching for suitable sites for maturation feeding and breeding. This happens twice a year, in the late spring and late summer when new adults emerge (Stipes & Campana 1981).

Dispersal by hitchhiking on vehicles

DED and its vectors may be able to spread very quickly and over long distances by hitchhiking on ferries, trains and cars as DED is believed to have introduced to Norway in vector beetles hitchhiking on vehicles. This is a) because the introductions are difficult to explain otherwise as import of elm wood to Norway has been rest-

stricted since the 1950s, and b) because many of the occurrences have been close to harbors or railway lines. The first occurrences of DED in Norway (1963 and 1972) were along the railway lines from Sweden, and the first occurrences of *O. novo-ulmi* ssp. *americana* (1981) were close to the ferry harbor from Kiel. Furthermore, in 1982 DED was found in Drammen which is the most important harbor for import of cars, in 1990 it was found in Horten which is the main harbor in the eastern part of Norway for military ships, in 1991 it was found in Larvik to which ferries arrive from Denmark, in 1995 it was found in Grenland which has an import harbor, and in 1996 and 2005 DED was found in Kritiansand to where ferries arrive from Denmark (Solheim 2016).

To the PRA area vectors carrying the pathogens could arrive by hitchhiking at least on trains, cars and ferries from Russia, and on ferries from Sweden, Estonia, Latvia and Germany.

Conclusions

DED and its vectors are considered moderately likely to be able to spread to the PRA area naturally or by hitchhiking on vehicles. Purely natural spread is most likely from Russia where the pathogens are present about 160 km from the Finnish border, and the vectors are present about 30 km from the border, and there are no clear barriers that would prevent the spread. The uncertainty of the assessment is considered moderate because the likelihood with which beetles hitchhike on vehicles is not known, and because there is no up to date information about the distribution of elms between Vyborg and the Finnish border.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
moderately likely	moderate	moderately likely	moderate

2.04 - How likely is the pest to be present in areas from which it could spread to the PRA area taking into account current management conditions?

No official measures are taken to eradicate, contain or control the DED pathogens or the vectors in any of the countries neighboring Finland. In the St Petersburg area, trees that have been killed by DED are removed (Mandelstam 2015), in Estonia DED is managed by removing dead trees and branches (Voolma 2015), and in Sweden DED is managed systematically only in Gotland (Lindelöw 2015).

Conclusions

The management practices which are applied in countries neighboring the PRA area are unlikely to affect the natural spread of the pathogens and the vectors, and therefore the rating here is the same as in the previous point.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
moderately likely	medium	moderately likely	medium

2.09 - Under current inspection procedures how likely is the pest to enter the PRA area undetected?

Currently there are no inspection procedures applied for detecting the natural spread of the pathogens or the vectors.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
very likely	low	very likely	low

2.10 - How likely is the pest to be able to transfer from the pathway to a suitable host or habitat?

Distribution of host plants

Naturally occurring elms are very rare in the PRA area. The total area of elm groves is only about 100-150 ha. In addition there are some solitary trees. (For more details see Pathway 1, point 2.10.)

In the Finnish cities there are at least 11 780 elm trees planted in parks and along roads. (For more details see Appendix 1, Table A1.) In addition there are also numerous naturally regenerated elm trees in the cities. Some elms are also planted in private gardens, but there is no information about the number or location of such trees. At least in Helsinki and Turku there are planted elms close to the harbors to which ferries arrive from areas where DED and its vectors are present (Männistö 2016; Terho 2016).

In southeastern Finland, in areas where the naturally spreading pests would be most likely to arrive, elms are present throughout the coast where the distance between separate elm patches is about 10–15 km, and the easternmost patches are about 5 km from the Finnish-Russian border (Lampinen & Lahti 2016; SYKE 2015).

Some of the vector species may have host plants also in genera that are very common in the PRA area, such as *Acer*, *Alnus*, and *Salix*. (See pathway 1, point 2.10 and Appendix 2, Table A3 for more information.) If the vectors are also able to utilize species that are common in Finland, their probability of transfer to a suitable host will be greatly improved. However, this does not improve the probability with which the pathogens are transferred to a suitable host plant. On the contrary, it may decrease the probability since the vectors would probably be more likely to feed and breed on the common hosts than to search for the more rare elm trees.

Conclusions

If vectors that were carrying DED pathogens entered Finland by ferries e.g. from St Petersburg, Stockholm or Tallinn they would be likely to arrive at an area where elms are present, i.e. in Mariehamn, Helsinki or Turku. If they entered Finland from Russia by car or train they could transfer to an area where elms are present, such as the forests in southeastern Finland or the cities located close to the Finnish-Russian border. The uncertainty of the assessment is rated medium since the likelihood with which a vector can find a suitable host plant in the PRA area varies a lot depending on the geographical location of the introduction.

Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty
likely	medium

2.11 - The probability of entry for the pathway should be described

The probability of natural spread aided by hitchhiking on vehicles is considered moderately likely, with medium uncertainty for the pathogens and the vectors.

This is because pathogen and vector populations are present in areas from which there is frequent traffic to the PRA area. Furthermore, they are present rather close to the Finnish border in Russia from where purely natural dispersal is possible. The uncertainty of the assessment is rated medium because the likelihood with which the vectors hitchhike on vehicles is not known, and because the likelihood with which a vector can transfer to a suitable host plant in the PRA area varies a lot depending on the geographical location of the introduction.

2.13b - Describe the overall probability of entry taking into account the risk presented by different pathways and estimate the overall likelihood of entry into the PRA area for this pest.

The probability of entry of DED pathogens and the vectors is considered moderately likely, with medium uncertainty. This is because pathogen and vector populations are present in areas from which there is frequent traffic to the PRA area. Furthermore, they are present rather close to the Finnish border in Russia from where purely natural dispersal is possible. The uncertainty of the assessment is rated medium because the likelihood with which the vectors hitchhike on vehicles is not known, and because the likelihood with which a vector can transfer to a suitable host plant in the PRA area varies a lot depending on the geographical location of the introduction. Other pathways of introduction are considered much less likely.

Section B: Probability of establishment

Table 2. The questions used to select which factors need to be assessed to delimit the area where there is potential for establishment, and to determine the suitability of this area for establishment.

No.	Factor	Is the factor likely to have an influence on the limits to the area of potential establishment?	Is the factor likely to have an influence on the suitability of the area of potential establishment?	Justifications for No answers
1	Host plants and suitable habitats (see note for Q3.01)	Yes (see 3.01)	Yes (see 3.09)	
2	Alternate hosts and other essential species	Yes (see 3.02)	Yes (see 3.10)	
3	Climatic suitability	Yes (see 3.03)	Yes (see 3.11)	
4	Other abiotic factors	No	No	We did not find any information indicating that any other abiotic factors could affect the probability of establishment of DED or its vectors.
5	Competition and natural enemies	No	No	DED and its vectors are present in wide areas in the Northern Hemisphere in spite of competitors and natural enemies. Therefore competition or natural enemies are not likely to affect their probability of establishment in the PRA area.
6	The managed environment	No	No	No such management is applied in the PRA area that could prevent establishment of DED or its vectors. The normal pest management practices applied on ornamental trees are not likely to have an impact on their probability of establishment.
7	Protected cultivation	No	No	DED host plants are trees grown outdoors.

Identification of the area of potential establishment

Host plants and suitable habitats

3.01 - Identify and describe the area where the host plants are present in the PRA area outside protected cultivation.

Several DED host species are present in the PRA area (Hämet-Ahti et al. 1992). They occur naturally and are planted in parks, along streets and in private gardens. There are natural elm groves on the southwestern coast and archipelago, in the Lohja area, in Häme and in Pirkanmaa (Raunio et al. 2008). The northernmost natural occurrences of solitary trees are found in North Savo, North Karelia and Central Finland (Raunio et al. 2008). Distribution maps of the most common *Ulmus* species and the numbers of planted trees in the cities are presented in Appendix 1. A more detailed description of the occurrence of elms is given in point 3.09.

Some of the vector species may also have host plants in genera other than *Ulmus*, such as *Acer*, *Alnus*, and *Salix*. (For more details see point 3.09 and Appendix 2, Table A3.). If the vectors can complete their life cycle on these plants, the area where their suitable host plants are present is, for some vector species, much larger than described above. However, these areas are not defined here since there is considerable uncertainty related to the host status of the possible other hosts.

Alternate hosts and other essential species

3.02 - Does all the area identified in 3.01 have alternate hosts or other essential species if these are required to complete the pest's life cycle?

The pathogens need vector beetles to transmit them to new trees, and the principal vectors are currently not present in the PRA area. Without vectors the pathogens can spread only over very short distances via root grafts (Stipes & Campana 1981).

One potential vector species, *S. mali* (Stipes & Campana 1981; Webber 2004) is known to be present in Finland (Lekander et al. 1977; Voolma et al. 2004). However, it is not clear if it could, under normal circumstances, act as a DED vector. Also, it seems to be very rare in Finland, and it seems that elms are not its preferred hosts. (For more details see Pathway 1 point 2.10.)

Two principal vector species, *S. scolytus* and *S. multistriatus* have recently (2014) been found in Vyborg in Russia less than 30 km from the Finnish border (Stcherbakova & Mandelshtam 2014). Therefore we cannot be absolutely sure that these species are absent from the PRA area, especially since no survey has been carried out to confirm their absence.

The vectors do not need alternative hosts or other essential species to complete their life cycle.

Conclusions

No, none of the principal DED vectors is known to be present anywhere in Finland, and the only potential vector which is present is very rare.

Climatic suitability

3.03 - Does all the area identified as being suitable for establishment in previous questions have a suitable climate for establishment?

Distribution of the pathogens and vectors

The pathogens and the vectors inhabit a range of climatic conditions and occur across several climate zones including areas where the climatic conditions are similar to those in the PRA area. (See point 1.07 for details of the distribution of the pathogens,

and Appendix 2, Figures A3 and A4 for distribution maps of the two principal vector species, *S. scolytus* and *S. multistriatus*.)

O. ulmi was found in the PRA area in the 1960s in five locations, in Helsinki, Turku and Loviisa, and in all these cases the fungus caused considerable damage (Hintikka 1974). No vectors were found from the diseased trees, and the disease was eradicated promptly (Hintikka 1974).

At present, DED and its vectors are present in all countries neighboring Finland (Russia, Sweden, Estonia and Norway). The closest occurrences of DED are in St Petersburg less than 160 km from the Finnish border (Serebritskiy 2014), and on the northern coast of Estonia about 100 km from the Finnish coast (Voolma 2015). In Sweden the pathogens are present as far north as the city Falun (Lindelöw 2015), which is roughly at the same latitude as Turku (60.4°N). The closest known vector populations (*S. scolytus* and *S. multistriatus*) are in Vyborg in Russia less than 30 km from the Finnish border (Stcherbakova & Mandelshtam 2014). In Sweden the vectors (*S. laevis*) appear as far north as in Dalarna (Lindelöw 2015).

Some of the vector species have recently expanded their range. *S. scolytus* is expected to have entered southern Sweden in the 2000s (Lindelöw 2012). In 2006–2007 it was found only in Skåne, Halland, and on Öland, but recently it has been found also in Södermanland, close to Stockholm (Lindelöw 2015). *S. scolytus* and *S. multistriatus* were found in Vyborg very recently, in 2014, about 15 years after they appeared in St Petersburg (Stcherbakova & Mandelshtam 2014).

All the vector species which are present close to the PRA area are of European or Asian origin (Stipes & Campana 1981). Hence they have had ample time to spread to Finland, yet for some reason, they have not done that. This may be due to unsuitability of climate, or to the patchy distribution of host plants. The fact that some vector species have recently expanded their range suggests that the situation has changed, either the climate has become suitable, or the host patches have become more connected due to increasing traffic.

Climatic requirements of the pathogens

The optimum growth temperature for the causal agents of DED is 20–22 °C for *O. novo-ulmi* and 27–33 °C for *O. ulmi* (Brasier 1991). Long periods of such high temperatures are not common in Finland. However, the pathogens can multiply in a variety of temperatures since they sporulate heavily during most of the period of larval development in areas where DED is present (Webber & Brassier 1984). We found no information about the minimum temperatures in which the pathogens can survive, but in laboratory conditions they can be stored at -10 to -15 °C (Stipes & Campana 1981).

Climatic requirements of the vectors

The vectors belonging to the genus *Scolytus* overwinter as larvae, and *H. rufipes* overwinter as larvae and adults (Stipes & Campana 1981). The supercooling point (SCP) of overwintering larvae have been found to vary from -26.4 °C to -33.4 °C for *S. scolytus* (Barson 1974), from -24.0 °C to -32.2 °C for *S. multistriatus* (Roden 1981), and from about -28 °C to about -31.5 °C for *S. laevis* (Hansen & Somme 1994). (The temperatures

given here for *S. laevis* are from experiments performed in December, when the SCP was observed to be at its lowest. In the other papers seasonality of the SCP is not considered.) The temperature required to kill 50% of *S. scolytus* larvae in bolts of elm has been shown to be -18.3 °C (Barson 1974).

Information about the effect of low temperatures on viability of the vectors is scarce. Roden (1981) reports that only about 20% of the supercooled *S. multistriatus* larvae reached adulthood but most of the adults were malformed. This is, however, likely to be due to the experimental design since high mortality and malformations were seen also in the control group. Hansen & Somme (1994) found that *S. laevis* larvae that were frozen in December can survive several weeks in -19 °C, and after that pupate. Barson (1974) reports that 59% of the *S. scolytus* larvae exposed to subzero temperatures reach adulthood in 14 days when kept at 30 °C. However, since the subzero temperatures experienced by the individuals that did reach adulthood are not given the relevance of the results cannot be evaluated.

Roden (1981) reports that in Ontario (Canada) the survival rate of supercooled *S. multistriatus* larvae increased from 5.2% to 63% in ten years (1970–1980), and suggests that this indicates that the beetle population may have quickly developed its tolerance to freezing. Also the fact that in mid-Asia *S. multistriatus* freezes at -53.0 °C, but in Michigan it freezes at -24.1 °C indicates that the vectors may adapt to local conditions (Turnock & Fields 2005).

In southern Finland temperatures close to the reported supercooling points of the principal vector species are rare. For example at Helsinki-Vantaa airport temperatures below -30 °C have been reported only during 21 days in 1966–2012 (Finnish Meteorological Institute 2015). Temperatures equal to or below the lowest reported supercooling points of the vector species are even rarer. Temperatures below -31.4 °C have been recorded in Helsinki-Vantaa only for 12 days, and temperatures below -33.3 °C only for four days in 1966–2012. The lowest temperature recorded in Helsinki-Vantaa is -35.9 °C (Finnish Meteorological Institute 2015). This indicates that the principal DED vectors may have the potential to survive most winters in southern Finland, yet in the most extreme years the conditions can be too cold for them.

Köppen-Geiger climatic classification

According to the Köppen-Geiger climatic classification (Kottek et al. 2006), which is based on winter and summer temperatures and precipitation patterns, Finland has two climate zones. The southern and south-western coastal areas have snow climate with warm summers (Dfb). The rest of the country has snow climate with cool summers and cold winters (Dfc).

DED is not present in areas with Dfc climate, but it is present in areas with Dfb climate, e.g. in Finland's neighboring countries. Both the occurrences in Falun and in St Petersburg are located in Dfb climate. The northernmost vector populations in Finland's neighboring countries are located in areas with Dfb climate, in the province of Dalarna in Sweden and in Vyborg in Russia. This suggests that the climate in only the southernmost Finland (Dfb) would be suitable for DED and its vectors.

Plant Hardiness Zones

Magarey et al. (2008) define 13 Plant Hardiness Zones based on the average annual minimum temperatures. According to this classification the areas in Finland where elms are present are located mostly in zones 5 and 6, and only a very narrow strip along the southern and southwestern coast is in zone 7. Both the pathogens and the vectors are present in Russia, Sweden, Northeastern Europe, Canada and USA in areas belonging to these same zones. For example St Petersburg, where DED is present is located in zone 5. This suggests that the climate in the whole PRA area would be suitable for DED and its vectors.

Temperature accumulation based on a threshold of 10 °C

The European Map of Temperature Accumulation (Degree Days) based on a threshold of 10 °C is presented in Brunel et al. (2013). According to this classification a narrow strip on the southern coast and parts of southeastern Finland is in the same zone (500-750) as St Petersburg in Russia where DED and its vectors are present. Most of the PRA area, where host plants are present, is in a cooler zone (250-500). In Sweden DED and its vectors are present also in this zone, but only in its southernmost parts. Therefore it is not evident that conditions would be suitable for the pathogens and the vectors in all parts of this zone in the PRA area.

Heikkinen et al. (2012)

Heikkinen et al. (2012) compared the climatic conditions in Finland with those in other parts of the world using five factors; 1) the average temperature of the coldest month, 2) index of continentality, i.e. the difference between the average temperatures of the warmest and coldest months, 3) growing degree days with base temperature of 5 °C, 4) rainfall seasonality index, and 5) yearly rainfall. Their analysis shows that the climatic conditions in Helsinki are highly analogous to those in parts of the current area of distribution of DED and its vectors in Estonia. In all other analyzed areas (Hanko, Tampere, Joensuu, Vaasa, Tornio) climatic conditions were found to be moderately analogous to those in areas where DED and its vectors are present in Sweden, the Baltic countries or Russia.

Conclusions

All the areas identified as being suitable for establishment in the previous questions are not likely to have a suitable climate for establishment. The uncertainty of the assessment is considered medium because the different climatic classifications suggest conflicting conclusions. Based on the comparison of plant hardiness zones and the analysis by Heikkinen et al. (2012) most areas in Finland where elms are present may have a suitable climate for DED and some of its vectors. However, based on the Köppen-Geiger climatic classification only the south and southwest coastal areas seem to be suitable. Also a comparison of the temperature accumulation in the PRA area and the present range of DED and its vectors suggests that the climatic conditions are likely to be suitable only on the southern coast and in parts of southeastern Finland. Information on cold tolerance of the principal DED vectors indicates that they may have the potential to survive most winters in southern Finland, yet in the most extreme years the conditions can be too cold for them. If climate in the PRA area gets warmer due to global warming, conditions in the southern Finland are likely to become more suitable for the pathogens and the vectors, and the limits of the suitable area are likely to shift northwards.

3.08 - By combining the cumulative responses to previous questions, identify the part of the PRA area where the presence of host plants or suitable habitats and other factors favor the establishment of the pest.

Host plants occur mainly in southern Finland, but there are individual trees as far north as Oulu. Vectors are currently not present anywhere in the PRA area. The climate is likely to be most suitable for DED and its vectors in the southernmost parts of the country along the coast. The climate may also be suitable in other areas where host plants occur, but the likelihood of that decreases northwards. Consequently, **the southernmost coastal areas are likely to be most favorable for the establishment of DED and its vectors. Other parts of southern Finland may also be favorable, but that is less likely.**

Suitability of the area of potential establishment

Host plants and suitable habitats

3.09 - How likely is the distribution of hosts or suitable habitats in the area of potential establishment to favor establishment?

Naturally occurring elms

Naturally occurring elms are very rare in the PRA area. Both *U. glabra* and *U. laevis* are classified as threatened vulnerable species in the PRA area (Rassi et al. 2010). The total area of *U. glabra* groves is about 50–100 ha, of which about 3 ha is on the Åland islands (Raunio et al. 2008). The average size of the groves is 0.5–2 ha, and in addition there are scattered solitary trees (Raunio et al. 2008). The groves are located on the southwestern coast and archipelago, in the Lohja area and in Häme. The northernmost solitary trees are found in North Savo, North Karjala and Central Finland (Raunio et al. 2008).

The largest natural occurrences of *U. laevis* are located in Häme, along the coasts of Vanajavesi, Pyhäjärvi and Kulovesi where there are about 2300 trees altogether (Wiksten 2015). The total area of *U. laevis* groves is less than 50 ha, of which about 10 ha is on the Åland islands (Raunio et al. 2008). The average size of the groves is 0.5–3 ha (Raunio et al. 2008). In addition there are about 80 trees in Lohja, and some individual trees in e.g. Hauho, Pälkäne, Hyvinkää, Heinola, Porvoo and Tammissaari (Wiksten 2015).

Planted host plants in urban areas

There are at least 11 780 elm trees in parks and along streets in urban areas in Finland. The number of ornamental elms is the highest in Helsinki (3 069), Turku (2 069), Espoo (1 633) and Lappeenranta (>1 000). (For more details see Appendix 1, Table A1.) In addition to the planted trees there are also numerous naturally regenerated elm trees in the cities. Some elms are planted in private gardens, but there is no information about the number of such trees.

Other host plants of the vectors

Some of the vector species are reported to have host plants also in genera that are very common in the PRA area, such as *Acer*, *Alnus*, and *Salix* (Wood & Bright 1992, see Appendix 2, Table A3). However, it is not clear whether the beetles have been observed to breed and complete their development on the plants, or if they have just been observed to feed on them. There is some indication that the latter might be true since Fransén (1939) reports that *S. scolytus* was not able to complete its life cycle on all the hosts listed by Wood & Bright (1992). In Finland's neighboring countries DED vectors have never been found on those plants (Mandelstam 2015, Lindelöw 2015).

If the vectors were able to utilize these plant species, which are much more common than elms, their probability of establishment in Finland would be greatly improved. However, it would not improve the probability of the establishment of DED.

Dispersal capacity of the vectors

It seems that the vectors frequently disperse naturally at least a few kilometers from the emergence site, and if host plants are not present, they may be able to disperse for at least 8 kilometers. (For details see Pathway 1 point 2.10.) Short range movement is directed by olfactory cues from the host trees and aggregation pheromones of conspecifics (Wood 1982; Byers 1995; Byers 1996), which assist in dispersal through areas of low host plant density. By hitchhiking on vehicles the vectors may be able to disperse over much longer distances.

The dispersal capacity of the vectors is limited by the fact that they disperse only as adult beetles while searching for suitable sites for maturation feeding and breeding. This happens twice a year, in the late spring and late summer when new adults emerge (Stipes & Campana 1981).

All the vector species which are present close to the PRA area are of European or Asian origin (Stipes & Campana 1981). Hence they have had ample time to spread to Finland, yet for some reason, they have not done that. This may be due to the patchy distribution of host plants, or to unsuitability of climate. The fact that some vector species have recently expanded their range (see point 3.03) suggests that the situation has changed, either the host patches have become more connected due to increasing traffic, or the climate has become suitable.

Conclusions

In general the low number and scattered distribution of elms in the area of potential establishment is unlikely to favor establishment of the pathogens or the vectors. Host density is only likely to favor establishment in areas where elms are present in greater density, like in the cities in southern Finland and in the few natural elm stands. For the pathogens and the vectors the uncertainty of the assessment is rated medium as the vectors seem to have been able to spread in Russia in areas where the density of elms is roughly similar to that in the southernmost Finland. Also, there is not enough information about the capacity of the vectors to spread in conditions where the distance between host patches is as high as in the PRA area.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
unlikely	medium	unlikely	medium

Alternate hosts and other essential species

3.10 - How likely is the distribution of alternate hosts or other species critical to the pest’s life cycle in the area of potential establishment to favor establishment?

None of the principal vectors of DED is known to be present anywhere in Finland, and the only potential vector which is present is very rare. (For more details see point 3.02 and Pathway 1, point 2.10.)

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
very unlikely	low	-	-

Climatic suitability

3.11 - Based on the area of potential establishment already identified, how similar are the climatic conditions that would affect pest establishment to those in the current area of distribution?

See point 3.03 for detailed information about the pathogens’ and the vectors’ climatic requirements and for comparisons of the climate in the PRA area and in the pathogens’ and vectors’ present area of distribution.

Conclusions

The southernmost part of the PRA area is likely to have climatic conditions that are largely similar to those in the present range of DED and its vectors. The climate may be suitable also in other areas where host plants occur, but the likelihood of that decreases northwards. For other than the southernmost parts of the PRA area, the uncertainty of the assessment is considered medium because the different climatic classifications suggest conflicting conclusions. If climate in the PRA area gets warmer due to global warming, conditions in the southern Finland are likely to become more suitable for the pathogens and the vectors, and the limits of the suitable area are likely to shift northwards.

Part of the area of potential establishment	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Similarity	Uncertainty	Similarity	Uncertainty
Southernmost parts	largely similar	low	largely similar	low
Other parts	moderately similar	medium	moderately similar	medium

3.17 - How likely are the reproductive strategy of the pest and the duration of its life cycle to aid establishment?

The pathogens

The pathogens' reproductive strategy relies heavily on transmission to new hosts by vectors. Therefore the probability with which DED is able to increase in prevalence and establish permanently in the PRA area is largely determined by the characteristics of the vectors.

Within a host plant the pathogens reproduce sexually as well as asexually (Stipes & Campana 1981; Webber & Brasier 1984). Yet, they are heterothallic, i.e. sexual reproduction is possible only when two mating types are present (Gibbs et al. 1994).

During most of the vectors' larval development the pathogens sporulate heavily in and around the beetles' breeding galleries (Webber & Brasier 1984). The number of the spores in the plants may decline due to e.g. nutrient depletion, cold temperatures and predation (Webber & Brasier 1984). However, the remaining ascospores and conidia form a resting inoculum which enables further colonization of the bark once conditions become more favorable (Webber & Brasier 1984).

For an effective xylem infection of susceptible elms 500-1 000 spores of *O. novo-ulmi* are required, while for moderately resistant elms about 5 000 spores are needed (Webber 2004). Since one *S. scolytus* individual can carry up to 350 000 spores and one *S. multistriatus* up to 30 000 spores (Webber 1990), one beetle is enough to infect a tree.

The pathogens can remain viable for many years within the root system, from where they can sometimes transport to the suckers growing from the roots (Gibbs et al. 1994).

The vectors

The vectors' reproduce only sexually, and in the PRA area's neighboring countries (Sweden and Russia) DED vectors have only 1-1.5 generations per year (Lindelöw 2015; Mandelshtam 2015). One *S. scolytus* female lays about 60-110 eggs, and *S. multistriatus* about 100-150 eggs (Fransen 1939).

The vectors have a life stage which is likely to enable them to overwinter in parts of the PRA area (For more details see point 3.03), but we found no evidence indicating that they would be otherwise particularly adapted to withstand unsuitable conditions.

Once a beetle has located a suitable host tree it releases aggregation and sex pheromones to attract more beetles to colonize the tree (Byers et al. 1980, Gore et al. 1977, Webber 2004). This trait may help the vectors to start a population with a relatively low number of individuals.

Conclusions

The pathogens' characteristics are likely to favor their multiplication and survival in the host tree. However, the probability with which DED is able to increase in preva-

lence and establish permanently in the PRA area is largely determined by its vectors' characteristics, which do not particularly favor establishment.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
moderately likely	low	unlikely	low

3.18 - Is the pest highly adaptable?

The pathogens

O. ulmi and *O. novo-ulmi* are adapted to a rather wide range of climatic conditions. They are present throughout Europe from the Mediterranean up to the Scandinavian region, and in North America within areas with different types of climate.

Although DED is caused by two species, of which one has two subspecies, it is not evident that the species or subspecies would have developed as an adaptation to new conditions in new geographical areas. This is because both *O. ulmi* and *O. novo-ulmi* are believed to originate from Asia (Brasier & Buck 2001), and the two subspecies of *O. novo-ulmi* appeared almost at the same time in Eastern Europe and in North America. The two subspecies of *O. novo-ulmi* can hybridize but the hybrids have the same growth rate and pathogenicity as their parents (Brasier & Kirk 2010).

The pathogens do not have other traits which would suggest that they are highly adaptable.

1. They have not increased the number of host genera they infest since all host plants are from the genus *Ulmus*, except *Zelkova carpinifolia* (CABI 2015 a, b).
2. We did not find any information indicating that they would have developed resistance against any plant protection products.
3. We did not find any information indicating that they would have overcome plant resistance. Yet, some of the cultivars resistant to *O. ulmi* developed after the first DED pandemic appeared to be susceptible to the more aggressive *O. novo-ulmi* (Mittempergher & Santini 2004).

The vectors

Some of the principal DED vectors, such as *S. multistriatus* and *S. scolytus* are distributed in areas with a wide range of climatic conditions. *S. multistriatus* is present from Northern Africa (Algeria and Egypt) to Northern Europe (e.g. Sweden and Estonia), and *S. scolytus* is present from southern Europe (e.g. Spain and Italy) to Northern Europe (e.g. Sweden and Estonia) (EPPO 2014).

The vectors do not have other traits which would suggest that they are highly adaptable.

1. We did not find any information indicating that the vectors would have increased the number of genera that they feed or breed on as a result of expanding their range. Although most of the principal DED vectors, except *S. multistriatus* have been reported to have host plants from several plant genera (Wood & Bright 1992) (For more details see Appendix 2, Table A3).

2. We did not find any information indicating that the vectors would have developed resistance to any insecticides. However, this could be a result from the fact that insecticides are not commonly used since they are not an effective method for control (D'Arcy 2000).

Conclusions

Both the pathogens and the vectors are considered highly or very highly adaptable since they are present in a wide range of climatic conditions.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Answer	Uncertainty	Answer	Uncertainty
yes, highly or very highly adaptable	low	yes, highly or very highly adaptable	low

3.19 - How widely has the pest established in new areas outside its original area of distribution?

The pathogens

The origin of *O. ulmi* is not known, but it is believed to originate in Asia because the Asian *Ulmus* species are highly resistant to DED (Gibbs 1974). *O. ulmi* appeared in northwestern Europe at the beginning of the 20th century and since then it has spread throughout Europe and North America and also to New Zealand. (For more details see point 1.07.)

O. novo-ulmi is also believed to originate in Asia (Brasier & Buck 2001). In the 1940's its two subspecies appeared in Europe (subsp. *novo-ulmi*) and in North America (subsp. *americana*) (Brasier & Buck 2001). Later *O. novo-ulmi* subsp. *americana* also spread to Europe (Gibbs 1978; Brasier 1990). Currently *O. novo-ulmi* is present also in New Zealand (NZOR 2015). (For more details see point 1.07.)

The vectors

S. multistriatus is the only DED vector which is known to have been introduced to new biogeographic realms, namely from the Palearctic region to North America (Stipes & Campana 1981) and to New Zealand (Gadgil et al. 2000). Also *S. scolytus* has been intercepted in imported wood both in North America (Stipes & Campana 1981) and in New Zealand (Gadgil et al. 2000), but it has not established in either location.

Conclusions

The pathogens have spread from their assumed origin in Asia throughout Europe, North America and to New Zealand. One of the principal DED vectors, *S. multistriatus* has spread from Europe to North America and to New Zealand. The distribution of the pathogens and the vectors are well known, and hence the uncertainty of the assessment is considered low.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Answer	Uncertainty	Answer	Uncertainty
very widely	low	widely	low

3.20 - The overall probability of establishment should be described

At the moment the probability of establishment of the pathogens is considered unlikely, with low uncertainty. This is because none of the principal vectors of DED are known to be present in the PRA area. If however a vector species was established, the probability of establishment of the pathogens should be considered very likely, since parts of the PRA area have climatic conditions similar to those in the pathogens' present range.

The probability of establishment of DED vectors is considered likely, with medium uncertainty. This is because parts of the PRA area have climatic conditions similar to those in the vectors' present range. The uncertainty of the assessment is considered medium since there is not enough information about the capacity of the vectors to spread in conditions where the distance between host patches is as high as in the PRA area.

Section B: Conclusion of introduction

c1 - Conclusion on the probability of introduction

The probability of introduction of DED and its vectors is considered moderately likely, with medium uncertainty. Entry by natural spread aided by hitchhiking on vehicles would be moderately likely because DED and its vectors are present in areas from which there is frequent traffic to the PRA area. Also they are present in Russia, rather close to the Finnish border (DED 160 km, vectors 30 km), and there are no obvious barriers for purely natural dispersal. Establishment would be likely since DED and its vectors are present in climatic conditions similar to those in the southernmost parts of the PRA area. The uncertainty of the assessment is considered medium because the likelihood with which the vectors hitchhike on vehicles is not known, and because the likelihood with which a vector can transfer to a suitable host plant in the PRA area varies a lot depending on the geographical location of the introduction.

Section B: Probability of spread

4.01 - What is the most likely rate of spread by natural means in the PRA area?

Spread of the pathogens via root grafts

The pathogens can spread via root grafts only to the nearby neighboring trees (Stipes & Campana 1981). According to D'Arcy (2000) large elms growing within seven meters from each other have almost 100% chance of becoming infected through root grafts, but the likelihood is lower if the trees are at least thirteen meters apart. The rate of spread via root grafts is likely to be very slow, and its extent is limited by the spatial distribution of the trees. Yet, it could affect areas where the density of elms is high, i.e. some urban areas and naturally regenerated elm stands.

Spread of the pathogens by vector dissemination/Spread of the vectors

Vector beetles can spread over rather long distances as they fly searching for host plants. Although the newly emerged beetles are not likely to fly farther than necessary to find suitable host plants (Fransen 1939) they may disperse over long distances by drifting downstream with the wind (Byers 1995; Byers 2000). For example, *S. multistriatus* has been found in traps that were more than 8 km from the nearest elm trees (Birch et al. 1981). Thus, the vectors' rate of spread, and consequently that of DED, could be at least 8 km per year. (For more details about the vectors' dispersal capacity see point 3.09.) However, the rate will, to a large extent, depend on the spatial distribution of suitable host plants. In dense stands the rate is likely to be slow, since the vectors have no need to disperse far. On the other hand, dispersal between separate elm stands is unlikely if the stands are far apart.

Distribution of host plants

The distribution of DED host plants in the PRA area is patchy. The total area of *U. glabra* or *U. laevis* groves is about 100–150 ha, and the average size of the groves is 0.5–3 ha (Raunio et al. 2008). The groves are located on the southwestern coast and archipelago, in the Lohja area and in Häme. In addition, there are planted elms in parks, private gardens, and along streets in urban areas in southern Finland. (For more details about host distribution see point 3.09.)

Some of the vector species may also have host plants in genera that are very common in the PRA area, such as *Acer*, *Alnus*, and *Salix*. (For more details see point 3.09 and Appendix 2, Table A3.) If the vectors are also able to utilize species that are common in Finland, their rate of spread will be greater. However, this does not increase the pathogens' rate of spread. On the contrary, it may decrease the rate since the vectors would probably be more likely to feed and breed on the common hosts than to search for the very rare elms.

Both the likelihood and the rate of spread of the vector population depend heavily on the availability of dead or weakened elms since the vectors need such trees for breeding. Therefore, if DED is present, the vector population is likely to spread faster than in the absence of DED.

Conclusions

At present the pathogens could spread in Finland only very slowly via root grafts to nearby trees since the only vector species that is present in Finland (*S. mali*) is very rare and it is not likely to act as a DED vector. (For details on the occurrence of vectors see Pathway 1, point 2.10.) If one or more of the primary vector species would establish in Finland, they would have the capacity to spread the pathogens several kilometers per year. However, the low number and scattered distribution of elms in Finland is likely to slow down and often hinder the spread. For the rate in the presence of vectors the uncertainty is rated high since there is not enough information about the capacity of the vectors to spread in conditions where the distance between host patches is as high as in the PRA area, and since it is not clear if the vectors could breed also on some tree species other than elms.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Rate of spread	Uncertainty	Rate of spread	Uncertainty
In the absence of vectors	low	low	-	-
In the presence of vectors	moderate	high	moderate	high

4.02 - What is the most likely rate of spread by human assistance in the PRA area?

The pathogens and the vectors could spread within the PRA area with the movement of infected wood (i.e. wood with bark, debarked wood, and chipped wood with bark), wood packaging material, and elm plants for planting, and by hitchhiking on vehicles. (For more details on the pathways see Section B: Probability of entry of a pest.)

Movement of wood

Transport of the pathogens or the vectors via the wood trade is unlikely since domestic elms are not used by the forest industry in Finland.

The most likely human assisted wood pathway would probably be the movement of wood of ornamental trees that have been cut down because of DED symptoms. Since such wood is likely to be disposed of locally (burned or taken to a landfill) this is likely to result only in local spread. Furthermore, the likelihood of spread via wood that has been disposed of depends on the availability of host plants in the vicinity of the place of disposal. Since the host plants are not very common in the PRA area, suitable host plants are, at the maximum, only moderately likely to be available close enough to the place of disposal.

As long as DED vectors are not present in Finland human assisted spread of the pathogens in any kind of wood is very unlikely. This is because the pathogens would not be able to transfer to living trees from infected wood without a vector.

Machinery and tools

The pathogens could spread via contaminated machinery or pruning tools (Oggenorth et al. 1983), but this is likely to lead only to local spread of DED since used tools and machinery are seldom moved over long distances.

Plants for planting

With infected plants for planting the pathogens and the vectors could spread quickly to other nurseries since nurseries regularly buy plants from each other (Evira 2006). The pathogens could also be transported to existing elm stands via plants for planting in all areas to which host plants are traded. However, the vectors and the pathogens are only considered moderately likely to be associated with plants for planting. (For more information about the probability of association see Pathway 2, points 2.03 and 2.04.)

As long as DED vectors are not present in Finland human assisted spread in plants for planting could only result in establishment of new foci but not in major spread by natural means.

Hitchhiking on vehicles

Vectors carrying DED pathogens could spread very quickly over long distances within the PRA area by hitchhiking on trains and cars. (For justification see Pathway 3, point 2.03.) However, due to the patchy distribution of host plants in the PRA area, the likelihood of successful spread is assumed to be low as only a very small proportion of hitchhiking vectors would end up in suitable host plants.

Conclusions

Movement of wood from ornamental trees that have been cut down because of DED is a likely pathway for human assisted spread of the pathogens and the vectors within the PRA area. However, since such wood is likely to be disposed of locally this is likely to result only in local spread. The uncertainty of the assessment is considered medium since even single exceptions from the normal disposal practice may lead to a very fast spread rate.

Movements of infected plants for planting and hitchhiking on vehicles would lead to a high rate of spread of the pathogens and the vectors. The uncertainty of these is rated medium/high since the vectors and the pathogens are only moderately likely to be associated with plants for planting, and since the likelihood with which the vectors can spread successfully in the PRA area by hitchhiking on vehicles is not known.

As long as DED vectors are not present in Finland, human assisted spread in wood or hitchhiking on vehicles is not possible, and spread in plants for planting can only result in establishment of new foci, but not in major spread by natural means.

In the presence of vectors	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Rate of spread	Uncertainty	Rate of spread	Uncertainty
Infected wood from removed trees	moderate	medium	moderate	medium
Plants for planting	high	medium	high	medium
Hitchhiking on vehicles	high	high	high	high

4.03 - Describe the overall rate of spread

In the absence of vectors the rate of spread of the pathogens would be slow since they could spread only to the neighboring trees via root grafts. If vectors were present, the rate of spread could be much higher. Yet, it would be limited by the low number and patchy distribution of elms in the PRA area. For the rate of spread in the presence of vectors the uncertainty is rated medium since the vectors and the pathogens are only moderately likely to be associated with plants for planting, and since the likelihood with which the vectors can spread successfully in the PRA area by hitchhiking on vehicles is not known.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Rate of spread	Uncertainty	Rate of spread	Uncertainty
In the absence of vectors	low	low	-	-
In the presence of vectors	high	medium	high	medium

4.04 - What is your best estimate of the time needed for the pest to reach its maximum extent in the PRA area?

DED's rate of spread in other countries

In Quebec (Canada) DED spread at a rate of 3 100 km² per year in 1954–1959, and caused the death of 600 000–700 000 elms (Davidson 1967). In New Brunswick (Canada) the disease has spread at the rate of 5 700 km² per year, and in Ontario (Canada) the spread rate was about 9 600 km² per year (Davidson 1967). Evans & Finkral (2010) have estimated that in the eastern parts of North America DED has spread at a rate of 25 km per year, while in the western parts the rate has been only 14 km per year. In the UK the northward spread of DED in the mid-1970s occurred at a rate of more than 50 km per year (Harwood et al. 2011).

The rate of spread of the vectors in other countries

There are no detailed analyzes available about the rate at which the vectors have expanded their range. There are, however, some records which can be used to assess the potential rate of spread in the PRA area. None of these records are, to our knowledge, based on comprehensive surveys, and therefore all the below deductions are uncertain.

Scolytus multistriatus was first recorded in Canada in 1948 in southwestern Ontario, in the vicinity of Windsor, after which it spread rapidly eastward, and by 1956 it was well established in the Toronto area (Anonymous 1957). This means that the beetle spread about 41 km per year (330 km in 8 years).

S. scolytus is expected to have entered Sweden in the 2000s (Lindelöw 2012). In 2006–2007 it was found only in southern Sweden, Skåne, Halland, and on Öland, but recently it has been found also in Södermanland, which is close to Stockholm (Lindelöw 2015). From this we can infer that the beetle may have been expanding its range about 47 km per year (380 km in 8 years).

S. scolytus and *S. multistriatus* were found in Vyborg in 2014, which is about 15 years after the beetles appeared in St Petersburg (Stcherbakova & Mandelshtam 2014). This implies that the beetles may have spread by about 8 km per year (120 km in 15 years).

The maximum extent of DED and its vectors in Finland

The maximum extent of DED and its vectors in Finland is limited both by the occurrence of host plants and by the suitability of the climate. The southernmost part of the PRA area is likely to have suitable climatic conditions for both the pathogens and the vectors. The climate may be suitable also in other areas where host plants occur, but the likelihood of that decreases northwards. (For more details see point 3.03.)

Elms occur in southern Finland, on Åland, Southwest Finland, Uusimaa, Häme, Pirkanmaa, Satakunta, Kymenlaakso and South Karelia (Lampinen & Lahti 2016). (In other areas there are only some solitary trees.) The total area of these regions is about 62 000 km² (National Land Survey of Finland 2015). However, the distribution of elms in this area is very patchy, and the total area of elm groves is only about 100–150 ha (Raunio et al. 2008). (For more information about the distribution of hosts see point 3.09.)

Some of the vector species may have host plants also in genera other than *Ulmus*. (For more details see point 3.09 and Appendix 2, Table A3.) If the vectors can complete their life cycle on these plants, their maximum extent and host plant density is larger than described above.

Conclusions

In Finland the time needed for DED to reach its maximum extent depends heavily on the corresponding time for the vector populations since none of the principal vector species is currently present.

If the rate of spread of the vectors in the PRA area was similar to that observed in Leningrad Oblast, i.e. 8 km per year, the time they would need to reach their maximum extent would be more than 40 years (assuming that the distance to be covered would be 350 km, which corresponds to the distance from the Finnish-Russian border to Turku). If the rate of spread in the PRA area was similar to that observed in southern Sweden, i.e. 47 km per year, the time needed would be only about 8 years. Since the climatic conditions and the distribution of elms in the PRA area are more likely to correspond to those in Leningrad Oblast (Hultén 1950; Chuhina 2008a, b) than to those in southern Sweden, the time which the vectors would need to reach their maximum extent in the PRA area is assessed to be **more than 40 years**. In reality, it is very likely that some isolated elm stands would never be infected due to the patchy distribution of elms in the PRA area.

The **uncertainty of the assessment is considered medium** since we have no information about the movement of elm plants for planting in Leningrad Oblast, and therefore the assumed similarity of the conditions in Leningrad Oblast and the PRA area is based only on their climatic similarity and on visual comparison of small-scale elm distribution maps.

4.05 - Based on your responses to questions 4.01, 4.02, and 4.04, what proportion of the area of potential establishment do you expect to have been invaded by the organism after 5 years?

In the absence of vectors the pathogens would spread very slowly, only via root grafts, and their range would be very limited. Therefore we assume that, if vectors were not present in the PRA area, a single introduction of the pathogens would result in less than 1% of the area of potential establishment to be invaded in 5 years. This conclusion was reached by assuming that in 5 years the pathogen could cover, at the maximum, 1 ha, which corresponds to about 1% of the natural elm groves. (There is no information about the total area of urban elms and therefore the assessment is based on the area of elm groves, although introduction of the pathogen in the groves in this scenario is very unlikely. For details on the rate of spread see point 4.01.)

If the vectors would spread 8 km per year (as they may have done in Leningrad Oblast, see point 4.04), the vectors and the disease could in 5 years cover, at the maximum, 5 000 km² which is less than 10% of the area where suitable habitats are located (62 000 km²). If the vectors would spread 47 km per year (as they may have

done in southern Sweden, see point 4.04), they could in 5 years cover all the suitable habitats in the PRA area. Since the conditions in the PRA area are more likely to correspond to those in Leningrad Oblast than to those in southern Sweden, the proportion of the area of potential establishment invaded after 5 year is assessed to be **about 10%**. (For information about the rate of spread see points 4.01 and 4.02.)

The **uncertainty of the assessment is rated medium** since we have no information about the movement of elm plants for planting in Leningrad Oblast, and the assumed similarity of the conditions in Leningrad Oblast and the PRA area is based only on their climatic similarity and on visual comparison of small-scale elm distribution maps.

Section B: Eradication, containment of the pest and transient populations

5.01 - Based on its biological characteristics, how likely is it that the pest could survive eradication programs in the area of potential establishment?

Ease of detection

Early detection of a DED invasion is not straight forward as it cannot be identified visually since similar symptoms may be caused by various reasons. Instead, identification of the pathogens requires laboratory testing (D'Arcy 2000). In addition, neither resistant plants nor very recently infected plants show clear symptoms (Stipes & Campana 1981).

The detection of the vector insects is laborious since they live in and under the bark, and the relevant life stages (eggs, larvae and pupae) are only 0.6–7 mm long depending on the life stage and species (EPPO 1983). The vectors' entrance and exit holes are visible in the bark, but they are likely to remain undetected since they are only 1 mm in diameter (EPPO 1983). However, there are pheromones available, which can be used for monitoring vector populations. In the Netherlands sticky traps with a pheromone are used on a routine basis to monitor the beetle populations in some cities, e.g. in Amsterdam (Hiemstra 2016).

Rate of reproduction

The probability with which DED is able to increase in prevalence is largely determined by its vectors' characteristics since transmission to new hosts relies heavily on vectors (Stipes & Campana 1981).

In the countries neighboring the PRA area (Sweden and Russia) DED vectors have only 1-1.5 generations per year (Lindelöw 2015; Mandelshtam 2015). Hence the generation time is neither long enough to make eradication especially easy, or too short to make it unachievable. One *S. scolytus* female lays about 60-110 eggs, and *S. multistriatus* about 100-150 eggs (Fransen 1939). The beetles use aggregation and sex pheromones to attract conspecifics to a suitable host tree (Byers et al. 1980, Gore et al. 1977, Webber 2004), and several females lay all their eggs in the same tree. This behavior is likely to make eradication somewhat easier than if the eggs were spread to many host trees.

Rate of natural spread and spread by hitchhiking on vehicles

In the absence of vectors the pathogens can spread only over very short distances, via root grafts (Stipes & Campana 1981). In such a situation the extent of spread is limited to individual stands of host trees.

If vectors are present they are able to disperse and spread the pathogens over long distances. Although the newly emerged beetles are not likely to fly further than necessary to find suitable host plants (Fransen 1939) they may disperse over long distances by drifting downstream with the wind (Byers 1995; Byers 2000). For example, *S. multistriatus* has been found in traps that were more than 8 km from the nearest elm trees (Birch et al. 1981). (For more details about the dispersal capacity of the vectors see e.g. point 3.09.) By hitchhiking on vehicles the vectors can spread very quickly over long distances.

Since elms are rare in the PRA area the vectors' rate of spread is largely determined by the spatial distribution of the host trees. However, once a beetle has located a suitable host tree it releases aggregation and sex pheromones to attract more beetles to colonize the tree (Byers et al. 1980, Gore et al. 1977, Webber 2004).

Suitability of climatic conditions and availability of hosts

The southernmost parts of the PRA area are likely to have climatic conditions that are largely similar to those in DED's and its vectors present range. In other parts of the country, where host plants are present, conditions may also be suitable but the likelihood of that decreases northwards. (For details on the suitability of the climate see point 3.03.)

Elm density in the PRA area is very low and their distribution is highly patchy. The density is higher only in some cities in southern Finland and in the few natural elm groves. (For details on the distribution of host plants see point 3.09.) This is likely to facilitate eradication efforts considerably.

Some of the vector species may have host plants also in genera that are very common in the PRA area, such as *Acer*, *Alnus*, and *Salix*. (For more details see point 3.09 and Appendix 2, Table A3.) If the vectors were able to utilize these plant species their eradication would be significantly more difficult, probably impossible. However, this would probably not hamper DED eradication programs since the pathogens cannot develop in the other plant species.

Ease of eradication measures

There are no effective measures which could be applied easily on a large spatial scale to eradicate either the pathogens or the vectors (Stipes & Campana 1981). Instead, eradication requires that all infected trees, including those that don't show symptoms, are felled, and their stumps are treated with herbicide to kill the root systems in order to prevent further spread of DED via roots and suckers (Stipes & Campana 1981; Menkis et al. 2015). This is necessary because the pathogens can remain viable for many years within the root system, from where they can sometimes transport to the suckers growing from the roots (Gibbs et al. 1994).

Eradication of the vectors in the absence of DED is complicated by the fact that the vectors alone do not damage the plants, and therefore locating all infested trees is very difficult.

Earlier eradication programs

O. ulmi was introduced into the PRA area in the 1960s, but it was eradicated soon after (Hintikka 1974). Eradication was successful because vectors were not present in the area.

In the town of Wainwright in Canada (Alberta) one tree was found infected with DED in 1998 (Tewari et al. 2001). This is the only finding of the disease in the state of Alberta. The tree was immediately removed and burned, and the disease was eradicated. Yet, small numbers of vector beetles have been found throughout the province since 1994 (STOPDED 2015).

In the eastern states of the USA eradication of DED was attempted in the 1930s by locating and destroying all infected trees (Worthley 1935; Wilson 1975). At the beginning of the eradication campaign DED was found in more than 7 600 trees, and it was already present in several cities in six states. During the first 4.5 years more than 28 000 diseased trees were removed, but eradication was not achieved, presumably due to the inability to detect all infected trees. Although the program failed to prevent the geographical spread of DED, it managed to reduce the infection rate to virtually zero in the affected areas.

In the region of Auckland in New Zealand an eradication program was launched immediately after the detection of DED in 1989 (Gadgil et al. 2000). The program included 1) surveys to locate all elm trees, 2) surveys to detect and remove the infected trees, and 3) a pheromone trapping program to delineate the distribution of the vector. During the first season of the program 83 infected elms were found in 19 different locations. In the first few years the number of new diseased trees declined, but in 1992-1993 the number was observed to have increased markedly. This was probably due to the failure to locate and remove the diseased elm trees that were not yet showing clear symptoms. Later, an attempt was made to prevent the disease from spreading via root grafts by digging a trench between the removed and the remaining trees. This turned out to be ineffective, and consequently at the final stage of the campaign all trees that could possibly have root grafts with diseased trees were removed. Still, the program has not been successful in eradicating DED although it has managed to prevent DED from spreading outside Auckland.

In the city of Napier in New Zealand, about 350 km from Auckland, some DED infected trees were found in 1993 (Kershaw 1994). The trees were removed, and DED was eradicated. Vectors were never found in Napier.

On the island of Gotland in Sweden measures have been taken to combat DED since 2005 (Menkis et al. 2015). During the first year of the campaign 71 infected trees were found in an area covering 15.8 km². In 2008 the number of new infected trees was more than 3 200, and the infected area was 1 446.2 km². During these first five years the strategy was to locate and destroy all visually diseased trees. Since 2009 also visually healthy elms growing in the vicinity of diseased trees have been

destroyed in order to target also the trees which may have been infected via root grafts. As a result the number of infected trees per year has remained relatively stable. Stumps of the destroyed trees have been treated with herbicides to kill the root systems and to prevent the spread of the disease via roots and sprouting. DED has not yet been eradicated from Gotland but the campaign is still ongoing, at least until 2018 (LifeELMIAS 2013).

In the Netherlands a national eradication program was started in the late 1970's after the onset of the epidemic caused by *O. novo-ulmi*. At the beginning of the program DED was already widespread and had killed hundreds of thousands of elms. The program included monitoring and sanitation. Diseased trees were removed as soon as possible, and the wood was burned, stored under water, or the bark was stripped away in order to prevent the vectors from breeding. That program was very successful in decreasing the proportion of diseased trees. Consequently, the national program was ended in 1992, and the responsibility was given to the local authorities. At the moment there are successful sanitation programs running in the city of Amsterdam and in two northern provinces (Friesland and Groningen). There the annual loss of trees is very low (< 0.5 %). In other areas DED is much more prevalent (Hiemstra 2015).

Conclusions from the earlier eradication programs

The climate in the areas where eradication has failed thus far differs from that in the PRA area. According to the Köppen-Geiger classification the climate type in the eastern states of the USA, Auckland, Gotland and the Netherlands is warm temperate (Cfa and Cfb) (Kottek et al. 2006). In the PRA area the climate type is snow climate (Dfb and Dfc). This difference may affect both the vectors' survival rate and their generation time. Consequently, the probability of successful eradication may be higher in the PRA area than in the reference areas.

Also host plant density in the areas where eradication has failed thus far differs from that in the PRA area. We did not find exact information about the density of elms in all of these areas, but the following reasoning supports the assumption that elm density is much lower in the PRA area than in the reference areas.

- In the PRA area the total number of elm trees is likely to be less than 20 000. (For details see point 3.09.) If all these elms were located in an area of the size of Uusimaa (9 568 km²), the overall density of elms in the area would be 2.1 elms/km². Since elms are in fact located in a much wider area the actual elm density in the PRA area is much lower.
- In New York City (1 214 km²) the number of diseased trees found at the beginning of the eradication campaign was more than 7 600. The density of these diseased trees was 6.3 elms/km². Since not all trees were diseased the actual density of elms in New York was much higher.
- According to Wilcox & Inglis (2003) there are about 20 000 elms in Auckland, and according to Gadgil et al. (2000) there are about 13 000 elm locations in Auckland. We were not able to deduce whether the authors refer to the City of Auckland (559 km²) or the Auckland Region (4 894 km²). However, based on the inconsistency between these figures we assumed that Wilcox & Inglis (2003) refer to the city and Gadgil et al. (2000) refer to the region. If this is the case, the density of elms in the city would be 36 elms/km².

- On Gotland (2 994 km²) there are more than one million elm trees (Menkis et al. 2015). Hence the density of elms there is about 334 elms/km².
- In the Netherlands (41 548 km²) hundreds of thousands of elms had already died due to DED at the beginning of the eradication program, i.e. the density of these dead elms was at least 4.8 elms/km². This considerable difference between host plant density in the PRA area and the reference areas is likely to affect the spread rate of DED and its vectors. Therefore the probability of successful eradication in the PRA area may be much higher than in the reference areas.

Conclusions

Currently the pathogens are very unlikely to survive eradication programs since the vectors are not present in the PRA area. If strict measures were taken, DED would be unlikely to survive a program aiming to eradicate it from the PRA area even if vectors were present. This is because the patchy distribution of elms would limit the spread of the disease and make eradication easier. Successful eradication might, however, require destruction of all elms in the affected area (e.g. a whole city). The uncertainty of the assessment is considered medium because eradication attempts in the present range of DED have not been successful, and because the needed measures may be too costly and too drastic to be implemented in a timely manner.

The vectors are considered likely to escape eradication programs. This is because the vectors alone do not damage the plants, and therefore locating all of the infested plants would be very difficult. Also, if the vectors were able to breed on the other reported host plants, eradication would be very difficult.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Likelihood	Uncertainty	Likelihood	Uncertainty
In the absence of vectors	very unlikely	low	-	-
In the presence of vectors	unlikely	medium	likely	low

5.02 - Based on its biological characteristics, how likely is it that the pest will not be contained in case of an outbreak within the PRA area?

For information on the relevant biological characteristics of the pathogens and vectors see point 5.01.

Earlier containment programs

In the region of Auckland in New Zealand an eradication program was launched immediately after the detection of DED in 1989 (Gadgil et al. 2000). Although the program has not been successful in eradicating DED it has managed to prevent DED from spreading outside Auckland. (For more details about the program see point 5.01.)

In Canada DED is present in all provinces except Alberta and British Columbia. Alberta has taken official measures to prevent the spread of DED and its vectors to its territory. For example, movement of elm firewood to Alberta is prohibited, and a monitoring

program is run to detect possible invasions of DED and its vectors (STOPPED 2015). British Columbia has not taken official measures, but it is advising e.g. not to transport elm firewood, and to buy elm plants for planting only from local nurseries (Anonymous 2010). These provinces have managed to contain DED outside their territory. However, it is not clear if their success is due to the measures or merely to the unsuitability of the climate. According to the Köppen-Geiger climate classification (Kottek et al. 2006) most of Alberta and British Columbia have snow climate with cool summers and cold winters (Dfc), and there are only some patches of snow climate with warm summers (Dfb). Only the areas close to the coast in British Columbia have warm temperate climate (Cfc). The present range of DED does not include areas with Dfc climate, but it does include areas with Dfb and Cfc climate.

In Great Britain some attempts were made to limit the spread of *O. novo-ulmi* after it was introduced there in the early 1960s (Gibbs 1978). But, by 1976 the pathogen had spread through most of England and Wales (Gibbs 1978). The failure of this containment attempt has been attributed to a delay in initiating the measures and to a lack of national measures. However, Harwood et al. (2011) used modeling to retrospectively assess the effect of different management strategies on the development of the DED epidemic in the United Kingdom. Their results suggest that even a high intervention starting at an early stage of the epidemic would have had little long term effect on spread of the disease. In the studied “high intervention” management strategy 90% of dead trees and 30% of live trees (infected and uninfected) were cut down annually. A higher removal rate was considered unachievable due to limitations of manpower.

Conclusions from the earlier containment programs

The fact that in New Zealand DED has been contained in Auckland suggests that containment could be possible also in the PRA area. This is especially since climate and host plant density are much less favorable to the pathogens and the vectors in the PRA area than in Auckland (For details see point 5.01).

The absence of DED in Alberta and British Columbia is not necessarily attributable to the measures taken by the provinces. Instead it may be, at least partly, owing to unfavorable climatic conditions. In most areas of these provinces the Köppen-Geiger climate type (Kottek et al. 2006) is the same as in most of Finland, i.e. snow climate with cool summers and cold winters (Dfc). Only some patches have the same type as that of southernmost Finland, i.e. snow climate with warm summers (Dfb). The fact that Alberta and British Columbia have managed to keep DED out of their territory, suggests that it may be possible to keep DED out of the PRA area too, and if it enters it may be possible to contain it.

The failure to contain *O. novo-ulmi* in Great Britain, and especially the modeling results of Harwood et al. (2011), suggests that containment of the pathogen is difficult. However, the Köppen-Geiger climate type in the UK is warm temperate (Cfb) whereas in the PRA area it is snow climate (Dfb, Dfc) (Kottek et al. 2006). Also, elm density in Great Britain (209 331 km²) at the time was much higher than it is in the PRA area since there were more than 20 million elms there at the beginning of the *O. novo-ulmi* epidemic (Harwood et al. 2011). This implies that the overall elm density was at least 96 elms/km², whereas the respective figure for the PRA area is

at most 2.1 elms/km² (see point 5.01 for details). These differences in climate and elm density are likely to profoundly affect the development of DED epidemics. Therefore the probability of successful containment in the PRA area may be much higher than it was in Great Britain.

Conclusions

Currently the pathogens are very unlikely to escape containment programs since the vectors are not present in the PRA area. Even if vectors were present, DED and its vectors would be unlikely to escape large scale containment programs, e.g. programs aiming to contain DED to one city in order to save the elms in other cities. This is because the distribution of elms in the PRA area is patchy, and because natural and human assisted spread between isolated patches is rather unlikely. (See points 4.01 and 4.02 for more details on natural and human assisted spread.) The uncertainty of the assessment is considered medium since it is not known how likely the vectors would hitchhike on vehicles, and since there is not enough information about the capacity of the vectors to spread in conditions where the distance between host patches is as high as in the PRA area.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Likelihood	Uncertainty	Likelihood	Uncertainty
In the absence of vectors	very unlikely	low	-	-
In the presence of vectors	unlikely	medium	unlikely	medium

5.03 - Are transient populations likely to occur in the PRA area through natural migration or entry through man’s activities (including intentional release into the environment) or spread from established populations?

Natural migration aided by hitchhiking on vehicles

Vectors contaminated with the pathogens may spread to the southern parts of the PRA area naturally or aided by hitchhiking on vehicles at least from Russia, Sweden and Estonia. The vectors would be likely to enter a part of the PRA area in which the climate is considered to be suitable for the pathogens and the vectors, i.e. southernmost Finland. Consequently, transient populations are unlikely to occur through natural migration or migration aided by hitchhiking on vehicles. (For information about the suitability of the climate see point 3.03.)

Adult vectors could migrate also to areas where winters are too cold for larval development, but this is considered unlikely. In such a case uncontaminated vectors would not cause damage, but contaminated vectors would transmit the disease to local elms.

Entry through man’s activities

The pathogens and the vectors could enter the PRA area with the movement of infected wood (wood with bark, debarked wood, or chipped wood with bark), wood packaging material, and elm plants for planting. At present the probability of entry via these pathways is considered unlikely, with low uncertainty. (For more details on the pathways see Section B: Probability of entry of a pest.)

If the pathogens or the vectors would enter the country through man’s activities, they could arrive at all parts of the PRA area although the probability of that would be higher in the southern parts of the country since the human population density there is higher. Also, the use of elms as ornamental trees is more common in the south since the conditions are more favorable there.

In the southern parts of the PRA area transient populations would be unlikely, but in the more northern parts transient populations might occur since the winters there may be too harsh for the vectors. Transient populations of uncontaminated vectors would not cause any damage, but contaminated vectors would transmit the disease to local elms.

In the absence of vectors the pathogens introduced by man’s activities could form transient populations even in the southernmost parts of the PRA area if the infected trees were not in close contact with other elms. In such a case the pathogens would not be likely to spread to other trees but the epidemic would eventually die out with the diseased trees.

Conclusions

Transient populations are considered unlikely to occur through natural migration aided by hitchhiking on vehicles since conditions in the areas where the populations are likely to arrive are considered suitable for the pathogens and the vectors. Through man’s activities transient populations are considered unlikely to occur since entry via human assisted pathways is considered unlikely, with low uncertainty.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Likelihood	Uncertainty	Likelihood	Uncertainty
no	low	no	low

Section B: Assessment of potential economic consequences

Economic impact “sensus-stricto”

6.01 - How great a negative effect does the pest have on crop yield and/or quality of cultivated plants or on control costs within its current area of distribution?

Nature of the damage

The symptoms of DED are crown discoloration, leaf wilting, and formation of dark streaks of discoloration in the infected sapwood visible in the cross section as brown rings (Stipes & Campana 1981; Ghelardini & Santini 2009). Depending on the severity of the infection the susceptible trees may die rapidly, within one year, or slowly, within two or more years (Stipes & Campana 1981). Resistant trees are able to deal with the disease by restricting the pathogen, and thereby also its symptoms, close to the area of the initial infection (Stipes & Campana 1981; Smalley & Guries 2000; Townsend 2000; Ghelardini & Santini 2009).

DED vectors alone do not cause damage since they breed on dead or weakened trees or branches (Stipes & Campana 1981).

Affected industries

DED infection severely affects the quality of the wood and decreases its value as symptomatic wood is suited only for fuel wood or low quality sawn wood used, e.g. as wood packaging material. DED infection also significantly decreases the value of ornamental trees as the aesthetic value of the trees degrades, and eventually most of the trees die.

In nurseries DED is not likely to have major direct effects since DED vectors are not likely to feed and breed on young trees. Still, measures are needed to ensure that the plants for planting are free from DED, and if the measures are not a part of the normal practice of the nurseries they incur some extra costs.

Effect of DED in its current area of distribution

In the USA DED was first recorded in 1930 in Cleveland and Cincinnati, Ohio, (Stipes and Campana 1981) from where it rapidly spread throughout eastern North America (Stipes and Campana 1981). In northeastern USA 75% of the elms had died by 1979 (Campbell & Schlarbaum 1994), and in midwestern USA more than 40 million elms have been killed by the disease (Dunn 2000). For example in 1979 in Colorado alone expenditures on DED control programs amounted to over 1 million euros. Nationwide the removal of dead and dying elms has cost up to 93 million euros per year (Campbell & Schlarbaum 1994). The disease has also virtually eliminated American elm as a timber species (Campbell & Schlarbaum 1994).

In Canada DED was discovered in the eastern parts of the country in the 1940's (Anonymous 1957). In some areas the disease incidence has been kept low with successful control programs, while in other areas DED has killed most of the elms. In Montreal DED killed 90% of the city's 50 000 elms in 1970–1980, and in Toronto 80% of the city's 35 000 elms were killed by 1976 (Rioux 2003). In Fredericton, where DED appeared in 1961, 30% of the elms were lost to the disease over 30 years (Rioux 2003). In Quebec City a program is run to control DED. As a result the disease incidence is only about 2% (Rioux 2003). In Regina, where DED was first recorded in 1981, only 28 of the city's 100 000 *U. americana* trees had been killed by 2003 due to a successful control program (Rioux 2003). In Manitoba about 1 million euros was spent annually to control DED in 1981–1991 (Westwood 1991). The program managed to keep the disease incidence under 2.5%.

In Germany DED causes losses of about 5 million euros annually in urban areas (Reinhardt et al. 2003). This consists of 1.7–1.9 million euros that is spent in removing and replacing infected trees, and about 3.2 million euros of lost value of established trees.

In Austria most of the mature elms have disappeared after the introduction of DED (Kirisits & Konrad 2004), and the elm has lost its place as an economically important timber species. In the forests along the Morava the proportion of elms has decreased from about 5–25% to about 1% (Kirisits & Konrad 2004). Likewise, along the Danube the proportion of elms in the forests has decreased from about 5–10% to about 1% (Kirisits & Konrad 2004).

In Amsterdam about 930 000 euros is spent annually in monitoring DED, removal and replanting trees, and coordination (Bleeker & Kaljee 2012).

In Sweden, in Skåne, 97 000 elms were felled in a DED control program in 1986–2004 (Gren et al. 2007). The original size of the elm population in the area was about 230 000 trees, ergo more than 40% of the elms were destroyed during the program (Gren et al. 2007). In Stockholm 2 600 trees were felled due to DED over a period of eight years (1999–2006) at an annual cost of approximately 105 000 euros (Gren et al. 2007). In Malmö 4 160 trees were felled over three years (2004–2006) at a total cost of 1.11 million euros (Gren et al. 2007).

In St Petersburg, Russia, where DED was introduced in 1998 (Stcherbakova & Mandelshtam 2014), 30% of the elms in the city were infected by the year 2013. The area of DED distribution in the city doubled in five years (2009–2013), from 65.1 km² to 134.5 km² (Serebritskiy 2014).

Conclusions

In its current area of distribution DED has caused massive elm mortality and huge control costs.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Extent	Uncertainty	Extent	Uncertainty
massive	low	-	-

6.02 - How great a negative effect is the pest likely to have on crop yield and/or quality of cultivated plants in the PRA area without any control measures?

Industries at risk in the PRA area

In the PRA area DED could affect ornamental trees in urban areas and elms occurring naturally in the forests. Forestry would not be affected though since elms are not used for forestry purposes in Finland. This is because both the naturally occurring elm species (*U. glabra* and *U. laevis*) are protected under the Nature Conservation Decree (160/1997). Although DED could infect nursery plants, the nursery production is not likely to be affected severely since there is some indication that DED vectors prefer to feed on large trees (Webber 2004), and they breed only on dead or severely weakened trees or branches (Stipes & Campana 1981).

Effect in areas climatically similar to Finland

DED has caused considerable elm mortality in areas which are climatically similar to southernmost Finland, i.e. areas with the Köppen-Geiger climate type Dfb (Kottek et al. 2006). In St Petersburg (Russia) the area occupied by DED doubled in five years (2009–2013, from 65.1 km² to 134.5 km²), and by 2013 30% of the elms in the city were infected (Serebritskiy 2014). In Montreal (Canada) the original population of 50 000 elms was reduced by 90% in ten years (1970–1980), and in Toronto (Canada) the original population of 35 000 elms was reduced by 80% by 1976 (Rioux 2003). In Fredericton (Canada) 30% of the elms were lost to the disease in 30 years (Rioux 2003). The situation in St Petersburg very much corresponds to a situation where no

control measures are applied. This is because infected trees aren't removed until they are dead (Mandelstam 2015). In the Canadian examples some control measures may have been applied, but no measures are described in the referred paper.

The expected severity and geographical extent of the damage in the PRA area

It is likely that DED would kill elms also in the PRA area. This is because all elm species that are present in the PRA area are highly susceptible to DED (Stipes & Campana 1981; Webber 2000; Solla et al. 2005; Ghelardini & Santini 2009), and because the climate in the southernmost parts of the PRA area is likely to be suitable for the pathogens and the vectors. The climate may be suitable also in other parts of the PRA area where host plants are present, but the uncertainty of that increases northwards. (For details on the suitability of the climate see point 3.03.)

As long as the vectors are absent from the PRA area the effects of DED would be very limited. This is because a) DED could spread naturally only to nearby trees via root grafts, b) human assisted spread in wood would not be possible, and c) spread in plants for planting would only result in establishment of new foci, but not in major spread by natural means. (For more information see points 4.01 and 4.02.)

If vectors were introduced to the PRA area, the rate of spread of DED would be much faster, it could spread between more isolated host patches, and consequently it could cause more damage. (For more information on the rate of spread see points 4.01 and 4.02.) However, the low number and patchy distribution of elms in the PRA area would still limit the distribution of DED. (For details on the distribution of host plants see point 3.09.) In some cases epidemics might even be contained spontaneously since natural spread between isolated elm patches would be unlikely. However, in the areas where the density of elms is high, such as in some cities in southern Finland and in the natural elm groves, DED could cause very high mortality.

Conclusions

In the absence of vectors the effects of DED would be minor even without any control measures. This is because without vectors DED can only spread to nearby trees via root grafts. If vectors were present in the PRA area, the effect of DED could be massive as the mortality of infected trees would probably be high. The uncertainty of the assessment is rated medium because the extent of the damage depends on the location of the invasion, and in isolated host patches epidemics might be contained even without control measures.

DED vectors alone do not cause notable damage since they breed on dead or weakened trees or branches (Stipes & Campana 1981).

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Extent	Uncertainty	Extent	Uncertainty
In the absence of vectors	minor	low	-	-
In the presence of vectors	massive	medium	minimal	low

6.03 - How great a negative effect is the pest likely to have on the yield and/or quality of cultivated plants in the PRA area without any additional control measures?

Current measures in the forests

No management measures are currently applied to elms occurring naturally in the forests. Elms are not used for forestry purposes in the PRA area, and both the naturally occurring elm species are protected under the Nature Conservation Decree (160/1997).

Current measures in the urban areas

The measures currently applied in Finnish cities are limited to removing dangerous dead trees and branches. No specific control measures are applied against any pests or diseases (Terho 2015). Although removing dead trees and branches is important in controlling DED the measures currently applied in the cities would not have much impact on the damage caused by DED. This is because non-dangerous dead trees and branches (e.g. small branches) are not removed, and therefore DED-infected material could be constantly available to support further spread of the disease.

Current measures in the nurseries

Some cultural practices which are commonly used in nurseries, such as strict hygiene and removing dead or severely weakened trees and branches, would provide some control over the pathogens and the vectors. Yet, such measures would not fully protect nursery trees from DED infections, especially if there are elm trees in the surroundings of the nursery.

Conclusions

The negative effect caused by DED in the PRA area without any additional control measures is expected to be similar to that without any control measures (see point 6.02) since the measures currently applied in the PRA area are not likely to have much impact on the damage caused by DED.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Extent	Uncertainty	Extent	Uncertainty
In the absence of vectors	minor	low	-	-
In the presence of vectors	massive	medium	minimal	low

6.04 - How great a negative effect is the pest likely to have on the yield and/or quality of cultivated plants in the PRA area when all potential measures legally available to the producer are applied, without taking phytosanitary measures?

Detection of infected trees

Detection of the trees that are infected with DED and/or attacked by its vectors is a prerequisite for all the other control measures in urban areas, forests, and in the nurseries.

Most trees infected with DED can be detected rather easily since in susceptible trees DED causes clear visible symptoms, such as crown discoloration and wilting, yellowing and drying of the leaves, death of individual branches, and eventually death of the whole tree (Stipes & Campana 1981). However, resistant trees and trees which have been infected very recently do not always show clear symptoms. Detection of DED is complicated by the fact that symptoms similar to DED may be caused by many other reasons, and therefore identification of *O. ulmi* s.l. always requires laboratory testing (D'Arcy 2000).

The presence of vector insects in an area can be monitored relatively effortlessly with pheromone traps or using trap trees or logs (de Bruin et al. 2013). Yet, detecting the individual trees attacked by the vectors is difficult. This is because the vectors live in and under the bark, and their relevant life stages (eggs, larvae and pupae) are only 0.6–7 mm long depending on the life stage and species (EPPO 1983). The vectors' entrance holes are visible in the bark, but they are likely to remain undetected since they are only 1 mm in diameter (EPPO 1983).

In most parts of the PRA area the number of elms is rather low which should facilitate detection of infected trees, especially in urban areas and in the nurseries.

Removal of infected trees and branches

Destroying all infected elms is the most effective measure to control DED (Stipes & Campana 1981; de Bruin et al. 2013). The roots of infected trees also need to be destroyed, e.g. with herbicides, because the pathogens can remain viable in the roots of dead trees for several years and spread from there to living trees (Stipes & Campana 1981; Menkis et al. 2015).

Sometimes only the diseased parts of the tree are disposed of, and the rest of the tree is left to regenerate (de Bruin et al. 2013). This may be effective only if the infections are located, identified, and removed very quickly, before the disease has spread to other parts of the tree and to its neighbors.

Prevention of the spread of DED via root grafts

The spread of the disease via root grafts can be prevented if all root grafts are broken, e.g. by digging a trench between adjacent elms. This is rather expensive, and therefore it is feasible only in locations which are easy to reach by large machinery. In East Sussex, where a DED control program has been running since 1971, the method is applied rather rarely due to the high costs and the difficulties in getting the digging equipment into remote places (de Bruin et al. 2013).

Another method used to prevent the spread of the pathogen via root grafts is ring barking which aims to stop the disease in the tree before it enters the root system. According to Cannon et al. (1982) prompt detection, girdling, and removal of diseased elms saved more trees at a lower cost than sanitation practices in which diseased elms were just removed promptly or were allowed to remain standing into the dormant season.

Removal of all dead or declining elm material

Removal of all plant material suitable for the vectors' breeding, i.e. all dead or weakened elm trees and branches, including those that have died for reasons other

than DED, is an important method for controlling vector populations (Stipes & Campana 1981; de Bruin et al. 2013).

Trap trees

Trap trees are infected or uninfected, dead or weakened elms or logs of elm which are left unremoved for the duration of the vectors' mating and oviposition season. The idea is to attract the vectors to lay their eggs in these trees, instead of unaffected trees. The trap trees are destroyed before the adult beetles emerge, thereby reducing the beetle populations and preventing spread of the disease. In East Sussex this has been seen as a cost-effective approach to reduce the beetle population with the minimum felling of elms (de Bruin et al. 2013).

Chemical control

Fungicide injections of individual trees can be used to prevent new DED infections or movement of the fungi into the healthy parts of the tree (D'Arcy 2000). At least propiconazole, thiabendazole and carbendazim are used to control DED in its current area of distribution (Haugen & Stennes 1999; Scheffer et al. 2008; Grondin & DesRochers 2015). Of these propiconazole and thiabendazole are approved in the EU (EU Pesticides database 2015). Several plant protection products with propiconazole are authorized also in Finland, but at the moment none of them is authorized for use on outdoor ornamental plants (Tukes 2015). In the USA fungicides are sometimes used to protect trees from DED, but because the treatment is expensive it is considered appropriate only for valuable, historically important trees (Haugen 1998).

Chemical control of DED vectors is possible, but it is expensive and difficult to apply because the crowns of the trees need to be treated individually (Stipes & Campana 1981). At least chlorpyrifos, carbaryl, methoxychlor, emamectin and azadirachtin are used to control the vectors in the current area of DED distribution (Hartman & Eshenaur 2002; Davis 2011; Oghiakhe & Holliday 2011; CWS 2015). Of these chlorpyrifos, emamectin and azadirachtin are approved in the EU (EU Pesticides database 2015), but no products with these active substances are currently authorized in Finland (Tukes 2015). Some pesticides, such as Calypso SC 480 (thiacloprid) and Cyperkill 500 EC (cypermethrin), are authorized for controlling insect pests, including beetles, on outdoor ornamental plants in Finland (Tukes 2015), but we have no information about their effectiveness against DED vectors. There are no pesticides authorized in Finland that could be used for controlling DED vectors in the forests (Tukes 2015).

Preventive treatment

Elm trees can be protected from DED infection by inducing their immune response using Dutch Trig® (Anonymous 2015). Its active ingredient is the conidiospores of a specific *Verticillium albo-atrum* isolate which enhance the natural defense mechanism of elms (Postma et al. 2014). The product does not protect already infected trees or trees connected with diseased trees via root grafts, but it is very effective in protecting healthy trees (Postma et al. 2014). However, the treatment is expensive as trees have to be treated individually, and the treatment has to be applied annually. The active substance of Dutch Trig® is approved in the EU (EU Pesticides database 2015), but it is not authorized for use in Finland (Tukes 2015).

Use of resistant elms

Use of resistant elms is an important method of protection against DED. In resistant trees the pathogens are usually restricted close to the area of the original infection, in the upper periphery of the crown (Stipes & Campana 1981), and the trees may be completely symptomless (Stipes & Campana 1981; Smalley & Guries 2000).

Use of resistant trees is likely to affect not only the prevalence of DED but also the density of the vector populations. This is because the number of dead elms available for the vectors' breeding sites is reduced. Still, the use of resistant varieties is not likely to eliminate the pathogens or the vectors completely since also resistant trees, or parts of them, may be infected once the tree has died or a branch has fallen off (Stipes & Campana 1981).

Cultural practices in the nurseries

Cultural pest management practices (such as the use of proper plant materials, proper fertilization, watering and pruning, preventative disease and insect control, strict hygiene, eliminating dead or severely weakened elm trees and unhealthy branches, and preventing root grafts) may significantly decrease the probability of nursery trees becoming infected with the pathogens and colonized by the vectors (Stipes & Campana 1981; Ward et al. 2012). Such practices will reduce the sources of infection, protect the trees from the vectors, and reduce plant stress, and hence make the plants less susceptible to the pathogens.

Applicability of the measures in the PRA area

All the above measures could be used in the PRA area in urban areas and in the nurseries, except for the fungicides, pesticides and Dutch Trig® which are not authorized in Finland. Use of resistant trees might, in some locations, have undesirable consequences as resistant trees might crossbreed with natural elms, and contaminate the genome of these threatened vulnerable species (Allendorf et al. 2001; Cox et al. 2014).

Most of the above measures could not be applied on naturally occurring *U. glabra* and *U. laevis* without special permission (Nature Conservation Act 1096/1996 sections 42 and 48) as the species are protected by the Nature Conservation Decree (160/1997). Also in national parks and nature reserves (kansallispuisto and luonnonpuisto) most of the measure would require special permission (Nature Conservation Act 1996/1096, sections 13 and 15). However, uninfected logs of planted elms could be brought to the forests to act as trap trees without special permission, and chemical control would require special permission only in national parks and nature reserves. Resistant trees could, in principle, be planted in the forests, except in protected areas. Yet, this is not a viable option as the resistant trees might crossbreed with natural elms, and contaminate the genome of these threatened vulnerable species (Allendorf et al. 2001; Cox et al. 2014).

Both in urban areas and in the forests DED control would be hampered by the fact that a part of the elm population is on privately owned land. If not all owners of infected and threatened trees would be willing to carry out the measures, the efficacy of the management would be seriously compromised. This is especially likely in privately owned forests as the naturally occurring elm trees have no monetary value.

Effectiveness of the control measures in the present area of distribution

Controlling DED in urban areas seems to be possible as there are examples of successful control programs run in urban areas. Quebec City (Canada) managed to keep the disease incidence at about 2% (Rioux 2003). In the city of Regina (Canada) only 28 of the city's 100 000 *U. americana* trees were killed by DED by 2003 (Rioux 2003). The province of Manitoba (Canada) managed to keep the disease incidence under 2.5% in 1981–1991 by a control program run in urban and rural areas (Westwood 1991). In East Sussex (UK) the control program has been so effective that the number of elms in the control zone has increased since the introduction of DED (ESCC 2015). All the above-mentioned Canadian locations are situated in the same Köppen-Geiger climate zones (Kottek et al. 2006) as the PRA area (Dfb and Dfc), while East Sussex is located in a more southern zone (Cfb). Therefore it is reasonable to assume that such management might be possible also in the PRA area.

Controlling DED in forests is likely to be much more difficult. *O. novo-ulmi* was introduced to United Kingdom in the early 1960s (Gibbs 1978). Some attempts were made to limit its spread in northern and western Britain, but by 1976 the strain had spread through most of England and Wales (Gibbs 1978). Harwood et al. (2011) used modeling to retrospectively assess the effect of different management strategies on the development of this DED epidemic. The management strategies compared were 1) no management, 2) the management that was applied, and 3) a high intervention continuous sanitation program. Their results suggest that a high intervention starting at an early stage of the epidemic could have slowed down the initial decline of the elm population, but would have had little long term effect on the spread of the disease.

Conclusions

In urban areas and in the nurseries the damage caused by DED could probably be reduced significantly (from massive to moderate) if all control measures legally available, without phytosanitary measures, would be taken.

In the forests most control measures would require special permission as the naturally occurring elm species are protected by the Nature Conservation Decree. Without the permission very little could be done, and the measures would be very unlikely to have any effect on the damage caused by DED. If permission was granted, the damage caused by DED could probably be reduced significantly (from massive to moderate) also in the forests. Since DED threatens the protected elm species it is reasonable to assume that special permission would be granted.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Extent	Uncertainty	Extent	Uncertainty
In the absence of vectors	minor	low	-	-
In the presence of vectors	moderate	medium	minimal	low

6.05 - How great an increase in production costs (including control costs) is likely to be caused by the pest in the PRA area in the absence of phytosanitary measures?

Urban areas

The increase in production costs in urban areas depends on the measures that are taken. At a minimum, dangerous dead trees and branches need to be removed. At a maximum, all control measures legally available, without phytosanitary measures, can be taken. (See point 6.04 for a description of the possible measures.)

If only dangerous trees and branches were removed, the costs would consist of the cost of monitoring, assessing the condition of the trees, removing dangerous trees and branches, and planting of new trees. These measures are taken also in normal situations, but if DED was introduced, the number of dead and weakened trees and consequently the cost of the measures would increase.

The cost of a management strategy in which all control measures legally available, without phytosanitary measures, are taken is difficult to assess as it would require information about the costs of all possible measures. However, as removing and destroying infected trees and the trees in their close proximity is the most important control measure the cost of these measures can be used to estimate the costs of the “all available measures” strategy.

The costs of DED management strategies were estimated using management costs in the city of Helsinki (Terho 2015). In Helsinki an assessment of the condition of an old tree costs about 250–500 euros per tree, and removal and destruction of a tree costs about 2 000 euros per tree. Planting of a new tree in a park costs 1 000 euros, and planting one by a street costs 2 500 euros on average. In special cases the cost of planting a street tree can be up to 10 000 euros. Hence the total cost of removing and replacing one diseased tree was estimated to be 3 250–3 500 euros in the parks and 4 750–5 000 euros by the streets. In special cases replacing a diseased tree by a street can cost up to 13 500 euros.

The cost of removing and replacing all elm trees in Helsinki was estimated to be about 13 million euros (Table 3). If 1% or 4% of the trees would need to be replaced, the cost would be about 136 000 or 538 000 euros respectively (Table 3). If the value of the existing trees is also taken into account, the losses become even greater. As the value of elms in Helsinki is roughly about six million euros (Terho 2015) the total cost of losing and replacing all the elms would be about 20 million euros. (This estimate is reached by assuming that the value of an elm in a park is 1 000 € and that of an elm by a street is 2 500 €.)

Table 3. The cost of removing and replacing elm trees in Helsinki for three scenarios differing in the percentage (1%, 4% and 100%) of trees which need to be removed and replaced. The numbers of trees were obtained from Raisio (2013).

Location	Number of elms	Cost of removal and replacement, €/tree	Total cost of removal and replacement for the different scenarios, €		
			1 %	4 %	100 %
In the parks	1 105	3 250	35 750	143 000	3 591 250
By the streets	1 964	5 000	100 000	395 000	9 820 000
Total			135 750	538 000	13 411 250

The cost of removing and replacing all elm trees in urban areas in the PRA area was estimated to be at least 59 million euros (Table 2). If 1% or 4% of the trees would need to be replaced, the cost would be at least 0.4–0.6 or 1.3–2 million euros respectively (Table 4). If the value of existing trees is the same in other urban areas as in Helsinki (in a park 1 000 €/elm, by a street 2 500 €/elm), the total value of elms included in the analysis adds up to about 12–29 million euros. This means that if all elms were destroyed by DED, the total losses would be about 50–88 million euros.

Table 4. Estimates of the cost of removing and replacing elm trees in the urban areas in the PRA area for three scenarios differing in the percentage (1%, 4% and 100%) of trees which need to be removed and replaced. As we had no information about the proportions of trees in the parks and by the streets (except for Helsinki) two estimates are presented; one in which all the elms are expected to grow in parks, and another in which all the elms are expected to grow along streets. The estimates are based on the numbers of elms in the cities which provided the data (For more details see Appendix 1, Table A1). Not all cities are included, and therefore the actual costs are likely to be higher than presented here.

All elms expected to grow	Cost of removal and replacement, €/tree	Total cost of removal and replacement for the different scenarios, €		
		1 %	4 %	100 %
In the parks	3 250	383 500	1 300 000	38 285 000
By the streets	5 000	590 000	2 000 000	58 900 000

At present the cost of monitoring, removing, and replanting trees in Helsinki is on average 250 000 euros per year (Terho 2015). Hence an annual loss of 1% of the elms to DED would increase these costs by more than 50%. We have no information about these costs in other urban areas. However, we believe that it is reasonable to assume that the increase in these costs would be roughly similar in other urban areas, i.e. an annual loss of 1% of the elms to DED would increase the costs by about 50%.

This estimate represents the minimum increase in the annual production cost for both the extreme management options, i.e. the “minimum management option” in which only dangerous trees and branches are removed and the “all available measures option” in which all measures legally available, without phytosanitary measures, are taken. In reality the increase in costs is likely to be higher for both management options. This is because in the “minimum management option” the proportion of trees lost annually is likely to be more than 1% as no proper management measures are taken. In the “all available measures option” the cost per tree is likely to be higher since also the roots of the infected trees have to be removed and destroyed. Also, for this management option the proportion of elms lost annually is likely to be higher than 1%. This is because in areas where the management of DED is considered to have been successful the losses have been about 2–2.5% (Westwood 1991, Rioux 2003). (For more details see point 6.04.) In conclusion, we consider that the increase in annual management costs caused by DED would be at least 50% for both management options considered.

Forestry

Elms are not used for forestry purposes in the PRA area as both the naturally occurring elm species are protected under the Nature Conservation Decree (160/1997). Therefore DED would not affect the production costs of forestry. However, the costs would increase if control measures were taken in the forests to protect the urban elms or

the environmental value of the protected elm species. At the moment there are no production costs related to elms occurring naturally in the forests. Therefore any increase in production costs measured in percentage would be massive. Also, the absolute increase in costs would probably be considerable since monitoring, removing, and destroying trees in remote locations is costly.

Nurseries

The production costs of elms in the nurseries are not expected to increase significantly due to DED control measures. This is because most of the measures that would be used to control DED (i.e. use of proper plant materials, proper fertilization, watering and pruning, preventative disease and insect control, strict hygiene, eliminating dead or severely weakened elm trees and unhealthy branches, and preventing root grafts) are part of the normal practices in the nurseries.

Conclusions

In the absence of vectors the increase in production costs would be minor because without vectors DED can spread only to nearby trees via root grafts, and very few measures would be needed.

If vectors were present, more extensive measures would be needed to control the disease. In urban areas an introduction of DED is estimated to increase the production costs by at least 50%. Also in the forests the control measures would be expected to cause a major cost increase, but in the nurseries only a minor increase in production costs would be expected.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Extent	Uncertainty	Extent	Uncertainty
In the absence of vectors	minor	low	-	-
In the presence of vectors	major	low	minimal	low

6.06 - Based on the total market, i.e. the size of the domestic market plus any export market, for the plants and plant products at risk, what will be the likely impact of a loss in export markets, e.g. as a result of trading partners imposing bans on exports from the PRA area?

Neither plants nor plant products of elms are exported or traded to other EU member states from the PRA area. Hence, no loss of export markets is expected.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Extent	Uncertainty	Extent	Uncertainty
minimal	low	-	-

6.07 - To what extent will direct impacts be borne by producers?

Nursery producers

If nursery plants were affected by DED, the producers could easily shift to producing other tree species, and hence the direct impacts of DED would only be minimally borne by nursery producers.

(Introduction of DED could have some indirect impacts on nursery production as it would probably affect the demand for elm plants for planting. If DED was introduced the buyers, especially cities and other major users of plants for planting would be reluctant to plant new elms. In the short run this would affect the producers since they would not be able to sell the elms which they have in their possession. Also, at short notice they might not all be able to provide all the plants for planting needed to compensate for the elms. As a result a share of these compensating plants would be bought from other producers or from abroad. Hence, in the short run these indirect impacts would be moderately borne by the producers. In the long run, however, the producers could easily shift to producing other tree species.)

Owners of existing ornamental elms

Since DED is most likely to affect large, highly valuable ornamental elms planted in urban areas the owners of these trees are treated here as producers. The direct impact of DED would be borne by the owners of the affected trees to a massive extent since they would bear all the costs of removing and replacing the dead trees.

Forest owners

Forest owners or forestry would not be affected by DED since elms are not used for forestry purposes in Finland. This is because both the naturally occurring elm species (*U. glabra* and *U. laevis*) are protected under the Nature Conservation Decree (160/1997).

Conclusions

The direct impact of DED would be borne by the nurseries to a minimal extent since they would be able to shift to producing other tree species. The direct impact would be borne by the owners of the existing ornamental elms to a massive extent since they would bear all the costs of removing and replacing the dead trees. Forest owners would not be affected since elms are not used for forestry in Finland.

	<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
	Extent	Uncertainty	Extent	Uncertainty
Nursery producers	minimal	low	-	-
Owners of ornamental trees	massive	low	-	-
Forest owners	minimal	low	-	-

Environmental impact

6.08.0A - Do you consider that the question on the environmental impact caused by the pest within its current area of invasion can be answered?

No, but there is some evidence that the environmental impact may be significant in the PRA area.

6.08 - How important is the environmental impact caused by the pest within its current area of invasion?

DED has caused considerable mortality of elms in natural habitats in its current area of invasion, in the USA (French 1993; Campbell & Schlarbaum 1994; Dunn 2000), Canada (Rioux 2003), Austria (Kirisits & Konrad 2004), and the UK (Gibbs 1978; Brasier 1996; Harwood et al. 2011). (For more details see point 6.01.) However, we do not have enough information about the situation in these countries to assess the environmental impact in as great a detail as is asked for in points 6.08.01-6.08.09.

The vectors of DED alone do not cause significant damage to the host plants since they breed on dead or weakened trees (Stipes & Campana 1981).

6.09.01 - What is the risk that the host range of the pest includes native plants in the PRA area?

Two of the major host plants of DED and its principal vectors, namely *U. glabra* and *U. laevis*, occur naturally in the PRA area (Lampinen & Lahti 2016). (See Appendix 1, Figures A1 and A2 for distribution maps of the most common *Ulmus* species in Finland.)

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Risk	Uncertainty	Risk	Uncertainty
high	low	high	low

6.09.02 - What is the level of damage likely to be caused by the organism on its major native host plants in the PRA area?

Nature of the damage

In its present area of distribution DED usually kills susceptible trees within one or two years, both in natural and in urban environments (Stipes & Campana 1981; Kirisits & Konrad 2004), and causes high levels of mortality of elm trees (Gibbs 1978; Campbell & Schlarbaum 1994; Brasier 1996; Dunn 2000; Rioux 2003; Kirisits & Konrad 2004; Harwood et al. 2011). (For more information on the nature of the damage see point 6.01.)

Susceptibility of native elms

In the PRA area the native elm species (*U. glabra* and *U. laevis*) are highly susceptible to DED (Stipes & Campana 1981; Webber 2000; Solla et al. 2005; Ghelardini & Santini 2009). Hence, DED can cause a high level of damage to infected native host plants in the PRA area.

Special features of the Finnish elm populations

Due to the small size and low number of natural elm stands in the PRA area DED invasions could have devastating effects on the natural elm population. Whole stands could be destroyed very quickly, and the destruction of even one stand could have a major impact on the elm population of the PRA area. (For detailed information on the number of elms and elm stands see point 3.09.)

The Finnish populations of *U. laevis* are characterized with low genetic diversity within the populations, but with high differentiation among the stands (Vakkari et al. 2009). This means that the disappearance of even some marginal populations may result in a considerable loss of the overall genetic variation of the species in the PRA area. Hence, the genetic variability of *U. laevis* is highly vulnerable to DED invasions.

U. glabra may be especially vulnerable to DED epidemics because it is believed to be self-incompatible, i.e. it needs pollen from other compatible individuals to be able to reproduce (Nielsen & Kjær 2010). Therefore the loss of individuals or whole stands, from an already sparse population, could make regeneration of the remaining *U. glabra* difficult or, in some cases, impossible. Furthermore, since *U. glabra* does not reproduce by suckers (Collin et al. 2000; Collin 2002) it cannot recover from DED epidemics by suckering, unlike, e.g. *U. minor* (Collin et al. 2000; Collin 2002). As a result, the genetic resources of its small populations might become seriously endangered if mature elms are lost to DED.

Factors which may limit the damage in the PRA area

DED epidemics in the PRA area would not necessarily be similar to those in the present range of DED. The low density of elms in the PRA area would probably limit the distribution of DED and the damage caused by it. Also the suitability of the climate is considered uncertain, except for the southernmost parts of the PRA area. (For more information on the suitability of the climate see point 3.03.)

Conclusions

DED is considered likely to cause high levels of damage to its native host plants in the PRA area, especially in the southernmost parts of the country where climatic conditions are considered to be most suitable. The vectors alone are very unlikely to harm their native host plants since they breed on dead or weakened trees (Stipes & Campana 1981).

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Level of damage	Uncertainty	Level of damage	Uncertainty
high	low	low	low

Impact on ecosystem patterns and processes

6.09.03 - What is the ecological importance of the host plants in the PRA area?

The number of elms in the PRA area is very low, and the total area of *Ulmus* groves is only about 100–150 ha (Raunio et al. 2008). However, the ecological importance of elms is considered high since elms are undoubtedly critically important species in the few remaining elm groves. For example, a critically endangered longhorn beetle species, *Rhamnusium bicolor*, which lives only in one place in Finland, is dependent on elms (Rassi et al. 2010).

Importance	Uncertainty
high	low

Conservation impacts

6.09.04 - To what extent do the host plants occur in ecologically sensitive habitats (includes all officially protected nature conservation habitats)?

Both *U. glabra* and *U. laevis* are protected by the Nature Conservation Decree (160/1997), and both *U. glabra* and *U. laevis* groves are critically endangered habitat types in Finland (Raunio et al. 2008). On Åland the natural *U. glabra* and *U. laevis* stands are protected by Åland's Nature Conservation Decree (1998/113). In addition, *U. laevis* and *U. glabra* are target species in the Finnish National Gene Conservation Program (Anonymous 2001; MMM 2012).

All or most of the *U. glabra* groves and the majority of the *U. laevis* groves are within protected habitats (Kontula 2015). Elm groves constitute about 5% of all the Finnish hardwood groves (i.e. jalopuulehdot), which too are classified as endangered habitats (Raunio et al. 2008).

In conclusion, DED host plants occur to a high extent in ecologically sensitive habitats.

Extent	Uncertainty
high	low

6.09.05 - What is the risk that the pest would harm rare or vulnerable species?

The native elm species in the PRA area (*U. glabra* and *U. laevis*) are both classified as threatened vulnerable species in the PRA area (Rassi et al. 2010), and they are both highly susceptible to DED (Stipes & Campana 1981; Webber 2000; Solla et al. 2005; Ghelardini & Santini 2009). Consequently, the risk that DED would harm rare or vulnerable species is considered high, with low uncertainty.

The DED vectors will also inhabit rare or vulnerable species since elms are their principal host plants. However, the vectors alone are unlikely to harm the rare species since they breed on dead or weakened trees (Stipes & Campana 1981).

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Risk	Uncertainty	Risk	Uncertainty
high	low	high	low

Impact of pesticides

6.09.06 - What is the risk that the presence of the pest would result in an increased and intensive use of pesticides?

Chemical control against DED is not widely applied since the fungicides used against DED are expensive, and none of them is completely effective (D’Arcy 2000). The only rather effective chemical control method for DED is injection of fungicides directly into the stems of individual trees (Stipes & Campana 1981; Haugen & Stennes 1999). Since this is very labor intensive it is very unlikely that such a method would become widely used, especially in the natural habitats.

Chemical control is not commonly used against DED vectors either since pesticides are not an effective method for control (D’Arcy 2000).

Due to the ineffectiveness and high cost of chemical control it is very unlikely that the presence of the pathogens or the vectors would result in an increased and intensive use of pesticides.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Risk	Uncertainty	Risk	Uncertainty
low	low	low	low

6.09 - How important is the environmental impact likely to be in the PRA area?

If DED invades some of the few remaining elm groves its impact is likely to be massive. This is because the native elm species, *U. glabra* and *U. laevis*, are classified as threatened vulnerable species in the PRA area (Rassi et al. 2010), and both *U. glabra* and *U. laevis* groves are critically endangered habitat types in Finland (Raunio et al. 2008). Furthermore, the majority of the largest and most important elm groves are within protected habitats (Kontula 2015).

Vectors alone are likely to have, at a maximum, a minor environmental impact since they breed on dead or weakened trees.

The uncertainty of the assessment is considered medium because the low density of elms in the PRA area would probably limit the distribution of DED and the damage

caused by it. Also, it is not completely clear how suitable the climatic conditions in other than the southernmost parts of the PRA area are for DED and its vectors. (For more information on the suitability of the climate see point 3.03.)

Social impact

6.10 - How important is social damage caused by the pest within its current area of distribution?

In its current area of distribution DED has had a considerable aesthetic and cultural effect on the landscape due to the loss of elms, especially in urban areas. For example in northeastern USA 75% of the elms had died by 1979 (Campbell & Schlarbaum 1994), in Montreal (Canada) 90% of the elms died in 1970–1980, and in Toronto (Canada) 80% of the elms were killed by 1976 (Rioux 2003). In Austria most of the mature elms have disappeared after the introduction of DED (Kirisits & Konrad 2004). In all these areas elms were important amenity and shade trees before the introduction of DED. (For more details see point 6.01.)

The vectors alone have not caused any social damage in their current area of distribution.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Importance	Uncertainty	Importance	Uncertainty
major	low	low	low

6.11 - How important is the social damage likely to be in the PRA area?

In the PRA area DED would be likely to have aesthetic and cultural effects on the landscape due to the loss of elms in urban areas and in the natural elm groves, of which a major proportion is located in protected areas.

The social effects caused by the loss of elms in urban areas would be only moderate since elms are not one of the common tree species in public greenspaces. For example in Helsinki, where the number of planted elms is the highest in Finland, elms constitute less than 2% of all the trees in parks and along streets (Raisio 2013).

The loss of the few remaining elm groves would also have a social effect, since elm groves constitute about 5% of all the hardwood groves (i.e. jalopuulehdot) in Finland (Raunio et al. 2008).

DED would not be expected to cause loss of employment in the PRA area. On the contrary, introduction of DED might temporarily increase the need for employees for management of public greenspaces.

The vectors alone are not expected to cause any social damage in the PRA area.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Importance	Uncertainty	Importance	Uncertainty
moderate	low	low	low

Section B: Degree of uncertainty and conclusion of the pest risk assessment

c2 - Degree of uncertainty: list sources of uncertainty

It is not known how likely the vectors are to hitchhike on ferries, trains, cars or other vehicles.

It is not known how commonly elm is present in fuel wood, wood waste and wood chips imported to the PRA area. If that is common, entry via the wood pathway should be considered more likely.

It is not sure if the British standard kiln drying schedules for the European elm species eliminates the pathogens. However, this is not relevant for the entry potential of DED since the vectors are eliminated by the treatment.

It is not known how often elm wood is used for WPM moving in intra-EU trade, for which the ISPM 15 requirements do not apply. If it is used frequently, the likelihood of entry in WPM should be considered higher.

It is not known how likely the vectors are to feed or breed on small nursery trees.

It is not clear if the vectors could breed also on some tree species other than elms. This affects the likelihood of transfer to a suitable host from the entry pathways, the rate of spread, and the likelihood of successful eradication and containment.

There is no up to date information about the distribution of elms between Vyborg and the Finnish border. This affects the likelihood of natural spread from Russia, and the likelihood of successful management by surveys and eradication and/or containment.

There is not enough information about the capacity of the vectors to spread in conditions where the distance between host patches is as high as in the PRA area. This affects the likelihood of transfer to a suitable host from the entry pathways, the rate of natural spread, and the likelihood of successful eradication and containment.

The results of the assessment of the climatic suitability of the PRA area depend on the climatic classifications used. This affects the probability of establishment and the potential impacts.

The assessment of the time needed for the pest to reach its maximum extent in the PRA area is based on information about the situation in Leningrad Oblast. This assessment is uncertain since the assumed similarity of elm distribution in Leningrad Oblast and the PRA area is based only on visual comparison of small-scale distribution maps.

It is not known how often wood from ornamental trees is disposed of locally. This affects the rate of human assisted spread.

Eradication of DED from the PRA area is considered possible although eradication attempts in the present range of DED have not been successful.

Eradication is considered possible although the needed measures may be too costly and too drastic to be implemented in a timely manner.

The extent of the damage caused by a DED invasion depends largely on the location of the invasion.

c3 - Conclusion of the pest risk assessment

DED is considered to present a major risk to the PRA area. It is moderately likely that it could enter the PRA area by natural spread aided by hitchhiking on vehicles from Sweden, Russia or other nearby areas, and it would be very likely to be able to establish, at least, in the southernmost parts of the country. It could cause massive environmental consequences to threatened vulnerable species and critically endangered habitats. Also the economic consequences caused to the owners of established elm trees could be major.

STAGE 3: PEST RISK MANAGEMENT

7.01 - Is the risk identified in the Pest Risk Assessment stage for all pest/pathway combinations an acceptable risk?

No, the concerned parties considered that the risk is not acceptable for the natural spread pathway, and decided that risk management measures for this pathway should be analyzed.

Since the PRA indicates that DED is currently very unlikely or unlikely to enter the PRA area in wood, WPM, or plants for planting the concerned parties decided that management measures do not need to be identified for these pathways. However, the likelihood of entry via these pathways was considered low mainly due to the low volumes of trade, and therefore the concerned parties recommend that management measures for these pathways should be analyzed later if there is any indication that the volume of trade would increase.

7.02 - Is natural spread one of the pathways?

Yes. (For details see point 2.01.)

7.03 - Is the pest already entering the PRA area by natural spread or is it likely to enter in the immediate future?

The vectors

The closest known vector populations (*S. scolytus* and *S. multistriatus*) are in Vyborg (Russia), less than 30 km from the Finnish border (Stcherbakova & Mandelshtam 2014). They were found in Vyborg in 2014, about 15 years later than they appeared in St Petersburg (Russia) (Stcherbakova & Mandelshtam 2014). This implies that the beetles may have been dispersing about 8 km per year (120 km in 15 years), and therefore the vectors may be entering the PRA area by natural spread in the immediate future. (For more details about the rate of spread see point 4.01.) Alternatively, instead of gradually dispersing from St Petersburg to Vyborg the vectors may have spread there very quickly by hitchhiking on vehicles. Similarly, such assumedly rare events may cause the vectors to enter the PRA area in the immediate future, either from Vyborg or the other neighboring areas where the vectors are present.

The pathogens

The closest known populations of the pathogens are in St Petersburg (Russia), about 160 km from the Finnish border (Serebritskiy 2014), and on the northern coast of Estonia, about 100 km from the Finnish coast (Voolma 2015). The dispersal capacity of the pathogens depends on the dispersal capacity of the vectors since transmission by vectors is their only means for medium and long range dispersal (Stipes & Campana 1981). Assuming that the vectors disperse 8 km per year, it would take at least 20 years for DED to spread from St Petersburg to the PRA area by natural spread. However, in vectors hitchhiking on vehicles DED could disperse to the PRA area very quickly, and thus DED may enter the PRA area in the immediate future. (For more details about the rate of spread see point 4.01.)

Distribution of host plants

Elms are present throughout the southeastern coast of Finland, where the distance between separate elm patches is about 10–15 km, and the easternmost patches are about 5 km from the Finnish-Russian border (Lampinen & Lahti 2016; SYKE 2015). On the Russian side of the border the known distribution of elms along the coast between St Petersburg and Vyborg is similar to that on the Finnish coast, i.e. the distance between separate elm patches is about 10–15 km (Hiitonen 1946; Hulten 1950). Also, between Vyborg and the Finnish border the distribution between documented patches is similar, except that the closest documented presence of elms is about 25 km from the Finnish border (Hiitonen 1946). However, there may well be undocumented elm patches closer to the border since the only source of information (i.e. Hiitonen 1946) we were able to find is from the 1940’s.

Conclusions

The vectors and the pathogens may enter the PRA area by natural spread aided by hitchhiking on vehicles in the immediate future as the vectors are known to be present less than 30 km from the Finnish border, and as there is frequent traffic to the PRA area from e.g. St Petersburg, Estonia, and Sweden, where DED is present. The uncertainty of these assessments is considered medium because the likelihood of hitchhiking is not known, and because the published records of the elm distribution between Vyborg and the Finnish border indicate that the distances between separate elm patches may be long enough to hamper the vectors’ purely natural dispersal.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Answer	Uncertainty	Answer	Uncertainty
yes	medium	yes	medium

7.04 - Is natural spread the major pathway?

Yes, natural spread aided by hitchhiking on vehicles is considered to be the most likely pathway for the pathogens and the vectors to the PRA area. The probability of entry is considered moderately likely, with medium uncertainty. (For more details see 2.13b.)

Identification of appropriate risk management options

7.29 - Are there effective measures that could be taken in the importing country (surveillance, eradication, containment) to prevent establishment and/or economic or other impacts?

Surveillance

Surveys could be carried out in southeastern Finland in areas close to the Russian border for early detection of the pathogens and the vectors.

In order to plan the surveys for DED and its vectors the distribution of elms has to be known sufficiently well. Known natural occurrences of elm are recorded in the Finnish environmental institute's Eliölajit database, and the cities probably have information about the elms in their territory. Yet, the comprehensiveness of these data should be evaluated, and further surveys should be carried out, if necessary, to map the distribution of elms in the target area.

The symptoms of the pathogens can be detected in visual inspections, except if the trees have been infected very recently, or if the trees are resistant (Stipes & Campana 1981). Yet, identification of the pathogens requires laboratory testing (D'Arcy 2000) since similar symptoms are caused by various reasons. The surveys have to be carried out during the vegetation period when external symptoms are recognizable.

DED vectors are very difficult to detect visually since they live most of their life in or under the bark, and leave no easily detectable signs on the surface of the bark (EPPO 1983). However, the vectors can be monitored using pheromone traps relatively easily (Birch et al. 1981; Anderbrant & Schlyter 1987; Pines & Westwood 2008). The traps should be employed during the flight period of the beetles, which starts when the air temperature reaches 20 °C (Fransen 1939) and ends in late summer or autumn (Birch et al. 1981; STOPDED 2015; Lindelöw 2015; Mandelshtam 2015).

Eradication

Eradication of naturally spread invasions of DED and/or the vectors from the PRA area may be possible if the invasions are detected early enough and if proper measures are taken. This is mainly due to the low number and patchy distribution of elms in the PRA area. (For a more detailed justification see point 5.01.)

Eradication of DED and/or its vectors requires that all infected trees, including those that don't show symptoms, are located and destroyed. The roots have to be killed with herbicides to prevent further spread of DED via root grafts, and the stumps have to be debarked to prevent vector beetles from breeding in them (Stipes & Campana 1981; Menkis et al. 2015).

To eradicate the vectors, sanitary measures, i.e. removal and destruction of dead and weakened trees or branches, have to be targeted also on apparently uninfected trees. This is because identification of the infested trees cannot be done without destroying the trees, either visually or with laboratory tests. (For more details about the eradication measures see 5.01.)

Containment

Containment of DED and/or its vectors could be possible if the invasions are detected early enough and if proper measures are taken. This is because natural spread of DED and its vectors between isolated elm patches is rather unlikely. (For a more detailed justification see point 5.02.)

If the infested patch was so isolated that natural spread is considered impossible, prohibiting movement of infested material might be enough to contain DED and its vectors. If natural spread or spread by hitchhiking on vehicles was considered possible, measures to suppress DED and its vector population would also be needed. The needed measures would be similar to the eradication measures described earlier, but, depending on the situation, they could be applied either in the whole infected area or only in a buffer zone around it.

Containment measures could be taken also against invasions which have not yet spread to the PRA area but are close to the Finnish border.

Removal of dead or weakened elm material

The suitability of the environment for the vectors could be decreased by removing dead and weakened elm trees and branches, which the vectors need for breeding. This preventive measure would be feasible in urban areas, but probably not in the forests since many of the elm patches are in remote locations.

Applicability of the measures in the PRA area

In the absence of phytosanitary legislation related to DED and its vectors the above measures could be targeted at planted trees in urban areas and in the nurseries. In the forests the measures would require special permission (Nature Conservation Act 1096/1996, sections 42 and 48) as the naturally occurring elm species are protected by the Nature Conservation Decree (160/1997). Also in national parks and nature reserves special permission would be required (Nature Conservation Act 1096/1996, sections 13 and 15). If, however, phytosanitary legislation regarding DED and its vectors was put in place, the measures could be targeted also at the naturally occurring elms, even in the protected areas (Agriculture and Forestry Committee 5/2008 vp).

In the absence of phytosanitary legislation taking the measures would be voluntary, but if appropriate phytosanitary legislation was put in place, the measures would be compulsory for all affected parties.

Conclusions

Surveys and eradication and containment measures could prevent invasions and/or economic impacts of DED. Yet in practice, the effectiveness of the measures depends on how well they are carried out. Also, if DED and its vectors become common in the areas close to the Finnish-Russian border, invasions may become too frequent to control. The uncertainty of the assessment is rated medium because eradication attempts in the present range of DED have not been successful (For more details see point 5.01), because there is not enough information about the capacity of the vectors to spread in conditions where the distance between host patches is as high as in the PRA area, and because it is not clear if the vectors could also breed on some tree species other than elms.

Eradication and containment measures would be less likely to be effective in preventing invasions of the vectors. This is because the vectors alone do not cause visible symptoms in the plants, and therefore locating all infected plants would be tricky. If the vectors can also breed on their other reported hosts, containing their populations would be very difficult. Yet, if they cannot breed on the other hosts, containment could be possible due to the patchy distribution of host plants in the PRA area.

<i>O. ulmi</i> s.l.		Vectors of <i>O. ulmi</i> s.l.	
Answer	Uncertainty	Answer	Uncertainty
yes	medium	yes	medium

Evaluation of risk management options

7.30 - Have any measures been identified during the present analysis that will reduce the risk of introduction of the pest?

Yes, surveillance and eradication and/or containment measures would reduce the risk of introduction.

7.31 - Does each of the individual measures identified reduce the risk to an acceptable level?

Surveillance and eradication and/or containment measures can reduce the risk, but the level of reduction depends heavily on the intensity of the measures taken. (For details see points 5.01 and 5.02.) There are no other measures that could be taken to prevent introduction by natural spread.

7.34 - Estimate to what extent the measures being considered interfere with international trade

Surveillance and eradication and/or containment measures would not interfere with international trade as all the measures would be carried out in the PRA area, and no requirements would be imposed on imports or intra-EU trade.

7.35 - Estimate to what extent the measures being considered are cost-effective, or have undesirable social or environmental consequences

Cost-effectiveness

The introduction of DED and its vectors is expected to have massive environmental consequences (For details see point 6.09). Also the economic consequences for the owners of existing elm trees are expected to be major (For details see points 6.01-6.07). Therefore the considered control measures could be cost-effective, especially if invasions are not recurrent. If DED and its vectors become common in the areas

close to the Finnish-Russian border, invasions may become too frequent to control with surveillance and eradication and/or containment measures.

Social and environmental consequences

Eradication and containment measures could have undesirable social and environmental consequences as a large number of amenity trees and protected trees would have to be destroyed. Yet, these consequences are insignificant since, if no measures were taken, the trees would be lost to DED.

Conclusions

The considered control measures could be cost-effective as long as invasions are not too frequent. The uncertainty of the assessment is considered high since neither the costs of the measures nor those of DED invasions have been evaluated in a manner that would enable their comparison. The undesirable social or environmental consequences of the measures are likely to be much smaller than those of the establishment of DED.

	Likelihood	Uncertainty
How likely are the measures to be cost-effective?	likely	high
How likely are the measures to have undesirable social or environmental consequences?	very unlikely	low

7.36 - Have measures been identified that reduce the risk for this pathway and do not unduly interfere with international trade, are cost-effective and have no undesirable social or environmental consequences?

Yes, surveillance and eradication and/or containment measures do not unduly interfere with international trade, can be cost-effective, and have no undesirable social or environmental consequences. (For justification see points 7.29, 7.34 and 7.35.)

7.38 – Have all major pathways been analyzed?

Yes, at the moment natural spread aided by hitchhiking on vehicles is the only major pathway. The likelihood of entry via the other pathways (i.e. wood, WPM and plants for planting) is considered to be unlikely or very unlikely, with low or medium uncertainty. This is mainly because there is no or very little trade. (For details see point 2.11 for Pathways 1 and 2.)

Conclusions

7.41 - Consider the relative importance of the pathways identified in the conclusion to the entry section of the pest risk assessment

In the present situation the likelihood of entry via natural spread aided by hitchhiking on vehicles is considered to be far more likely than via any other pathway. Therefore, management measures are not considered for the other pathways. However, the likelihood of entry via the other pathways is considered low mainly due to the low volume of trade, and therefore management measures for these pathways should be analyzed later if there is indication that the volume of trade would increase.

7.45 - Summarize the conclusions of the Pest Risk Management stage. List all potential management options and indicate their effectiveness. Uncertainties should be identified.

Management measures were considered only for natural spread aided by hitchhiking on vehicles since the likelihood of entry via the other pathways was considered unlikely or very unlikely. However, this is mainly due to the low volume of trade, and therefore management measures for these pathways should be considered later if the volume of trade increases.

Natural spread aided by hitchhiking on vehicles of DED and its vectors could be managed by surveillance and eradication and/or containment measures targeted in areas where the likelihood of entry is the highest, i.e. major harbors in the southern Finland, and southeastern parts of the PRA area close to the Finnish-Russian border. Management is considered possible mainly because the number of elms in the PRA area is relatively low and their distribution is patchy. **The uncertainty of this assessment is rated medium** because eradication attempts in the present range of DED have not been successful. Also in practice, the efficacy of the measures depends heavily on the intensity of the surveys, on proper implementation of the eradication and containment measures, and on the location of the original invasion. Furthermore, if DED and its vectors become common in the areas close to the Finnish-Russian border, e.g. as a result of global warming, invasions may become too frequent to control.

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Appendix 1. Distribution of elms in the PRA area

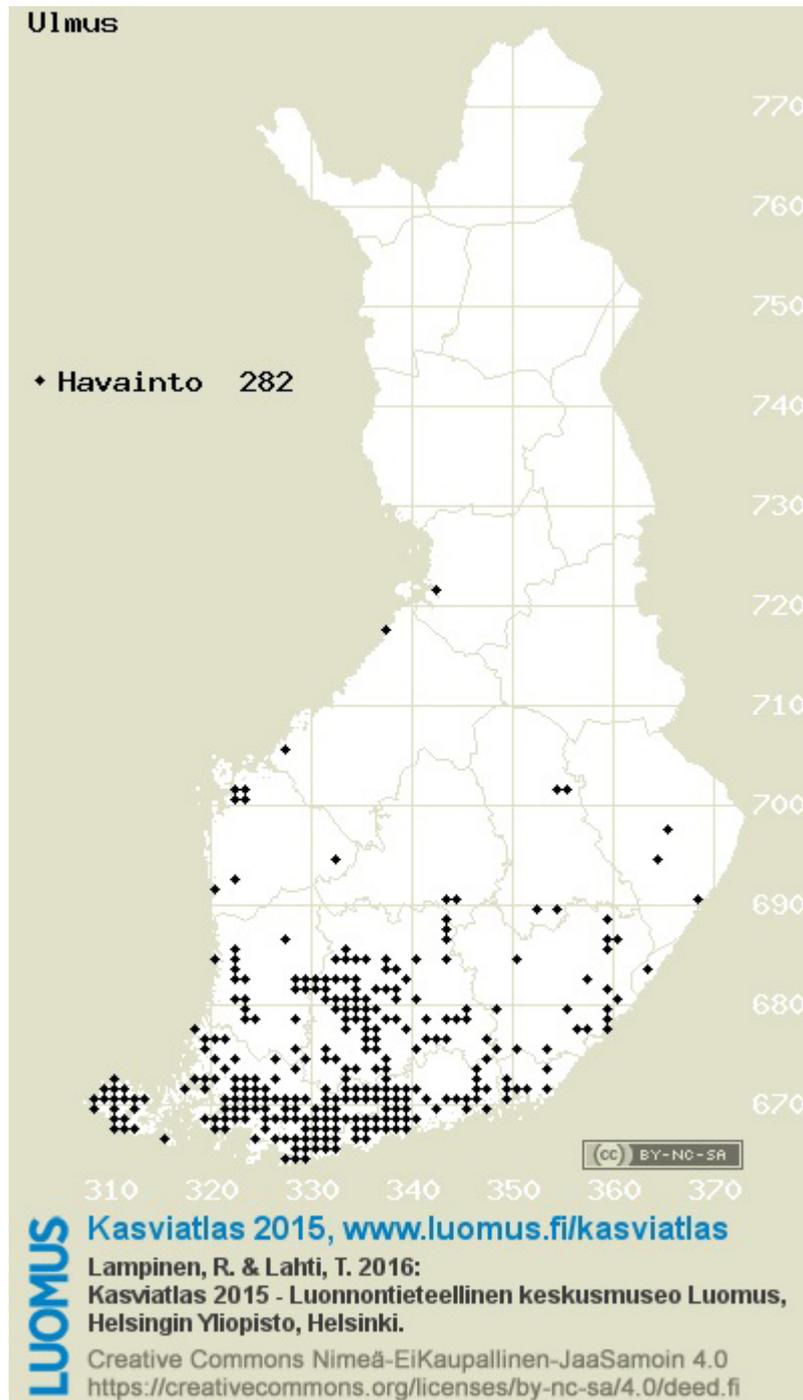


Figure A1. The distribution of *Ulmus* spp. in Finland (Lampinen & Lahti 2016).

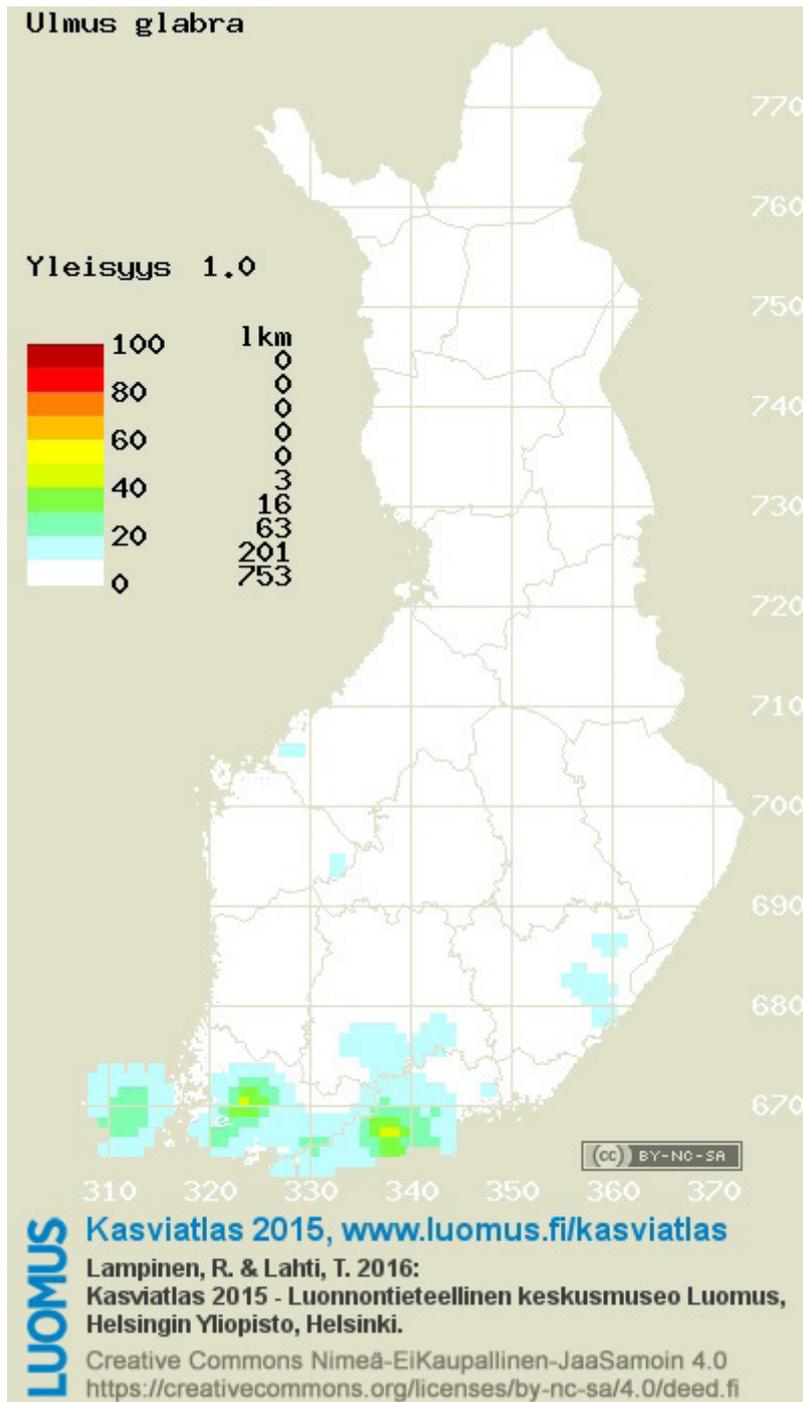


Figure A2. The frequency of cells occupied by *U. glabra* (Lampinen & Lahti 2016). The frequency is calculated as the proportion of 1 km² cells occupied by at least one tree on each 10 km² cell. The frequency is expressed on a scale of 0-100% and indicated by the colors shown in the figure.

Table A1. The number of elms in public areas in some cities in southern Finland. The information was acquired from the city and church yard gardeners.

City	The number of elms in parks and along streets
Helsinki	3 069
Turku	2 069
Espoo	1 633
Lappeenranta	>1 000
Kotka	700-800
Hämeenlinna	635
Kuopio	604
Lahti	604
Jyväskylä	308
Imatra	260
Kouvola	252
Pori	231
Järvenpää	205
Hyvinkää	100
Lohja	50
Hanko	40
Loviisa	20
Total	11 780–11 880

Appendix 2. Vectors of DED

Table A2. The potential DED vectors (Stipes & Campana 1981; Webber 2004), the principal DED vectors (Gibbs 1978; Stipes & Campana 1981; Hansen & Somme 1994; Webber 2004) in bold, and the presence of the principal vectors in Finland's neighboring countries.

Vector	Presence of the principal vectors in the neighboring countries	References for the presence in the neighboring countries
<i>Hylurgopinus rufipes</i>		
<i>Pteleobius kraatzi</i>		
<i>Pteleobius vittatus</i>		
<i>Scolytus ensifer</i>		
<i>Scolytus jacobsoni</i>		
<i>Scolytus kirschi</i>		
<i>Scolytus laevis</i>	Estonia, Norway, Russia, Sweden	Voolma et al. 2004; Solheim et al. 2011; Lindelöw 2012
<i>Scolytus multistriatus</i>	Estonia, Russia, Sweden	Voolma et al. 2004; Lindelöw 2012
<i>Scolytus orientalis</i>		
<i>Scolytus pygmaeus</i>	Russia, Sweden	Lindelöw 2012; Stcherbakova & Mandelshtam 2014
<i>Scolytus scolytus</i>	Estonia, Russia, Sweden	Voolma et al. 2004; Lindelöw 2010; Lindelöw 2012
<i>Scolytus semenovi</i>		
<i>Scolytus sulcifrons</i>		
<i>Scolytus triarmatus</i>	Estonia, Sweden	Voolma et al. 2004; Lindelöw 2010; Lindelöw 2012
<i>Scolytus zaitzevi</i>		
<i>Scolytus mali</i>	Finland, Estonia, Russia, Sweden	Voolma et al. 2004, ArtData-banken 2015

Table A3. Host plants of the principal DED vectors (Wood & Bright 1992). Minor hosts are shown in brackets. Wood & Bright (1992) do not indicate whether the beetles have been observed to breed and complete their development on the plants, or if they have just been observed to feed on the plants. There is, however, some indication that the latter might be true since Fransen (1939) reports that *S. scolytus* was not able to complete its life cycle on all the hosts listed by Wood & Bright (1992).

Vector	Hosts plants
<i>Hylurgopinus rufipes</i>	<i>Ulmus thomasi</i>
	<i>U. americana</i>
	<i>Fraxinus</i> sp.
	<i>Tilia americana</i>
<i>Scolytus laevis</i>	<i>Ulmus</i> spp.
	<i>Acer</i> sp.
	<i>Alnus</i> sp.
	<i>Corylus</i> sp.
	<i>Fagus</i> sp.
	<i>Malus</i> sp.
	<i>Quercus</i> sp.
<i>Tilia</i> sp.	
<i>Scolytus multistriatus</i>	<i>Ulmus</i> spp.
<i>Scolytus pygmaeus</i>	<i>Ulmus</i> spp.
	<i>Carpinus</i> sp.
	<i>Fagus</i> spp.
	<i>Olea europea</i>
	<i>Prunus</i> spp.
<i>Quercus</i> spp.	
<i>Scolytus scolytus</i>	<i>Ulmus</i> spp.
	(<i>Carpinus betulus</i>)
	(<i>Fraxinus excelsior</i>)
	(<i>Juglans regia</i>)
	(<i>Populus nigra</i>)
	(<i>Quercus</i> spp.)
	(<i>Salix</i> spp.)
<i>Scolytus triarmatus</i>	<i>Ulmus</i> spp.

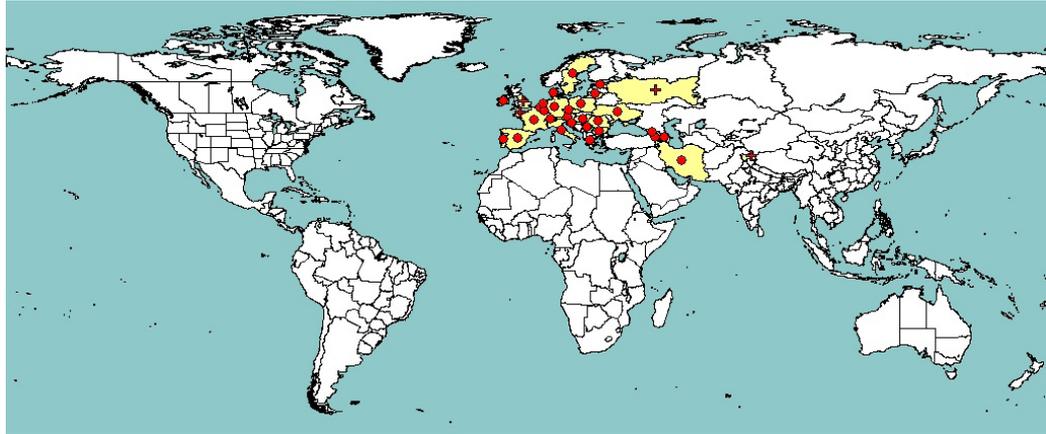


Figure A3. The distribution of *Scolytus scolytus* (EPPO 2014).

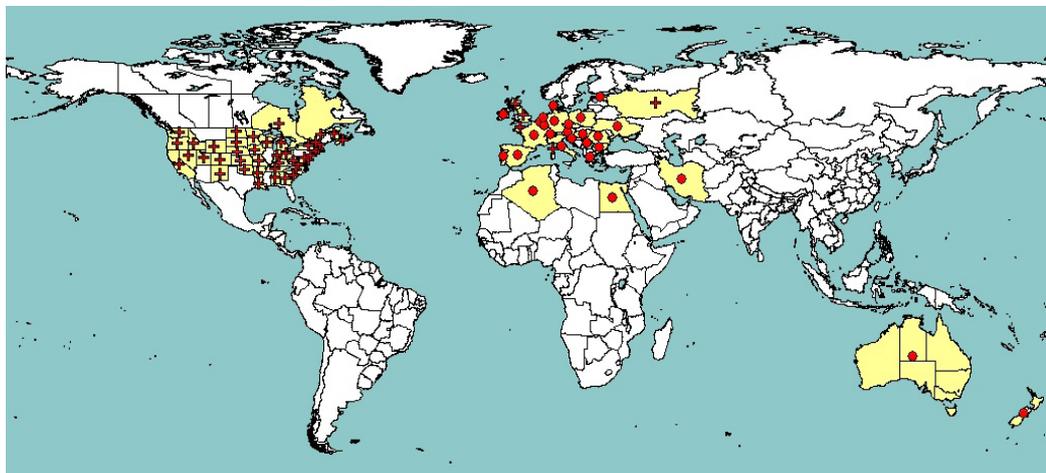


Figure A4. The distribution of *Scolytus multistriatus* (EPPO 2014).

