Phytosanitary risks of wood chips

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Abstract

This report describes the potential risks of spreading harmful pests and diseases by wood chips. Wood chipping is used as a measure against spread of certain harmful insects in wood, but is not effective to prevent spread of bacterial, fungal and viral pathogens. Here additional measures like composting and heating are necessary. Also in the biofuel chain infestations and spread of diseases are possible. For both the biofuel and phytosanitary wood chains the potential risks are described.

Keywords: wood chips chipping, composting, wood chain, harmful diseases, insects, bacteria, fungi, viruses, nematodes

Photos cover: Cees Niemeijer (photo top), Anton Looijen (photo below)

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Contents

Preface

This report is the result of a literature study. The study was conducted by order of the Plant Protection Service of the Netherlands in Wageningen.

The authors that have contributed to the specific parts according to their expertise are:
– Jitze Kopinga - bacteria, fungi, viruses, treatments
– Leen Moraal - insects, nematodes
– Caspar Verwer - wood chain
– Sandra Clerkx - project management

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Summary

Wood chips, as side product of (urban) forestry management practices, are increasingly becoming a substantial source of bio-energy to power plants. Wood chips, especially those harvested from diseases trees, may carry potentially harmful or infectious organisms. Storage or transport of this material entails the risk of spread of harmful organisms into the environment, hence threatening commercial cropping systems and natural vegetation. Currently, there are no science based measures taken by practice to eradicate potentially harmful organisms that may be present in the wood chips or to prevent their spread. This literature study aims to:
– get insight in the wood chip supply chain from source (plantation) to end user (power plant);
– to assess the survival and spread of pest organisms and diseases during transport and storage and to identify the gaps of knowledge in this context;
– determine which treatments or practices can be applied in addition to wood chipping to prevent survival and spread of harmful organisms during transport and storage;
– assess possible risks related to importing (infected) wood chips from other EU countries to the Netherlands.

On the harvest site, parts of trees and shrubs are chipped by commercially available wood chippers that produce chips of highly variable sizes. In the Netherlands the common maximum chip size length is 200 mm (which accounts for either of the dimensions, although chips are normally flake-shaped). There are no data on the average chip size of bulk of chips that are sold to power plants, nor on the probability that chips exceed certain sizes (e.g. 2.5 cm).
Before transport to the end user (power plant) the material is temporarily stored on the harvest site itself or compiled into a central depot in the vicinity of the harvest site from where it is transported further to the power plant. The total storage time can be highly variable. Normally it ranges from several weeks to several months. This might be enough for some pathogens to enter or escape from the material, or to survive and/or reproduce in the material and built up infectious potential. In practice, during storage no special on-site measures are taken to prevent these processes. Those measures could be heating, fumigation or (re)chipping the material to sizes of less than 2.5 cm (any direction). Chipping to finer degree particles is expected to be effective. For heating, aerobic composting of the chips (>70° C for at least several hours) is regarded to be the most practicable method, both from an economic and a technical point of view. Use of covering sealing material or transport in closed containers also will be effective in preventing spread of diseases during transport. Use of biocides is regarded to be not practicable because of technical implications or legislative restrictions.

Insects
Chipping of infested wood to pieces of max 2.5 cm is an effective method to eradicate the two Asian Longhorn Beetles *Anoplophora glabripennis* and *A. chinensis* (ALB) in all developmental stages and no further treatments of the chips are required. It is also effective to eradicate larvae of the Emerald Ash Borer (EAB) *Agrilus planipennis*. These species do not survive the current chipping process adjusted to 2.5 cm and untreated wood chips larger than 2.5 cm should be rejected. However, it cannot be excluded that small numbers of (pre)pupae of the EAB may survive in untreated wood chips slightly smaller than 2.5 cm. Therefore, untreated wood chips should be smaller than 2.5 cm when chipping is used as an eradication method. Additional research is necessary to determine the maximum chip size for eradication measures.

It is advised to chip suspected tree parts during the beetle's flight season, early in the morning or in the evening when temperatures are still low, thus minimising possible beetle dispersal. Above this, harvesting and chipping wood during winter time, when insects are less active, is preferred.

For smaller insects wood-chipping is not suitable as an eradication method, and additional treatments are required. Material could be re-chipped to finer graded material, converted to pallets, composted or burned in a non-quarantine area.

Nematodes

For nematodes, such as the Pine Wood Nematode (PWN) *Bursaphelenchus xylophilus,* only chipping of wood will not eradicate the organism and additional treatments are required. At temperatures above 45° C, the population densities of the nematode in pine chips rapidly declines, so heat treatment or aerobic composting is an effective method to eliminate the nematode.

Bacteria

For bacteria only chipping is not sufficient to eliminate the pathogen. Spreading of bacterial pathogens into the environment during storage and transport of wood chips, can be prevented by keeping the wood chips covered with material that prevents the entrance of arthropods that may serve as a vector for the diseases. Drying the chipped material or heating (e.g. by partial aerobic composting) inactivates bacteria or makes them less attractive to their vectors.

Fungi

For fungi only chipping is not sufficient to eliminate the pathogen. Spread can be prevented by transporting or storing the chips under controlled (closed) conditions. Heating the chips before storing (e.g. by partial aerobic composting) inactivates the fungi and also is a recommendable method. Only the drying of chips is a less effective and thus reliable method.

Virus like pathogens

For viruses and viroids chipping is not sufficient to completely eliminate the pathogen. However, the risk of spreading virus like pathogens during the processing, storage and transport of wood chips is low because of the absence of suitable vectors to transmit the pathogen from wood chips to healthy plants. This implies that no (additional) precautions have to be taken with regard to virus like pathogens.

It is concluded that the phytosanitary risks of certain large insect pests like cerambycids can be reduced to a phytosanitary acceptable level by current practices of wood-chipping. All other insects and infectious diseases potentially can survive the wood-chipping process and for phytosanitary safe handling they require additional treatments. Aerobic composting seems to be most practicable and affordable (financially and energetically) approach. However, for this purpose more insight must be acquired into the management of the composting process need to be fine-tuned to meet both the phytosanitary and quality standards for bio-energy. It is also advised to validate the heat tolerance of some of the mentioned pathogens by further experimental research. Beside this, more insight is needed into the development of the future wood 'supply chain' in order to refine some of the geographical aspects of the risk assessment presented in this report.

1 Introduction

1.1 Project aims

The international trade of biofuel is increasing rapidly. Likewise, production of solid biomass such as wood chips, residues, and pellets is a growing market. However, data on production and trade flows of biofuel are limited and transparency of the market appears to be low. To fulfill the government targets for future bioenergy production, it is necessary to increase the production within the Netherlands and to increase the import of biomass. Most of the woody biomass used in power plants is wood pellets. The majority is currently imported from other EU countries, but considering the increasing global trade in especially wood pellets, it is likely that the Dutch import of wood pellets from Canada, the USA and Russia would increase in the future. The risk of contamination of imported biomass with pathogens or pests (e.g. insects, fungi) is an important limiting factor in international trade. However, untreated round wood and chips from outside Europe are currently banned for import into the EU. Therefore there is an increasing interest to use wood chips that are produced in the Netherlands or neighboring countries as other source of biofuel. However it is not yet sufficiently known what phytosanitary risks are linked to import and use of wood chips and to what extent current regulations are adequate to prevent import of potentially hazardous insects or organisms.
So far there are inadequate measures taken by practice to eradicate potentially harmful organisms or to prevent their spread. Considering that the Dutch government aims to produce 20% of the total Dutch energy supply from sustainable sources in 2020, with one third of that supply coming from woody biomass (VROM, 2007), it is expected that the national and international trade of wood chips will increase the coming years. This increasing market for woody biofuel requires clear regulations to avoid or minimise phytosanitary risks.

Chipping of woody biomass is often applied to process it to biofuel. Chipping is generally understood to reduce the risk of disease outbreak and spread via harmful organisms in the wood. However, it is not exactly known which potentially harmful organisms are eradicated during chipping. When chipping is not sufficient, the remaining potentially harmful organisms that can survive within the wood chips need to be eliminated by additional treatments. It is unclear which methods are required to transport and store possibly disease infected material in a secure way, before it is to be burned in a power plant. Partial composting of the wood by temperature treatment is regarded as an adequate way to diminish the survival of pathogens and pests within the woody material and risks of dispersion of harmful organisms into the environment. In this context the way to reach sufficiently high temperatures needs special attention.

The aims of the project are:
– To get insight in the effective chip size to prevent survival and spread of certain harmful organisms and to identify the gaps of knowledge in this context.
– To determine whether partial composting can be used as a measure to prevent survival and spread of harmful organisms via wood chips.
– To assess the risks related to transport of (infected) wood chips from other EU countries.

Recommendations are presented for preventing outbreaks of these organisms together with the assessment of potential risks within the various phases of the wood chain.

1.2   Limitations

The group of potentially harmful organisms is too large to mention all individual species and not all infections are threatening or potentially epidemic. In the framework of this study a number of infectious diseases have been taken as examples. The examples are limited to diseases that may seriously form a threat to the environment when they are introduced in areas where the disease or pest is not yet present or only present on a scale where it still can be controlled at affordable efforts. From these, only the diseases that are important for <u>trees</u> have been considered. Diseases that are exclusive for other plants such as agricultural or horticultural crops (e.g. potatoes, cereals) are not discussed here.

The diseases mentioned in the Alert list and the A1 and A2 lists of the EPPO[1] standards, together with the list of quarantine organisms of the Plant Protection Service of the Netherlands have been used as guidelines. As a second source for the estimation of potential risks, additional information is obtained from the Status Reports of the EXFOR[2] Database.

Special attention has to be paid to diseases that are known for their potential epidemic development, especially when their spread is depending on the presence of certain indigenous vectors that inhibit wood and bark (e.g. *Scolytus* spp.).

Furthermore, the considered diseases are limited to those that are present, or may develop, in the bark and wood of stems or thick branches of trees that usually serve as source of wood chips, such as vessel diseases and bark cancers. Diseases that exclusively attack weaker tree parts such as twigs or leaves are regarded as less relevant. Also the so called weakness parasites that only attack older trees, such as many of the wood rotting fungi, are not considered because of their comparatively low relevance for healthy trees.

Insects (Emerald Ash Borer and Asian Longhorn Beetle as model insects) form the highest risk, followed by nematodes (Pine Wood Nematode), bacteria and fungi.

As a result, the examples of infectious diseases have been restricted to the organisms mentioned in Table 1.1.

1.3   Reader

To describe the potential risks in the wood chain a lot of information is gathered on the selected species, the treatments and the wood chain, including the process of chipping and the measures that possibly could be taken to avoid the spread of any disease. To get all this information we conducted separate literature studies on these various topics.

The emphasis of this study however, is to make clear the potential phytosanitary risks in biofuel chain of both possible infested and possible non infested or contaminated woody material, and here only the conclusions on the various topics are needed. We therefore divided the report in two parts, to be sure that the essential information on the risks in the chains wouldn't get lost in the mass of information we collected. Part I describes the two chains and their risks. All the information used in this part is based on the separate chapters given in Part II, the background information. Part I should be understandable on itself; Part II gives the detailed information and references we used.

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[1] European and Mediterranean Plant Protection Organisation.
[2] Exotic Forest Pest Information System for North America.

Table 1.1

List of organisms considered in this report.

Type	Organism	English name
Insects	*Agrilus planipennis*	*Emerald Ash Borer (EAB)*
	Anoplophora glabripennis	*Asian Longhorn Beetle (ALB)*
	Anoplophora chinensis	*Asian Longhorn Beetle (also Citrus long-horned beetle (ALB)*
Fungi	*Ceratocystis fagacearum*	*Oak wilt*
	Ceratocystis fimbriata f.sp. Platani	*Canker stain of plane*
	Chalara fraxinea	*Ash dieback*
	Cronartium spp.	*Blister rust*
	Cryphonectria parasitica	*Sweet chestnut blight (or canker)*
	Gibberella circinata (Fusarium circinatum)	*Pitch canker of pine*
	Gymnosporangium spp.	*Juniper rust*
	Phytophthora lateralis	*Root rot of Chamaecyparis*
	Phytophthora ramorum	*Sudden oak death*
Bacteria	*Erwinia amylovora*	*Fireblight*
	Pseudomonas syringae pv aesculi	*Bleeding canker*
	Pseudomonas syringae pv persicae	*Bacterial dieback of peach*
	Xanthomonas arboricola pv pruni	*Bacterial leaf spot, shot-hole*
Viruses	*Plum pox potyvirus*	*Sharka, plum pox, PPV*
	Peach rosette mosaic nepovirus	*PRMV*
	Cherry rasp leaf nepovirus	*CRLV*
	Peach mosaic closterovirus	*American peach mosaic, PcMV*
	Plum American line pattern ilarvirus	*Plum line pattern, APLPV*
Nematodes	*Bursaphelenchus xylophilus*	*Pine Wood Nematode*

Part I　Phytosanitary risks of wood chips

2 Risks of wood chips

Table 2.1

Overview of species studied in this report (I = insects, F = fungi; B = bacteria; V = viruses; N = nematodes; FA = flying adults, Be = beetles, Bi = birds, A = aphids, M = mites; W = wind, R = rain, RC = root contact; PT = pruning tools; U = otherwise partially unknown); Inc. = incidental; Pt = Portugal; * nc = not confirmed; **: Juniperus communis is a protected species

Type	Organism	Most susceptible host plants in the EU	Means of dispersal	Presence in EU					Target parts plant			Area of impact				
				EU	NL	B	G	F	Bark	Wood	Other	Forest	Urban	Landsc.	Fruit	Nature
I	*Agrilus planipennis*	*Fraxinus* spp.	FA	Inc.	-	-	-	-	(+)	-	-	+	+	+	-	+
	Anoplophora glabripennis	Polyphagous (e.g. *Acer, Populus, Salix*)	FA	Inc.	-	-	-	-	(+)	+	-	+	+	+	(-)	+
	Anoplophora chinensis	Polyphagous (e.g. *Acer, Populus, Salix*)	FA	Inc.	-	-	-	-	(+)	+	-	+	+	+	(-)	+
F	*Ceratocystis fagacearum*	*Quercus* spp.	Be	-	-	-	-	-	+	+	-	+	+	+	-	(+)
	Ceratocystis fimbriata f.sp. *platani*	*Platanus* spp.	RC, PT	+	-	-	-	+	+	+	-	-	+	(+)	-	-
	Chalara fraxinea	*Fraxinus excelsior*	W, *U*	+	-	-	+	-	+	(+)	-	+	+	+	-	-
	Cronartium (North American species)	*Pinus* spp.	W	-	-	-	-	-	+	-	+	+	(+)	(-)	-	(+)
	Cryphonectria parasitica	*Castanea* spp.	W, R, Be, Bi	+	-	+	+	+	+	-	-	(-)	+	-	-	-
	Gibberella circinata (*Fusarium circinatum*)	*Pinus* spp.	W, I	nc*	?	?	?	?	+	-	-	+	(+)	(-)	-	(+)
	Gymosporangium spp.	*Juniperus* spp. (main host)	W	-	-	-	-	-	+	-	+	-	+	(-)	+	+*
	Phytophthora lateralis	*Chamaecyparis lawsoniana*	R (spores), W (?) *U*	+	+	-	-	+	+	-	-	(-)	+	(-)	-	-
	Phytophthora ramorum	*Rhododendron, Viburnum*	R (spores), W (?) *U*	+	+	+	+	+	+	(+)	-	+	+	(+)	-	(-)
B	*Erwinia amylovora*	*Rosacaea* (e.g. *Pyrus, Crataegus, Sorbus*)	W, R, I	+	+	+	+	+	+	+	+	(+)	+	+	+	(+)
	Pseudomonas syringae pv *aesculi*	*Aesculus* spp.	W, R, PT	+	+	+	+	+	+	-	-	-	+	+	-	-
	Pseudomonas syringae pv *persicae*	*Prunus domestica, Prunus persicae*	W, R, PT	+	-	-	-	+	+	-	+	-	(-)	-	+	-
	Xanthomonas arboricola pv *pruni*	*Prunus* spp.	R, W	+	?	-	-	-	+	-	+	-	(-)	-	+	-
V	Plum pox potyvirus	*Prunus* spp.	A	+	+	+	+	+	(+)	(+)	+	-	-	-	+	-
	Peach rosette mosaic nepovirus	*Prunus* spp.	N	-	-	-	-	-	(+)	(+)	+	-	-	-	+	-
	Cherry rasp leaf nepovirus	*Prunus* spp.	N	-	-	-	-	-	(+)	(+)	+	-	-	-	+	-
	Peach mosaic closterovirus	*Prunus* spp.	M	-	-	-	-	-	(+)	(+)	+	-	-	-	+	-
	Plum American line pattern ilarvirus	*Prunus* spp.	P	-	-	-	-	-	(+)	(+)	+	-	-	-	+	-
N	*Bursaphelenchus xylophilus*	*Pinus* spp.	Be	Pt	-	-	-	-	(+)	+	-	+	(+)	(+)	-	(-)

The source of wood chips may be either healthy material (regular chain) or contaminated or infested material which requires different processing to avoid further spread of the infestation (phytosanitary chain). These two options are elaborated in the sections 2.3 and 2.4.

General information on species considered in this study is presented in Table 2.1.

2.1 Treatments

Organisms that are potentially harmful to woody crops and trees can be divided into animal infestations (pests) and infections (diseases caused by pathogens). Besides there is a group of plant parasites (e.g. *Viscum album*), that is also often seen as infection. Both groups of organisms can be spread into the environment during the transportation of stems, branches, or other plant parts. To reduce the risk of spreading potentially harmful organisms or viruses, it is important to effectively treat the wood, for example by chipping, heat exposure or application of chemical pesticides.

2.1.1 Chipping

Chipping or wood shredding is seen as an important way to reduce the risk of disease outbreak and spread of harmful organisms in the wood. It will eliminate many infestation vectors (insects) partly or completely, but is normally not sufficient to reduce fungal, bacterial or viral infections, except those who are exclusively spread by wood or bark beetles, such as Dutch Elm Disease. Infections that are spread by spores and can reproduce in dead wood, will survive chipping.

Wood boring insects are dependent on the size of chips to dig holes and tunnels. In the Netherlands the common maximum chip size length is 200 mm (which accounts for either of the dimensions, although chips are normally flake-shaped). EU legislation for the quality of wood chips is underway. So far, New Zealand has the most strict regulations on maximal chip size for the import of wood chips with a chip size of maximal 10 x 15 x 3 mm (see 4.7).

Research indicated however that the standard chip size may be highly variable in practice. After visiting several wood chip factories in the US, Roberts and Kuchera (2006) found that none of the chip piles consistently contained only chips of one cubic inch (2.54 cm) or smaller. The larger chips (up to several inches) were observed to carry live Emerald Ash Borers (see 5.1.3). Spread of the Emerald Ash Borer from infected wood chips stored in piles at the Genesee Power Station in Michigan, presumably caused the massive ash dieback near to the power station.

Chipping is effective in killing insects at a chip size less than 2.5 cm. Larvae that are still feeding in ash phloem are more vulnerable to exposure, injury, and desiccation resulting from bark separation during chipping than prepupae. The prepupae are situated within the sapwood or thick bark, where they may be somewhat protected from desiccation or injury during chipping.

From the model insects used in this study (see 5.1), chipping is effective to eliminate the Asian Longhorn Beetle and larvae of the Emerald Ash Borer (EAB). However, it cannot be excluded that prepupae of EAB or other small beetles such as Scolytidae may survive in untreated wood chips with dimensions of 2.5 cm (McCullough et al., 2007a). No information was found on the effect of chipping on smaller insects.

There was no evidence of EAB survival in chips smaller than 2.5 cm. This means that import of untreated wood chips larger than 2.5 cm in any direction should be rejected. Otherwise the material could be re-chipped, converted into pellets, heat treated, composted or burned in a non-quarantine area.

In case of outbreaks of the EAB in the Netherlands, chipping as a measure against spread of the infestation, must be adjusted to a maximum chip size of 2.5 cm. The chipping should be done before the larvae enter the stage of prepupae.

We were not able to find literature on the capability of larvae to migrate from one chip into another. However our own observations have indicated that larvae from different insect families failed to penetrate into fresh non-infested pieces of wood. It is very unlikely that immature larvae might complete their development in a pile of wood chips.

Many infestation vectors may be partly or completely eliminated during wood and bark chipping. Chipping is normally not sufficient to reduce fungal (see 5.3), bacterial (see 5.2) and viral (see 5.4) infections nor nematodes (see 5.5), except for infections that are exclusively spread by wood or bark beetles, such as the Dutch Elm Disease. Destruction of the vector insect is enough to stop the spread of the disease, but this may not be the case for infections, that are able to reproduce in dead wood and the spread of the disease may occur via spores. These infestations need additional or other measures like composting and heating.

2.1.2   Heat treatment

Direct exposure to high temperatures (of which the exposure time is adjusted to the height of the temperature and the solid volume of the wood) will eliminate all living organisms in wood. The minimal required temperature and the length of exposure time mainly dependent of the type of organism. Viruses and viroids are as a rule more heat resistant than many bacteria (Noble et al., 2009).
For all quarantine pests in general, special requirements are 74° C at four hours, 80° C at two hours or 90° C for one hour (EPPO, 2008).

2.1.3   Composting

Research has shown that during composting the heat released by aerobic decomposition of organic material will eliminate most pathogenic organisms (fungi, bacteria and insects). The heat that is released by anaerobic composting is not as high as by aerobic composting and pathogens normally aren't killed by partial anaerobic decomposition, although they might gradually disappear by biological antagonism. This process however, usually takes more than six months.

Aerobic composting is recommended to eliminate any remaining living insect (no prepupae survive exposure to 60° C for 120 minutes). To reach the required high temperatures for a sufficient length of time, special attention has to be paid to engineering the composting process (minimal volume, rotation cycles, etc.; see Chapter 6).

For nematodes (PWN) chipping wood to the required maximal sizes will kill the vector beetles (*Monochamus* spp.) that may be present in the wood. Importation of untreated chips from these countries thus forms no risk for spreading because the vector beetles are eliminated. However, non-specific potential vector beetles (*Rhagium, Hylobius* and *Hylastes*) for the PWN have been reported to be attracted to heaps of sawdust and, occasionally, thousands of individuals may be present. It is possible that wood chips could act in a similar way, leading to contamination of any beetles attracted to nematode-infested chip piles. These beetles also breed in freshly dead trees and nematode transmission during oviposition cannot therefore be ruled out. It is shown that, in principle, PWN can be transmitted from contaminated wood chips used as mulch to freshly wounded tree stumps when the chips are mixed in the soil around the wounds (Braasch, 1996; EPPO, 1996).

During composting at temperatures above 45° C, the population density of the PWN in wood chips rapidly declines.

Pine Wood Nematodes aren't present in the Netherlands. Only by import of woody material from infested trees from other countries would form a possible risk. In wood chips, the Pine Wood Nematode (PWN) was able to survive at 20-22° C for up to fourteen months, it could therefore survive shipment to Europe from any source. The optimum temperature range for the reproduction of PWN in pine chips is 35 to 40° C. Populations of nematodes in pine chips decline rapidly at temperatures above 45° C.

2.2 Risks of spreading harmful organisms

2.2.1 Insects

The Emerald Ash Borer is a strong flyer. Flight under laboratory conditions suggests that a mated female may fly more than 20 km (USDA, 2009). In the Netherlands many ash (*Fraxinus*) trees are planted in and outside cities. So, host trees are available everywhere and escape of beetles must be prevented at any time.
If after chipping infested trees, some of the chips still have a size larger than 2.5 cm, the material could be re-chipped, converted into pellets, heat treated, composted or burned in a non-quarantine area (e.g. Roberts and Kuchera, 2006).
When host trees in the Netherlands are found to be infested, it is recommended that, when beetles are active, infested tree removal occurs within three days of detection. It is recommended that the roots of host material to be removed to a minimum of 25 cm below ground level. Any above ground roots of 1.5 cm or more in diameter should also be removed. Chipped material must be no larger than 2.5 cm in three dimensions. Host material that is not chipped may be moved to an approved burning site with proper safeguards: vehicles must be covered to prevent spillage and host material may be held no longer than 24 hours at the burn site prior to burning (USDA, 2008).

The Asian Longhorn Beetle is much more larger than the EAB and a poor flyer. In the USA, 80% of the infestations occurred within a distance of 84 meter and 99% within a distance of 335 meter from the source. Only few infestations were found over a distance of 600 meter. Experiments in China however, indicated the ALB was able to fly for 1.5 km within three weeks (USDA, 2008). In the Netherlands many host trees e.g. *Acer, Aesculus, Betula, Salix* and *Ulmus* are very common trees and the escape of beetles from a suspected bulk of unchipped wood must be prevented at any time. However, chipping the wood with the 2.5 cm criteria for maximum size, from infested trees provides a highly effective method for destroying this large species (Wang et al., 2000b).

2.2.2 Nematodes

Wood chips represent a significant Pine Wood Nematode inoculum source for potential transfer to European forests. It is possible that chips could act in a similar way, leading to contamination of any beetles trapped in nematode-infested chip piles. The fact that these beetles also breed in freshly dead trees points to possibilities of nematode transmission during oviposition. The possibilities of vector transport from chips after they have arrived in Europe cannot therefore be ruled out (Evans et al. 1996). If introduced without an insect vector, or with no insect vector already established, PWN could still establish itself in a suitable host by means of non-vector transfers. The likelihood of establishment however, would be low. In this case, the long-term survival of PWN depends on finding a native or established vector (Halik and Bergdahl, 1992). In principle, PWN can be transmitted from contaminated wood chips to freshly wounded stumps (Braasch, 1996).

2.2.3　　Bacteria

Over short distances (from plant to plant) bacteria are usually spread by wind, rain or arthropods, mostly insects. They also can be spread by various animals or human activities by means of pruning tools, etc. Over longer distances they are mainly spread by transportation of infected material (such as shredded or non shredded parts of an infected tree).

Bacteria can survive and stay latent infectious for long periods in diseases material, also in small parts such as wood chips, regardless of their size. Also at low temperatures bacteria can survive and be latent infectious. Therefore the risk of spreading the organism by transportation of wood chips is very high.

Because insects can be attracted by the presence of bacteria in infected wood, there is also an additional risk that during transportation inoculum is spread into the environment. Therefore raw material must be transported under conditions that prevent entrance of insects into the shipped bulk. In many EU countries Plant Protection Agencies have put strict regulations on the transport of diseased material (e.g. infected by *Erwinia amylovora*). The risk of spreading bacteria by insects can be decreased by transporting the raw processed material during periods when most insects are less active (usually wintertime).

2.2.4　　Fungi

The highest risk of spreading during transportation are fungi that form fructification bodies and spores on dead wood and besides that, have a broad range of target plants.

Transporting of wood chips from infected trees that have been stored for some period at the site of harvesting implies an increased risk for spread of the organism into the environment. The risk can be diminished by harvesting, processing and shipping the wood products during periods in which the organisms have low activity (normally wintertime)

From some fungi (e.g. *Ceratocystis fimbriata*) it is known that spores or mycelium parts attract insects that subsequently serve as vector for the disease. Wood and bark beetles that already are present in the diseased wood during harvesting and that also may serve as vector for the inoculum can be (partly) destroyed by diminishing the size of the wood chips. However this does not account for the non-wood and bark inhabiting insects. The risk of spreading fungi by insects can be decreased by transporting the raw processed material during periods when most insects are less active (usually wintertime). For other periods the risk for spreading the disease by insects can be diminished by covering the load of chips by material that prevent entrance of insects or by shipping the load in closed containers.

2.2.5　　Viruses, viroids and phytoplasmas

The risk of the spreading of virus like organisms into the environment during storage and transport is low. It is not likely that organisms that usually serve as vectors for virus like diseases (aphids, mites, nematodes) will take wood chips as a feeding source. Even when the raw material is still fresh the chance is low because most of the vectors as a rule prefer the weak parts of a plant as feeding source, such as leaves, buds or inflorescences, and not hard parts such as wood or bark. As far as virus like diseases are concerned, a short period of air drying of the material would provide sufficient guarantee that no potential inoculum is spread into the environment during transportation.

On the other hand, the comparatively limited range of target species of most of the virus like diseases already constitutes a restricted risk for spreading into the environment. From the virus diseases that are taken as example in this report, the target species are limited to stone fruits such as cherry, peach and plum. As commercial products these are grown in the Netherlands on only a modest scale, often concentrated it certain regions of the land. The geographical spread of the largest commercial orchards is usually known and chips of

possibly virus infected wood preferable must be stocked before transportation on some distance from these orchards.

Another risk lowering aspect is that a number of known vectors form the earlier mentioned diseases do not naturally occur in Europe. Nevertheless it must be taken into account that other vectors that are already common in (some parts of) Europe may possibly serve as potential vector within the course of time.

2.3 Wood biomass chain
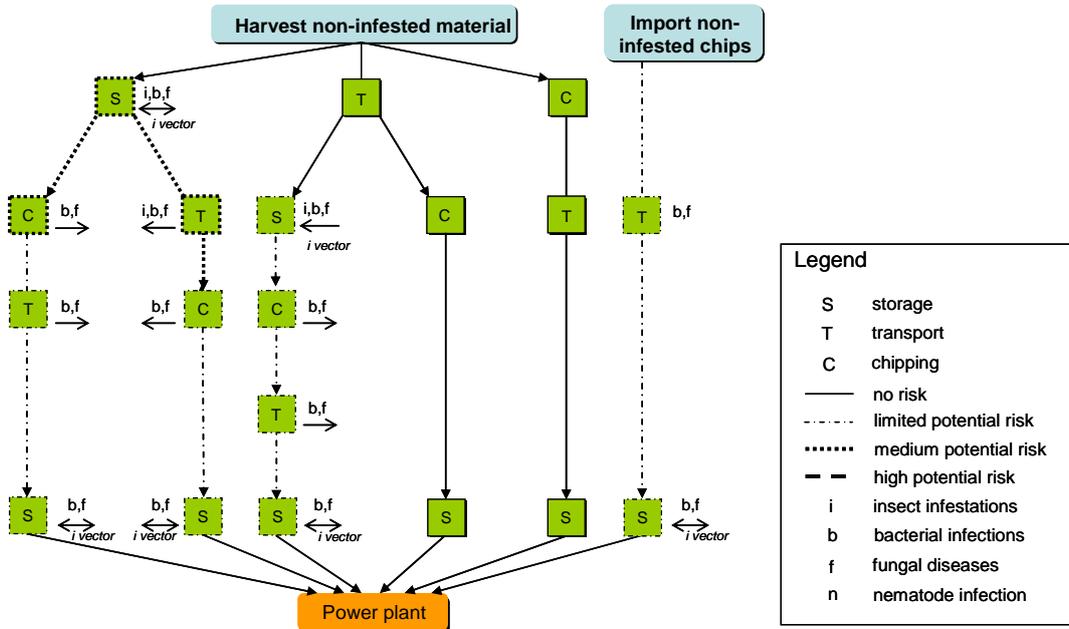
Figure 2.1

The wood biomass chain.

The regular wood biomass chain mainly involves biomass resulting from pruning of landscape and urban elements, without any known harmful infestations or infections. After pruning or harvesting in forests, the biomass can either be stored at the site for a short period (up to half a year (Boosten et al., 2009)) or at a storage depot outside the area, or it can immediately be chipped at the site. Chipping at the site has the advantage that it prevents potential insect infestation, which may occur during temporal storage at the site. Temporally stored biomass may also potentially carry bacterial or fungal infection. Biomass piles also could become infected from an external source and than may form a source of inoculum and potential source of further spread. There is practically no risk of spread by wood boring insects when the material is chipped at the site where it was temporally stored. However, material which is stored in the field will often be transported to a storage depot first before it will be chipped. If the material is indeed infected, the infestation might spread during this transport, for example through woody biomass falling or blowing from the truck.

Non-infested material that is transported directly after harvesting and then stored in an open air depot also runs a risk of bacterial, fungal and insect infection, albeit less severe compared to storage at the site because this storage site is generally more isolated and takes place under more controlled conditions. Nevertheless, there still is a potential risk of infection and spread of possibly harmful bacteria and fungi (spores) during chipping (through sawdust) and transport (Evans et al., 1996).

Chips piles always will attract particular insects, including vectors for bacteria, fungi and nematodes. This could introduce diseases to the pile, which on its turn, forms a source for further spreading. Infestations occurring in this way have not further been investigated within the framework of this study.

Risk of contamination of the chips with organisms that are not already present in the Netherlands is only theoretical and therefore of little relevance.

Wood chips that are imported from abroad must be handled with care as they may carry bacterial and fungal infections. The material imported as biofuel is assumed free of harmful infections, but as the trade chain of this material might not always be transparent, risks cannot be completely excluded. Since the free trade within the EU is allowed, control only takes place in the country of origin.

Therefore it is recommended that imported chips should always be containerised or covered with appropriate materials.

The quantity of imported wood chips from other EU countries (mostly Belgium and Germany) to the Netherlands is currently negligible, but is expected to grow in the nearby future.

However, in the future it is to be expected that chips are increasingly imported from countries where diseases occur that are not yet present in the Netherlands. If wood chips from these countries are stored for a period of time before it is burned, there is an increasing risk that diseases may spread from this material into the environment.

It is to be expected that in the future the use of pellets will increase. The process of pellet production includes chiseling, drying and compressing the material (see chapter 4.4) in a way that will definitely eradicate all possible organisms and pathogens apart from some virus like diseases that may survive. However the latter are no threat because of the absence of suitable vectors. Wood pellets therefore do not contribute to any risk for introducing and spreading diseases.

2.4 Infested wood biomass chain
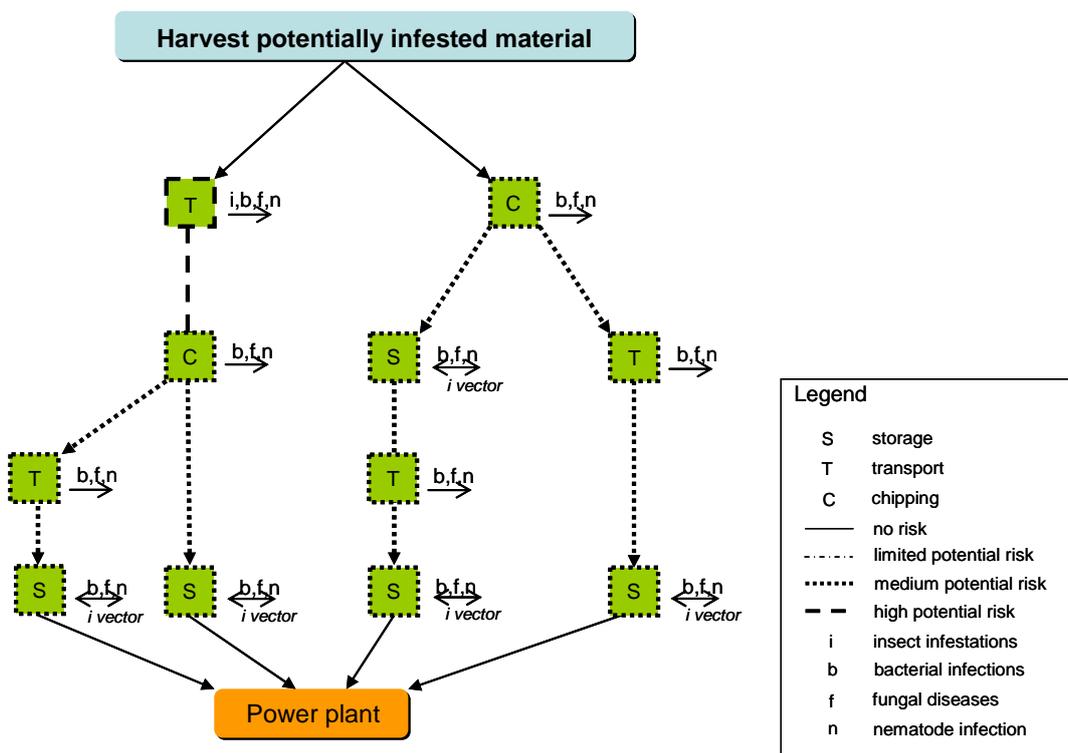
Figure 2.2

Infested wood biomass chain.

The infested wood biomass chain is directed towards a rapid elimination of potential hazardous infestations, and consequently storage time is reduced to a minimum. Infected material is harvested and either chipped at the site or transported to a storage depot where it is chipped. Temporal storage needs to be isolated, and transport may be subject to specific regulations in order to minimise potential spread.

Chipping wood to small sizes, as concluded in 2.1 is a useful measure against insect infestations. Other organisms need further measures, such as partial composting during storage. Hence, chipping of woody material in the field may not completely eliminate the risk of contamination. Therefore, certain additional measures will be required.

Chipping on the harvest site is not always possible or practicable. The infested material has to be transported (T) to a (regional) centre where the material can be chipped.

The risk of spreading bacteria during transport of raw material is high: insects can be attracted by the presence of bacteria in infected wood, and inoculum can be spread into the environment.
Transport of raw material can best be done during winter, when insects are less active. In case of bacterial diseases, it is best to transport the unchipped stems and branches according to the 'transport routing' in Figure 2.2. The transport of wood chips from trees infected by fungi that have been stored for some period at the site of harvest implies an increased risk for spread of the organism into the environment whenever the fungus can build up infectious potential within the stored material during the storage period. This risk can be diminished by harvesting, processing and transporting the wood products during periods in which the organisms have low activity.

Both transport and storage form a risk of spreading diseases by insect vectors (Figure 2.2). Chip piles may attract insects that potentially serve as disease vectors. For example, infectious nematodes and inoculum from bacteria and fungi can be transmitted by insects (*i-vector* in Figures 2.2-2.4) and consequently form a risk for spread of these diseases from the pile into the environment. Transport of woody material also forms a potential risk of spread of infections, particularly when it is exposed to open air and can be visited by insects. In case of bacterial infections it is preferable to transport the raw, unsawn material before chipping (Transport routing). To prevent spread of diseases during transport, the material in any stage of processing should be covered (Figure 2.4).
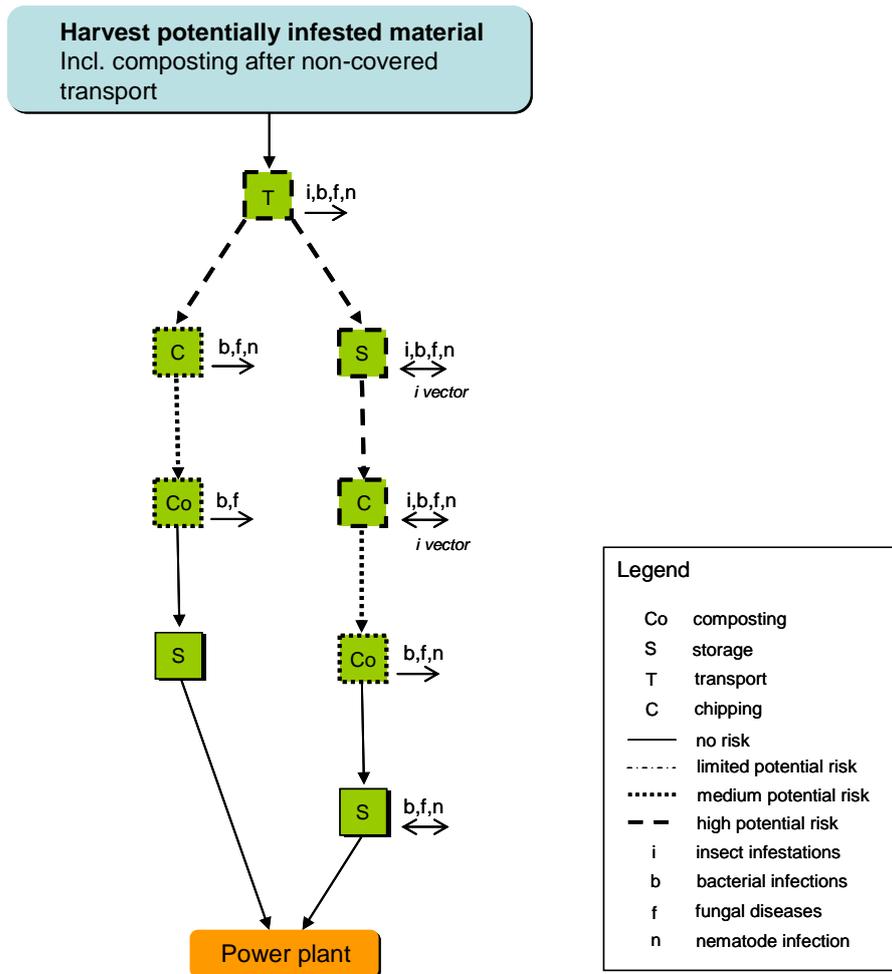
Figure 2.3

Chip risk chain of potentially infested material with non-covered transport prior to composting.

Research has indicated that besides chipping and coverage, composting is a highly effective measure to reduce risks of spread of infectious diseases. Preferably, all the material is chipped and composted on the same site so that all risks of spread are restricted to the pre-composting stage. When the material is properly stored and transported in covered or closed containers, the risk of spread of organisms is very low. In the literature it is recommended to use enclosed vehicles (USDA, 2009) or to use strong pvc or plastic sheets as covering material (USDA, 2008) (Figure 2.4).
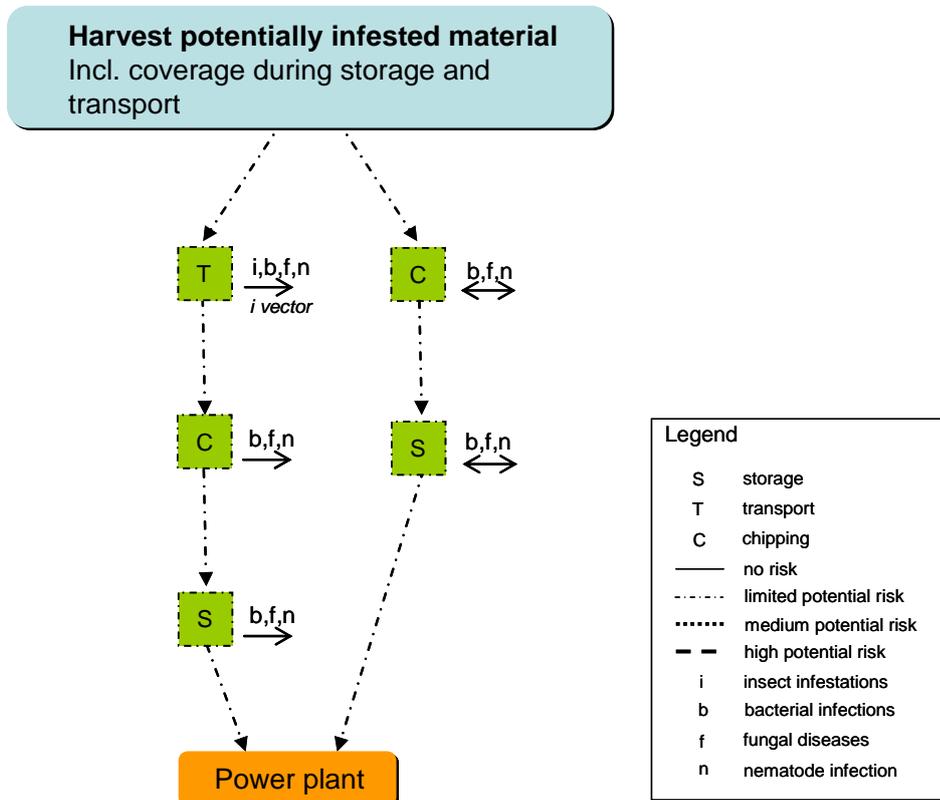
**Figure 2.4**

Chip risk chain of potentially infested material with covering during transport and storage

When the material is properly stored and transported in covered or enclosed containers, the risk on spread of organisms is very low. In the literature it is recommended to use enclosed vehicles (USDA, 2009) or to use strong pvc or plastic sheets as covering material (USDA, 2008).

3 Conclusions and recommendations

3.1 Conclusions

Currently, the Netherlands use 850,000 Mg wood pellets and 275,000 Mg wood chips from locally harvested biomass, for the production of bioenergy from woody biomass. Most of the wood chips from Dutch sources are burnt as fresh material in bioenergy plants, although some 20,000 Mg (dry matter) of the wood chips are dried and grinded for by-burning in coal plants each year. 95% of the wood pellets used in the Netherlands is imported from other EU countries and Canada and the remaining 5% is produced in the Netherlands. The global trade in wood pellets has been increasing following the increase in production capacity from 7 mln. Mg in 2006 to 14 mln. Mg in 2008. As a result, the Dutch import of wood pellets from Canada, the USA and Russia is likely to increase in the coming years. Beside this, there is an increasing interest in the use of wood chips as biofuel. Currently, all the wood chips used for bioenergy production in the Netherlands are produced within the country itself. Some small wood chips may have been imported in previous years, but the exact quantities remain unknown because the trade flows of wood chips are not transparent. Like wood pellets, also the Dutch import of wood chips is likely to increase in the near future. Considering the relatively high transportation costs, it is to be expected that only adjoining EU countries will form the main source of import for the Netherlands. Import of wood chips from overseas is not very likely to happen on short term because of high transport costs.

Wood chips produced inside the EU, made from non-quarantine-pest infested trees, will not cause important threats when imported into the Netherlands. These threats are comparable with those of the free trade for plants and wood products within the EU.

The import of suspicious non-treated (gas, chemicals, heat) wood chips partly larger than 2.5 cm in all dimensions should be rejected. This is because it cannot be excluded that prepupae of the insects such as the Emerald Ash Beetle and Asian Longhorn Beetle may survive in untreated chips larger than 2.5 cm. Otherwise the material could be re-chipped, converted into pellets, heat treated, composted or burned in a non-quarantine area. Artificial aerobic composting of wood chips may be an effective method to eliminate the risk of infestation by insects and nematodes, provided that sufficient high temperatures are reached during the composting process.

Aerobic composting also inactivates infectious diseases caused by fungi, bacteria and virus like pathogens, provided that the temperature, time of composting and moisture content of the substrate are high enough (70° C for at least several hours at moisture contents of >40%).
If, for some reason, composting on, or close to the harvest site, is not practicable, several precautions have to be taken during storage and transport of the chips.
As far as bacteria are concerned, covering of the chips with appropriate material (e.g. fly screens) that keep off insects is necessary as many insects are known to be able to transmit bacteria to healthy plants. Also only drying to the air will reduce the risk of spread by insects, because it makes the bacteria less attractive as a feeding source, but will not inactivate bacteria.
Spread of fungi is more difficult to control because some fungi may still develop sporulating bodies on dead wood which spores can be spread by wind over large distances during storage and transportation. Therefore, if heating or composting the wood chips on the harvest site is not an option, the material must be stored and transported under conditioned circumstances that prevent spreading of infectious material (spores, surviving structures).

Virus like pathogens on their own are of less importance as phytosanitary threat, mainly because the possible vectors (insects, mites, nematodes) that transmit virus diseases do not use wood chips as a feeding source. As far as only virus like diseases are concerned, no special precautions are necessary.

Nematodes such as the Pine Wood Nematode may survive in imported wood chips. Pine wood chips imported from Japan, China, North-America and Portugal could thus be contaminated with living Pine Wood Nematodes. Import of untreated chips from these counties may form a potential risk. In general, heating of the chips, e.g. by composting at temperatures above 45° C will reduce the Pine Wood Nematode population rapidly.

Wood that already is transformed into wood pellets does not form any risk at all for spreading pests and diseases as during the production process: the heat that is required to press the saw dust together destroys all living organisms.

3.2 Recommendations for further research

During the study we identified several gaps of knowledge related to the wood chain and to the potential spread of infectious diseases:

The market of wood chips is far from transparent. It is estimated that currently hardly any wood chips are imported to the Netherlands, but the exact trade flows and volumes of wood chips remain unknown. It is assumed that the entire trade of wood chips occurs within the EU, because international trade between EU countries is free and unregistered. Contrary to wood pellet shipping, there is no overseas transport of wood chips because chip prices do not outweigh the high transport costs involved. However, this may change as the wood chip market grows and the bulk of traded volumes increase.

Future demands of wood chips is very likely to increase in order to meet the governments target for the level of bioenergy production from biomass in 2020. Nevertheless, the production of biomass other than woody biomass to be used as

biofuel may increase as well. The exact contribution of woody biomass in the total of future energy supply will depend very much on the future market. New initiatives of bioenergy supply, such as central heating systems in city districts or office buildings will increase the demand, whereas low prices of other fuel sources is likely to lower the demand for wood chips.

Within the EU there are no trade regulations for woody biomass and consequently it will be hard to monitor the phytosanitary risks of transportation. Strict regulations for potentially infectious material, related to transport (e.g. packaging) and storage (e.g. heating) can play an essential role in reducing the risks of spreading serious pests or diseases.

It has been clearly demonstrated that bacteria, viruses and nematodes already present in shrubs and trees may survive in wood chips. Survival in wood pellets is unlikely. When chips are pressed to pellets, the high temperatures that are required for this process will almost certainly inactivate all living organisms in the material. The same may be expected of material that is partially composted or kiln (= by heat) dried before transport. These extra treatments however are either time taking or energy consuming and will raise the price of the material. As the import of wood pellets is expected to grow, it is important to evaluate the phytosanitary risks specifically related to the wood pellet chain and how wood pellets are handled in practice.

All of the infectious diseases mentioned in this report are parasites that are mainly found on, or even restricted to, bark and wood of trees. It may be expected that some methods of preprocessing wood chips, already will limit the risk for spread of the diseases into the environment to an acceptable level. For example, removal of the bark of trees that may be infested by typical bark diseases (e.g. *Cryphonectria*) before chipping may bring the infectious potential risk substantially down. However, it is not sufficiently known yet to what extent

debarking of wood before chipping is an attractive option both from a commercial, technical, and also phytosanitary point of view.

Little is known about the residual infective potential of the various diseases once the material has been dried to the air to low humidity (e.g. 16%) as only precaution method. It may be expected that at low humidity of the substrate the activity of some of the fungal diseases will also be low. However, it is insufficiently known to what extent and for which diseases conditioned air drying of the raw material is sufficient to prevent spread of the diseases into the environment.

Chipping of wood to small sized 2.5 cm chips is very effective for killing large sized beetles such as the Asian Longhorn Beetle. The Emerald Ash Borer is much smaller, the larvae will not survive the chipping but the prepupae are less vulnerable and it cannot be ruled out that they might survive the chipping. We did not search for literature on the effect of chipping on very small insects such as bark beetles that might serve as possible vectors for infectious diseases. When in the future, wood chips would be imported from overseas, it is essential to know the risks of survival of this kind of insects in the wood chips. Bark beetles such as the Douglas Fir Beetle, *Dendroctonus pseudotsugae*, and the Southern Pine Beetle, *Dendroctonus frontalis,* are extremely harmful in North-America, killing many trees over large areas. It's no need to elucidate that it is very important to prevent importing these insects into Europe.

As fumigation of chips is expected to be prohibited and direct heat treatment is an energy consuming process, partial aerobic composting of chips turns out to be the most attractive and most secure method for further treatment. However, it is a time taking process and it may be expected that there will be an increasing demand for methods that will accelerate the process, while maintaining the quality of the chip for use as biofuel. These aspects require further study, and practical research as most, if not all of the existing knowledge is based on composting agricultural debris and other organic matter than wood chips.
By doing so, also the heat tolerance of organisms of which lethal temperatures are insufficiently known c.q. are based on estimates of relate species, has to be validated.

Part II   Background information

4   The wood chain

4.1   Wood energy

In 2007, 2.83% (or 94.1 PJ[3]) of the total energy consumption originated from sustainable sources, and more than two thirds consisted of bioenergy (De Nie and Blom, 2008). So far in the Netherlands wood based bioenergy only has a minor share in the total primary energy supply, with 0.51% in 2005 (Figure 4.1). By contrast, in Finland and Sweden this was 18.5 and 15.6% respectively. However, the market for biomass energy is growing in the Netherlands due to initiatives to increase biomass production for bioenergy purposes (Min. van LNV, 2008). Increase of biomass production in the Netherlands is necessary to meet the government target of 200 PJ from biomass by 2020. It has been estimated that currently about 32 PJ of energy can be produced from woody biomass in Dutch forests, landscape elements and nature areas (Kuiper and De Lint, 2008).

In Europe, some 90.9 Tg of biomass, mainly wood, was used for bio-heat and bio-electricity in 2007 (AEBIOM, 2009) and this consumption is predicted to increase over the coming years. For example the European consumption of wood pellets is predicted to increase to 13 Tg in 2010 of which an estimated 4.5 Tg will be imported from outside Europe (Swaan and Melin, 2008). Currently the largest producer and exporter of wood pellets is the USA, followed by Germany, Sweden and Canada (Junginger, 2009). Germany has the largest production capacity of wood pellets, followed by Canada, Sweden and the USA. In view of the increasing Dutch wood pellets consumption, future imports from these countries could be expected to grow, which might have implications for the spread of potentially harmful organisms, although most organisms are unlikely to survive the process of pellet production.

[3]

Symbol	Name	Value
Mg	megagram (tonne)	10^6 g
Gg	gigagram	10^9 g
Tg	teragram	10^{12} g
Pg	petagram	10^{15} g
TJ	terajoule	10^{12} j
PJ	petajoule	10^{15} j
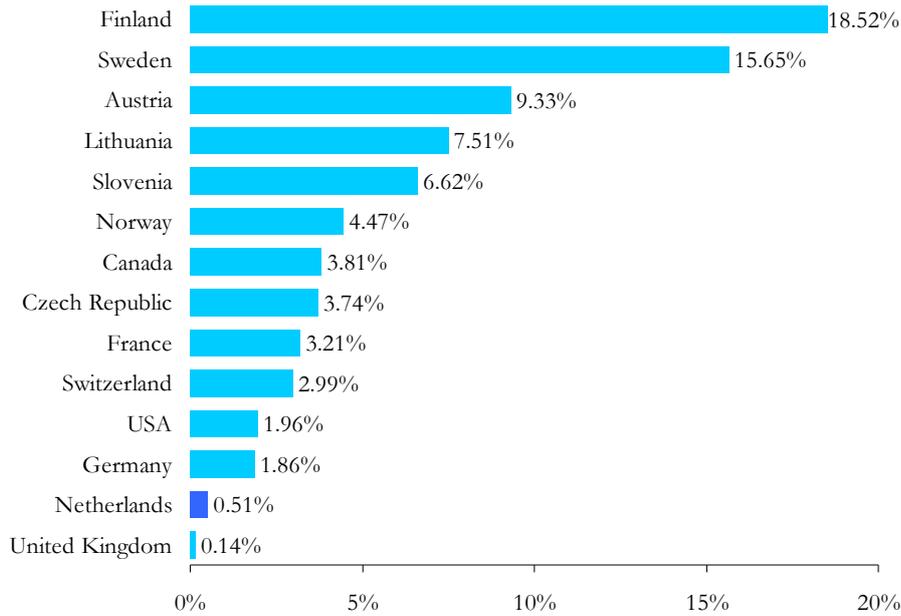
Figure 4.1

Role of wood energy in the total primary energy supply, 2005 (Steierer et al., 2007)

Most of the wood based energy in the Netherlands is used to generate power and heat (1,4 mln. m^3), 21% is used for private households (412,000 m^3) and 7.6% for industrial use (150,000 m^3) (Figure 4.2). Compared to other European countries the Netherlands has a relatively large share of wood consumption for power and heat supply.
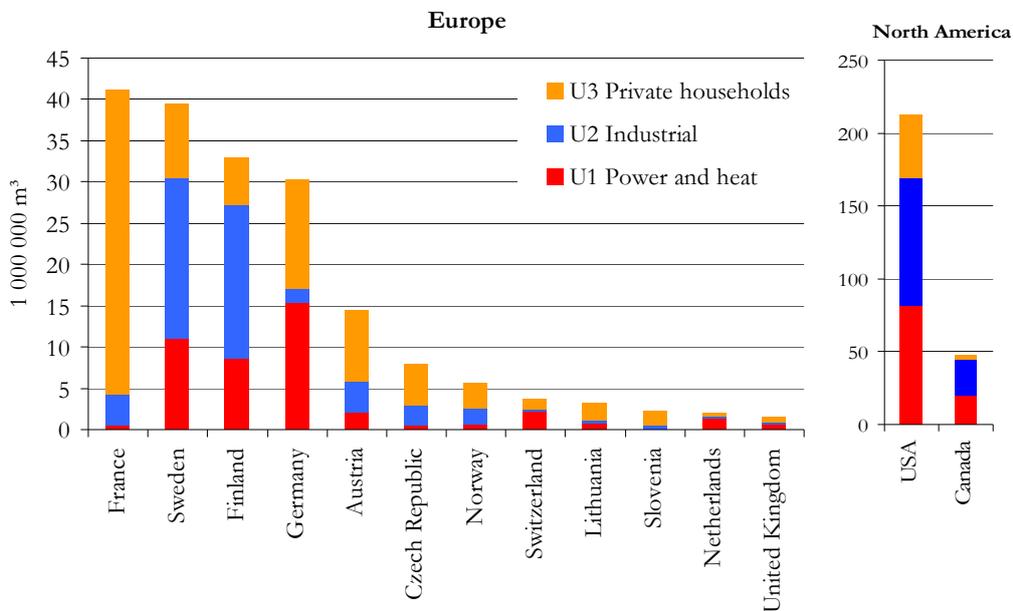
Figure 4.2

Wood energy consumption by user in Europe and North America, 2005
(Steierer et al., 2007).

4.2 Sources of wood chips in the Netherlands

It has been estimated that in the Netherlands there is a total of 475 Gg dm/yr of woody biomass available, mostly form forests (Boosten et al., 2009). Currently the potential harvestable volume for energy production from Dutch forests is about 217 Gg dm/yr (Spijker et al., 2007). Small forest elements, line shaped landscape elements and landscape elements managed by nature organisations have a potential harvestable volume of 78, 57 and 32 Gg dm/yr respectively (Boosten et al., 2009).

Table 4.1

Area of woody biomass and potential harvestable volume in the Netherlands (Boosten et al., 2009) dm=dry matter).

| Terrain type	Area	Unit	Potential harvestable biomass (Mg dm/yr)
1. Forest	**360,000**	**ha**	**217,360**
Tall forest	289,000	ha	
Special tall forest	37,000	ha	
Tree forest	2,000	ha	
Spontaneous forest	24,000	ha	
Estate forest	6,000	ha	
Other	5,000	ha	
Exceptional forest types	34,000	ha	
Avenues	5,000	ha	
Hedgerows	1,000	ha	
Windbreaks	3,000	ha	
Coppice	6,000	ha	
Osier plantation-energy	700	ha	
Recreational forest	3,000	ha	
Vegetated landscapes	8,000	ha	
Other	7,300	ha	
2. Landscape elements of nature organisations	**9,560**	**ha**	**31,816**
3. Small landscape elements			**225,595**
Solitary trees	257,530	st	2,713
Small forest patches (<0.5 ha)	30,949	ha	78,104
Woody line shaped elements	3,894	km	8,638
Hedges	6,996	km	7,223
Roadside trees	5,724	km	10,078
Tree rows	42,366	km	38,633
Orchards	3,316	ha	1,747
Osier plantation (<0.5 ha)	22	ha	85
Duck decoys	150	st	1,496
Farm terrains	91,367	st	32,085
Civil terrains in the country	170,071	st	44,792
Total 1+2+3			**474,771**

In total an estimated 275,000 Mg dm/yr of woody biomass from forest, landscape and nature areas is currently used for bioenergy production (Kuiper and De Lint, 2008), which is about half of the potential harvestable volume (Table 4.1). The largest source of wood chips produced in the Netherlands currently originates from biomass harvesting during development of housing areas, industrial terrains and infrastructure. The second largest source of wood chips and chunks comes from landscape management such as pruning of trees and bushes. A study by Feil and Frederiks (2006) showed however that the majority of this biomass is

not used for bioenergy production but left at the site after fragmentation. The same holds for Dutch forests, where most of the woody biomass in the Netherlands grows, but only some 150,000 m^3 is harvested for bioenergy production in power plants and about 250,000 m^3 is harvested to produce firewood (Kuiper and De Lint, 2008). The State Forest Service (SBB) is the biggest producer of wood chips from nature areas in the Netherlands.

Most of the wood chips from Dutch sources are burnt as fresh material in biopower plants, although, according to (Spijker et al., 2007), some 20,000 Mg dm of the wood chips are dried and grinded for by-burning in coal plants each year. Besides the use as energy source, woodchips are also used as filter material in composting and for chipboard production. According to Beeks (2009) some 100,000 Mg of biomass is exported each year to Belgium and Germany, mainly for bioenergy production, but also for fibreboard.

4.3 Sources of imported wood chips

In 2007 part of the wood chips used for bioenergy production in large power plants was imported from Belgium and Germany, but this import has been decreasing as a result of higher demand in the exporting countries (Spijker et al., 2007). Currently the Dutch import of wood chips seems to be negligible, especially because chip prices are relatively high in neighbouring countries (Beeks, 2009). Considering the growing demand for wood chips in the Netherlands, it can be expected that import will increase in the near future, most probably from within the EU to avoid high transportation costs. Countries with a high direct source of wood energy, like France, Czech Republic, Slovenia, Norway and Switzerland (JWEE), may be expected to increase their export of wood chips to the Netherlands. Nevertheless, how the future wood chip supply would look like, remains unpredictable at the moment, because production figures are often not available, especially not when chips are produced as by-product.

4.4 Production methods

Woody biomass for the production of bioenergy in large power plants is usually processed to wood pellets (energy pellets). Wood pellets are a form of densified biofuel. They are made from pulverised biomass and usually have a cylindrical form, random length typically 5 to 30 mm, and broken ends (Figure 4.3a). The moisture content of wood pellets is usually less than 10% of mass (FAO, 2004). They are usually made from industrial residues such as sawmill rejects. Currently some 850,000 Mg wood pellets are used in the Netherlands (15 PJ), and some 95% of these wood pellets is imported, mainly from Scandinavia and Canada (Alakangas et al., 2007). Production of wood pellets in the Netherlands is about 15,000 Mg, of which most is exported to Germany and Scandinavia (ProcedeBiomassa, 2009). Within the Netherlands wood pellets are only used for co-firing in coal-fired power plants and not in power plants that are specialised in biomass fuel. In those plants wood chips, shredded green waste and compost sieve overflow are being used as energy sources. Wood chips are made from woody biomass which has been chiselled to small pieces of usually a few centimeters in size (Figure 4.3b). The Dutch consumption of wood chips and particles in 2007 has been estimated to be 350.000 Mg (Grontmij, 2008).
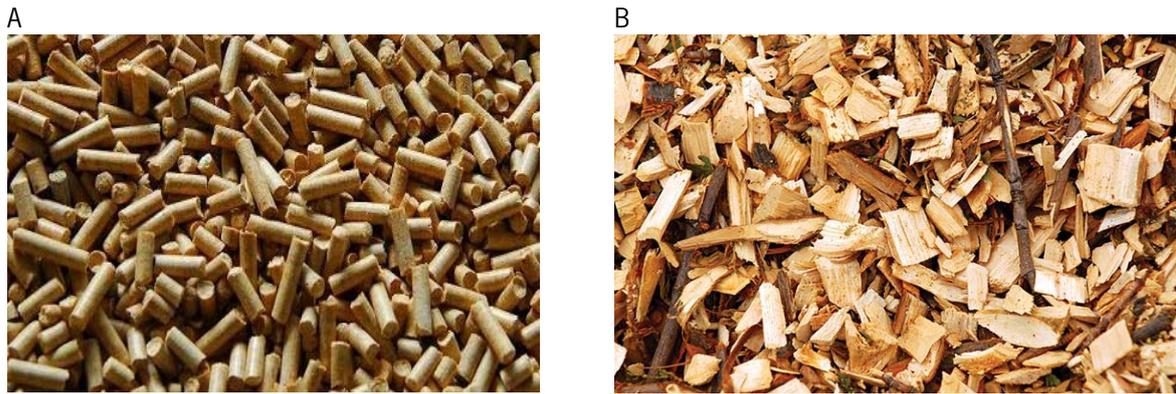
Figure 4.3
Wood pellets (A) and wood chips (B).

Currently wood chipping in the Netherlands is done primarily to reduce the volume for transport. Bioenergy is not the primary cause but it is likely that wood chip quality will increase as their importance in bioenergy production raises. The quality of wood chips is mainly determined by fraction size, energy-, moisture- and ash content.

Table 4.2
Characteristics of some biomass types used for bioenergy production (FAO, 2004).

	Moisture % dry basis	Net calorific value (MJ/kg)	Total ash (% dry basis)	Volatile compounds
Spruce wood (with bark)	20-55	18.8	0.6	82.9
Beech wood (with bark)	20-55	18.4	0.5	84
Poplar wood (Short rotation)	20-55	18.5	1.8	81.2
Willow wood (short rotation)	20-55	18.4	2	80.3
Bark (softwood)		19.2	3.8	77.2
Road side green		14.1	23.1	61.7

Table 4.2 shows some characteristics of frequently used sources of woody biofuel. Quality reduction is sometimes observed during skidding, as woody biomass mixes with soil. Wood boring insects are dependent on the size of the wood piece to dig holes and tunnels. Therefore processing wood to small sized chips may be an efficient way to prevent survival of insects in the wood, depending on the chip size and the insects involved. Depending on the technique used to burn wood chips, their size may vary from 20x25x10 mm to 50x50x20 mm, with a moisture content of 20-60% (Boosten et al., 2009). However, in the Netherlands wood chips can be somewhat bigger than that. The maximum chip size (L+W+H) in the Netherlands is 200 mm (Table 4.3).

Table 4.3

Chip sizes in the largest biopower plants in the Netherlands (Feil and Frederiks, 2006).

	Share of total	Chip size L+W+H
Cuijk	100%	<200 mm
	90%	<100 mm
	70%	<50 mm
	70%	>15 mm
	Share of total	Chip size LxWxH
Lelystad	100%	<200 x50 x 50 mm
	90%	<50 x 20 x 20 mm
	95%	>2 x 2 x 2 mm

EU legislation for quality of wood chips is underway (CEN prEN 14961-1 2008.4 solid biofuel) which is to replace all other national legislations. This standard will describe the requirements for fraction size, moisture content, ash content and density of the wood chips.

Research indicated however that the standard chip size may be highly variable in practice. After visiting several wood chip factories in the US, Roberts and Kuchera (2006) found that none of the chip piles consistently contained only chips of one inch or smaller. The larger chips (up to several inches) were observed to carry live Emerald Ash Borers. Spread of the Emerald Ash Borer from infected wood chips stored in piles at the Genesee Power Station in Michigan, presumably caused the massive ash dieback near to the power station.

4.5 Processing areas in the Netherlands

The average annual amount of chips processed in the Netherlands is 400,000 Mg (Steierer et al., 2007). In the Netherlands there are about ten big parties active in the distributive trade of woody biomass for bioenergy production (Boosten et al., 2009). These companies deliver about 285 Gg dm/yr to both the bigger power plants and smaller private companies. The largest consumers of wood chips in the Netherlands are the specialised biopower plants such as in Cuijk (Essent) and Lelystad (Nuon) (Table 4.4).

Table 4.4

Five largest biomass fired power plants in the Netherlands in 2007.

	Company	Location	Capacity 2007 (Mg dm)
1	Essent	Cuijk	120,000
2	Nuon	Lelystad	11,000
3	Vink-Sion BV	Beetgum	9,000
4	Delta T. Bio Energy BV	Beetsterzwaag	2,132
5	Ecological care farm De Mikkelhorst	Haren	273

1,2,3: converted from Mg fresh to Mg dm. Conversion factor used: 0.5 (Kuiper and De Lint, 2008);
4,5: converted from m^3 to Mg dm. Conversion factor used: 0.52 (Spijker et al., 2007).

4.6   Transport and storage

Transport of woody biomass is one of the most costly aspects of the bioenergy chain (Kofman, 2008). This includes: 1) transport of the woody biomass after harvesting to a field storage location, where it may be left for up to half a year before it is processed to fragments, 2) the transport of these fragments to a regional biomass depot, and 3) the transport of the fragments to biopower plants.

The storage of wood chips requires a moisture content of <30% in order to prevent fungi colonisation and heating. This can be reached by leaving harvested stems to dry in the field before chipping or by chipping the fresh stems immediately after harvest and then drying the chips (Boosten et al., 2009). Temporal field storage of the wood chips is an efficient way of drying but it could induce the risk of bark beetle infestation and other faunal activity and decay, which may impede further processing. Bigger chip or chunk sizes will help reduce the risk of decay but could on the other hand boost insect infestation. Further drying to the optimal moisture content is mainly done during storage at the biopower plant or in special biomass depots (Figure 4.4). Alternatively, wood chips can be processed and burned directly without storage. The disadvantage of that is however the lower energy content of the fresh material. Of the biomass produced in the Netherlands, only fresh wood chips are used for bioenergy production in Dutch biopower plants. The harvested biomass is stored on average two months before it is burned (Beeks, 2009). It is especially this storage that may entail the risk of pathogen attack and spread of potential harmful organisms to neighbouring trees or forests.

Figure 4.4
Open air storage of wood chips in Flent, Michigan (Roberts and Kuchera, 2006).

4.7   International import regulations

Of all countries in the world, presumably the most stringent import regulations for wood products like chips are imposed by the New Zealand Ministry of Agriculture and Forestry (MAF). For chipped material a standard chip size of maximally 10 by 15 mm, or a maximum of 3 mm in diameter at longer sizes is prescribed. Larger sized chips are classified under the regulations for sawn timber. It is not known on which research data the directives are based. But as far as arthropods are concerned, the recommended chip sizes are somewhat lower than the order of magnitude as described by e.g. McCullough et al. (2007).
Wood chips may also be labeled as bark products, depending on the wood/bark-ratio of the raw material. The volume of the bulk of transport may not exceed 40 m^3 and has to be packed in separate, with clear plastic sealed portions of 2 m^3 at the most. The material must be packed and shipped in a manner that prevents infestation or contamination by regulated pests. Appropriate packings are e.g. plastic wrapping, six side boxing or closed shipping containers. The material must be free of extraneous material such as leaves or soil (max. 0.01% of the total weight). Transportation of treated wood chips (by heat or gaseous pesticides) to their

destination is required to take place within 21 days after the treatment (source: MAF, 2003). Practically this implies that all material is treated before or during shipping by heat or fumigation.

The Canadian Food Inspection Agency (CFIA, 2009) imposes less stringent regulations on the size of the wood chips, but prescribes that wood products such as chips must be subject to heat treatment (minimal 30 minutes at minimal 56° C) or fumigation with methyl bromide (as only fumigation agent) and than can be shipped after approval.

The essence of both regulations is that all material has to be free of regulated pest before it is allowed to be imported, regardless of possible presence of a disease, and that shipment is allowed only after approval of an inspection agency, normally the national plant protection agency of the exporting country. Within the continental EU countries transport of raw woody material from a non infested location is not yet subject to restricted bulk volumes or chip sizes and no stringent regulations are imposed on any mandatory pre-treatment except when presence of a disease or pest is evident or assumed to be evident. Great Britain is a 'protected zone' in the EU and imposes regulations on material that is imported from other continents and third countries, especially tropical wood products. Prescribed heat treatment is kiln drying to a moisture content of 20% or less. Chip size for wood chips of trees that are possible hosts of the Emerald Ash Borer must be less than 2.5 cm diameter. For products from continental countries in the EU so called plat passports (form the national PPA's) are required for import of wood products. Some exceptions are made. From coniferous wood which is bark free no plant passport is required. On the other hand special requirements are assigned to wood of *Castanea* and *Platanus* by reason of possible presence of respectively Sweet Chestnut Blight and Canker Stain of Plane (source: Forestry Commission, 2009).

5 Potentially harmful organisms in wood chips

5.1 Insects

Many insects living in bark or wood are not forming a problem because they are not capable to infest vital living trees. However, some insects are. Three categories of insects can be distinguished:
– indigenous insect species in NL and EU;
– invasive species established in NL and EU;
– potential invasive species, not yet established in the EU.

5.1.1 Categories of insects

Indigenous insect species in NL and EU

Primary insect pests

Only a few of the indigenous wood and bark inhabiting insect species are able to infest vital trees such as Cossus cossus, Zeuzera pyrina, Paranthrene tabaniformis, Saperda carcharias and Saperda populnea. These insects are abundant all over the country. Even when these insects would survive in wood chips, they would not have an important impact on living trees adjacent to the power plants.

Secondary insect pests

Most of the wood and bark inhabiting species are so-called secondary insects that infest only weakened or fresh felled trees. Trees which are dead for a long time may be infested by insects which are harmless to living trees and they are not discussed here. The most important insect species which are able to breed in (weakened) living trees are longhorn beetles (Cerambycidae), jewel beetles (Buprestidae) and bark beetles (Scolytidae). When wood chips are made from weakened or fresh felled shrubs and trees they theoretically could contain stages (egg, larva, pupa, adult) of the secondary insects. Most of these insects are abundant all over the country. The indigenous secondary longhorn beetles are not able to infest vital trees. Also the jewel beetle *Agrilus biguttatus* and the bark beetles *Scolytus intricatus*, *Scolytus scolytus, Tomicus piniperda* and *Ips typographus* are of secondary importance. *Ips typograpus* is able to produce several generations per year. By reaching very high population densities this beetle is able to kill vital spruce trees. In the past, debarking of infested trees showed to be effective to kill the larvae in the bark. Therefore it can be concluded that chipping is also diminishing the populations.

Invasive species established in NL and EU

Another category are invasive insects such as the Asian longhorn beetles, *Anoplophora glabripennis* and *Anoplophora chinensis* which have caused infestations on a few locations in the Netherlands. These insects are subject of eradication programs. Production and transportation of wood chips infested with living stages of these invasive insects must be avoided at any time because they are able to infest vital living trees adjacent to

the transportation routes and power plants. It is very important to avoid the survival of these insects within wood chips.

Potential invasive species, not yet established in the EU

Many new invasive pest insect species will have the potential to establish in the EU in the future. The emerald ash borer *Agrilus planipennis* from Asia has invaded the USA and Canada. When this species might arrive in Europe, it will become subject of eradication programs. With the removal of infested trees it is very important to avoid the survival of these insects within wood chips.

5.1.2   Survival in wood chips

We have studied the literature of two model quarantine insect species:
1. Emerald Ash Borer - *Agrilus planipennis*, a small species;
2. Asian Longhorn Beetle - *Anoplophora glabripennis* (and *A. chinensis)* being a large species.

These species are native in Asia and have caused outbreaks in the USA and Europe. In the USA, the effect of wood chipping and other treatments on the insects have been studied and are incorporated in our recommendations.

5.1.2.1   *Agrilus planipennis* - **Emerald Ash Borer (EAB)**

The larvae reach a length of 26-32 mm and feed in the phloem of ash (*Fraxinus* sp.) trees from late summer through early fall. Most larvae overwinter as prepupae in the outer bark of large trees or in the outer sapwood on smaller trees. Pupation occurs in spring, and adults emerge from May through August.
Mechanical destruction of infested trees with grinders or chippers has previously been used as a regulatory treatment for wood infested by wood-boring or phloem-feeding insects. However, effectiveness of grinding or chipping infested ash material in winter and early spring, when most of the insects are prepupae, is very important. Infested ash wood should be chipped preferably before May every year because adults will still emerge in the spring and summer from ash wood which was cut the previous winter (Haack et al., 2009). Prepupae could potentially complete development without intact host material. Processing infested ash material with the chipper is more effective than grinders. In experiments, some prepupae in the chips survived, but no evidence was found that EAB adults emerged from the chip piles (McCullough et al., 2007).
So, it cannot be excluded that prepupae of the Emerald Ash Borer may survive in untreated chips larger than 2.5 cm. Otherwise the material could be re-chipped, converted into pellets, heat treated, composted or burned in a non-quarantine area (e.g. Roberts and Kuchera, 2006). If not, the import of suspicious non-treated (gas, chemicals, heat) woodchips partly larger than 2.5 cm in all directions should be rejected.
Larvae do not migrate from one wood chip to another. However, we were not able to find literature if this account for all insects as a rule.
The survival of larvae at heat treatments was consistently higher in wood chips than bark chips at 40° C, whereas no prepupae survived exposure to 60° C for eight or more hours. No prepupae survives exposure to 60° C for 120 minutes, but 17% survives exposure to 55° C for 120 minutes. This suggest that some fraction of the population may survive within the internationally recognised phytosanitary standards (ISPM-15) for treatment of wood packing material (McCullough et al., 2007).
Aerobic composting at 60° C for four continuous days will eliminate the insect. Heat treatment procedures may employ steam, hot water, oven or any other method that raises the temperature of the center of the wood pieces to the minimum temperature of 71.1° C during 75 minutes. Also fumigation with methyl bromide is

regarded to be effective. These methods are described in the USDA Treatment Manual (USDA 2009). For more information see Appendix 1.

5.1.2.2 *Anoplophora* glabripennis and *A. chinensis* - Asian Longhorn Beetles (ALB)

The Asian Longhorn Beetles, *Anoplophora glabripennis* and *A. chinensis* (ALB), are two of the most serious insect pests on poplar (*Populus* spp.) in China. Mature larvae cut pupal chambers in the xylem and then pupate (length of pupa, 30-37 mm). Adults emerge through a circular hole (ten mm diameter) cut through the xylem and bark. Normally, one - two year is required for the beetle to complete its life cycle.
Results of two tests, described elsewhere in this report (see attachment) indicate that only chipping wood from infested provides a highly effective method for destroying wood inhabiting insect pests such as *A. glabripennis*.
Eradication programs are being conducted in the USA and some European countries. When infestations of the Asian Longhorn Beetle in the Netherlands should occur, the felled trees can be removed by chipping (max. 2.5 cm in all dimensions) the wood on-the-spot. The most suitable time is during the larval or prepupal stage. During the beetle's flight season, the trees are preferably chipped early in the morning or in the evening when temperatures are still low thus minimising beetle dispersal. It is recommended that the chips are used for compost (at sufficient high temperatures) or for biofuel to eliminate any remaining living insect.
Chipped material must be no larger than 2.5 cm in three dimensions. Host material that is not chipped may be moved to an approved burning site with proper safeguards: vehicles must be tarped or covered to prevent spillage and host material may be held no longer than 24 hours at the burn site prior to burning (USDA, 2008). For more information see Appendix 1.

5.2 *Bursaphelenchus xylophilus* - Pine Wood Nematode (PWN)

Pine wilt is a disease of *Pinus* spp. caused by the Pine Wood Nematode (PWN), *Bursaphelenchus xylophilus*. It is an important non-native disease in countries where PWN has been introduced. The PWN is transmitted to conifers by cerambycid beetles of the genus *Monochamus*. The PWN can be transferred from wood chips to healthy trees by vector routes and non-vector routes.
In the Netherlands, the cerambycid beetles *Monochamus sutor* and *M. galloprovincialis* which are considered to be potential vectors for the PWN are occurring in some areas. The process of chipping wood will kill the majority of *Monochamus* spp. that may be present in the wood. Any vectors that survive the initial chipping process will be unlikely to complete development because the wood will tend to be too small to support the full larval and pupal gallery. Therefore the risk is very low of vector transfer with wood chips (Evans et al., 1996). There is ample evidence that PWN reproduces successfully in wood chip piles and could be present in larger numbers at the end of transportation than at the start (Dwinell, 1986; Halik and Bergdahl, 1992; Panesar et al., 1994). Wood chips therefore represent a significant inoculum source for potential transfer to European forests. The possibilities of vector transport from chips after they have arrived in Europe cannot therefore be ruled out (Evans et al., 1996). If introduced without an insect vector, or with no insect vector already established, PWN could still establish itself in a suitable host by means of non-vector transfers. The likelihood of establishment however, would be low.
The development of micro-organisms in chip piles is mainly governed by temperature. The spontaneous heating of the interior chips caused by oxidation during aerobic composting is sufficient to kill all nematodes. At temperatures above 45° C, the population densities of the nematode in pine chips rapidly declines.
The basic biological requirements of vectors (*Monochamus* spp.) can not be found in wood chips (Dwinell, 1986). So, the risk of the nematode being vectored from wood chips appears to be extremely low (Dwinell and Nickle, 1989).
For more information see Appendix 2.

5.3 Bacteria

The biology and epidemiology or the ways bacterial diseases are spread are for many bacteria more or less similar. As a rule, bacteria overwinter in the target plant and will be present in there the whole year around. During the growing season they multiply by cell division and spread through the plant. Spreading of the disease occurs when droplets of bacterial slime is brought to other plants by means of wind or splashing rain. Also arthropods such as insects are attracted by the slime and carry it to other trees. Infections may occur via small wounds such as leaf scars. Some bacteria species infect trees via the blossoms that are visited by infected insects that feed on nectar. Insects may thus form the vector responsible for spreading potential bacterial infections. Spread of bacterial infection may also occur via transport of infected material. It has been suggested that for example that transport of infected material is the most likely factor to introduce Bark bleeding of horse chestnut (*Pseudomonas syringae* pv. *aesculi*) in areas that are not yet infested by the disease.

By chipping infected wood, bacteria will stay alive and even in chipped fresh material bacteria may further develop to some extent. Under laboratory conditions bacteria may survive for a long time. Bacterial leaf spot (*Xanthomonas aroricola* pv. *Pruni*) is known to survive frost conditions between -2 and +2° C during five months. It is hosted in many *Prunus* species, some of which are common in urban areas (e.g. *P. laurocerasus*). Fireblight (*Erwinia amylovora*) is a potentially harmful bacterium that overwinters in infected plant tissue and thus can survive freezing temperatures that normally occur in the Netherlands during wintertime. Its principal hosts are in the sub-family Pomoideae (Rosaceae), such as *Crataegus* and *Sorbus*, which are commonly used in landscape elements such as small forest patches, and could consequently end up in wood chips. So far, there is no adequate chemical or other treatment for the elimination of the pathogen from plant material without destroying the plant tissues (EPPO, 2008).

Only when plant material is dried under natural conditions for long periods, bacteria that are present become inactive. However, they may become active and infectious again when plant material is rewetted. Forced drying or heating will be necessary to eliminate all bacteria. Entire inactivation can only be expected when bacteria are exposed to sufficiently high temperatures (depending on the bacteria species 64-70° C) during a sufficient length of time (Noble and Roberts, 2004). Above this temperature only some thermophyllic bacteria are able to survive and maintain activity, but as a rule, aerobic composting at high temperatures is effective in destroying all pathogenic organisms (wsu.edu).

For more information see Appendix 3.

5.4 Fungi

The biology and epidemiology of fungi may differ, according to the species and the way they form fructification bodies and spores and surviving structures. Some fungi may be latent infectious in fresh and even in dry plant material for several years and can withstand very low temperatures. For example, from *Giberella circinata* it is known that pathogen may be staying active for over a year in infected wood at moderate temperatures. In dry bark *Cryphonectria parastica* may stay active for a period of over ten month. *Ceratocystis fimbrata* f. sp. *platani* is able to survive temperatures of -17° C for several years, although it only will be active at temperatures between 10 and 45° C, with an optimum temperature of 25° C. Temperatures of 70° C are lethal for all the fungi species serving as model organisms in our study (Noble et al., 2009).

Many fungal pathogens spread by spores that disperse from fruiting body that are formed by the fungal mycelium. Spread of spores is mostly done by wind, but also rain drops, active through stagnant water (e.g. *Phytophthora* spp.) and also carried by arthropod vectors (e.g. *Ceratocystis* spp.) or direct or indirect by human or animal organisms (e.g. *Ceratocystis fimbriata*). Not only spores, but also parts of fresh mycelium or dry mycelium structures may serve as infectious inoculum (e.g. *Armillaria* spp.; *Verticillium* spp.). Most of the fungi considered in this study have a rather narrow range of host plants although some of them are able to invade plants of relative species, but are usually less harmful for these hosts. Sometimes however certain

fungi species may develop strains during the course of time hat have a higher level of aggressiveness (e.g. Dutch Elm Disease). Therefore the introduction of a species on itself may not form a serious risk, but the introduction of potentially more aggressive strain may result in large scale epidemics.

Chipping of wood will not eliminate fungi. Some parasitic fungi are also saprophytic and might even develop further, and also sporulate in heaps of chips during storage. Storage therefore under favorable conditions of moisture and temperature might raise the infectious potential of fungi enormous within a short period of time. Therefore, before transport, chips of wood from suspected origin should be treated by methods that eliminate any fungal organism present in the wood such as direct heating or aerobic composting. Only air drying of wood chip will bring down growth and reproduction of fungal organisms, but will not eradicate them.

For more information see Appendix 4.

5.5 Viruses and virus like organisms

The biology and epidemiology or the ways viral diseases are spread, are for many viruses more or less comparable. Natural dispersion of viruses over short distances (from one plant to the other) mostly occurs by vectors such as nematodes or insects and mites. Some viruses can be transmitted by pollen and seed or by using material for vegetative propagation in which the virus is already present. Long distance spread often occurs by transporting diseased material such as root stocks or grafting or budding material.

Many viruses are rather host specific, which means that virus diseases are normally restricted to one plant species or group of species of the same genera. The areas of impact of virus diseases are mainly commercial fruit production and nursery trade.

As a rule, viruses are present in a plant the whole year around. Viruses are not destroyed by chipping of plant material. When plant cells die, viruses become inactive because they need livings cells for their multiplication. However, many virus species can stay latently infectious in dry plant material for many years (e.g. Tobacco Mosaic Virus). Total inactivation only can be expected at high temperatures. This however strongly depends on the moisture status of the substrate. A rule of thumb is: the higher the moisture content, the lower is the lethal temperature (Noble et al., 2009). Thus, for inactivating viruses by composting a sufficient high moisture content of the substrate is required (see also section 6.3).

For more information see Appendix 5.

6 Treatments to eliminate the risk infections

Organisms that are potentially harmful to woody crops and trees can be divided into animal infestations (pests) and infectious diseases (illnesses). Besides there is a group of plant parasites (e.g. *Viscum album*), that is also often seen as infection, but these are not relevant as serious tree diseases and have not been taken into consideration. Both pests and diseases can be spread during the transportation of stems, branches, or other plant parts. To reduce the risk of spreading potentially harmful organisms, it is important to effectively treat the wood, for example by chipping, heat exposure, composting or application of chemical pesticides.

6.1 Chipping

Many animal organisms, including those that serve as infestation vectors may be partly or completely eliminated during wood and bark chipping (see also chapter 5.1). And for infections that are exclusively spread by wood or bark beetles, such as the Dutch Elm Disease, destruction of the vector insect by chipping is normally effective to prevent the spread of the disease. But this does not account for pathogens that are able to stay alive or even reproduce or fructificate in dead wood and of which the spread of the disease may occur via spores, or other contaminants such as bacterial slime, carried by wind, rain or insects. For these type of diseases additional treatment of the chips is essential to eliminate all risks of spreading of the disease.

6.2 Heat treatment

Direct exposure to high temperatures for a certain period of time will eliminate all living organisms in wood. The minimal required temperature and the length of exposure time mainly dependent of the type of organism. Viruses and viroids are as a rule more heat resistant than many bacteria (Noble et al., 2009).
For the heat treatment to be effective, the particle size of the material must not be too large (>12 mm) and the material should be homogenised during treatment. In this case it may be expected that a treatment of one hour with temperatures of 70° C or more, preferably by wet heat, will destroy most plant pests (EPPO, 2008). However viruses like Tabamovirus, viruses and fungi with hardy resting spores, may stay alive and require adjusted time/temperature combinations.
So, for these type of diseases, and all quarantine pests in general, special requirements are 74° C at four hours, 80° C at two hours or 90° C for one hours (EPPO, 2008).
If heat treatment is a practicable alternative above other alternatives for wood or wood chips that are used for biofuel, and for which phase of the production chain will depend on the extra costs of the use of extra energy and investment in equipment. For the time being it is not likely to be a attractive alternative above other treatments such as partly composting of the raw material.

6.3 Composting

Composting may be seen as a self heating process in which temperatures are reached that equal or even exceed the above mentioned level of 70° C. Composting is a process in which the biomass is degraded by microbial organisms such as fungi, actinomycetes and bacteria. The process can be roughly divided into three successive phases:
1. the psychrophile phase, at low temperatures (temperature range: -5 to 30° C);
2. the mesophile phase, at medium temperatures (10-60° C);
3. the thermophile phase (35-70° C).

During the composting process the mix of microbial species that are part of the composting process gradually change from psychrophyllic over mesophyllic to thermophyllic species. About halfway the process only the heat resistant thermophyllic species will be active and the only one that are able to survive the high temperatures. With a few exceptions, most of the genera of bacteria and fungi of which some species are also known to be plant pathogenic are of the mesophyllic type (Ryckeboer et al., 2003). This implies that these genera will be eliminated within the course of the composting process. So, on bases of the data of Ryckeboer et al. (2003) it may be stated that at least the pathogens mentioned in list 1.1. of this report can be eliminated by composting. Also other research has shown that, during composting, the heat released by aerobic decomposition of organic material will eliminate most pathogenic organisms. This concerns both fungi and bacteria as well as nematodes and arthropods and their eggs.

Guidelines, presented by EPPO (2009) for the minimum temperature / time requirements for eliminating pests and diseases through composting are at least 55° C for a continuous period of two weeks to a temperature of at least 65° C over a continuous period of one week. This accounts for aerobic composting at a minimal water content of 40% and not a composting process in which the material is partly degraded at anaerobic conditions.[4]

However, also EPPO (2008) indicates that more studies are needed to determine the necessary time/ temperature combinations to eliminate some presumably more heat tolerant organisms.

The lethal temperature for most pathogens is much lower than the temperatures reached within compost piles by aerobic decomposition. Whether lethal temperatures are reached depends on some criteria:

1. The C:N ratio of the organic matter in the pile cannot go beyond 50° C to prevent the composition process become too slow and therefore high temperature will not be reached. Wood chips are therefore mixed with fresh organic waste of which the C:N ratio lies between 20 and 30 (see Figure 6.1a). However, this mixing reduces the quality of the material as a biofuel, and requires the smaller parts to be sieved out. Wood chips have an average C:N ratio around 600:1, but only the outer surface of the wood chip is really available to react with microbes in the compost pile. In practice only about 1/3 of the wood chip will decompose in a 3-6 month composting period. So, when determining a compost mix, only count 1/3 of the stated C:N ratio. Wood chips, with an average C:N ratio of 600:1 would be mixed in as though they had a C:N ratio of 200:1.

[4] As a rule, partial anaerobic decomposition/conversion takes place in a temperature range which normally does not kill pathogens. However, these organisms might disappear gradually by biological antagonism, although this process usually takes more than six months.

2. During composting, the surface of the compost pile reaches lower temperatures than the centre of the pile. To guarantee that all material in the pile is exposed to lethal temperatures, the pile needs to be turned over several times. For logistic reasons stock volumes have to be small and the decomposition period less than six months. Therefore it is required to turn over the piles frequently. Composting in open air normally needs turning over at least three times to ensure the elimination of all pathogens. Turning the pile also favours the aeration of the pile, which in turn enhances the composting process (Figure 6.1b).

3. In order to reach the required temperature, the chip pile must have a minimum volume. A 2.3 m^2 (25 ft^2) pile may reach 71.1° C (160° F), whereas a smaller pile of 1.4 m^2 (15 ft^2) only reaches 60° C (140° F) (Figure 6.1c).

4. Large open spaces in the pile complicate the heating. Figure 6.1d shows that a pile consisting of six inch wood chips will reach no more than 37.7° C (100° F), whereas a pile consisting of one inch wood chips may reach 71.1° C (160° F). Wood chips should thus not be too big and rules on maximum chip size in this context will be needed.

Composting of wood chips, or wood chips containing biowaste of which the end product is garden compost has become a well known and practised process during the past decades. However in most processes the wood chips mainly serve as an amendment to maintain optimal aeration of the compost heap during the composting process. As a rule the compost process is maintained till a certain desired C/N ratio of the organic matter is reached. Besides this, composting is a time taking process.
For the use of compost for biofuel a too high degradation of the chips is less desirable and also a higher ratio of wood chips to fresh biowaste may be demanded. More information is needed on managing the process at higher rates of wood chips and in a shorter period of time.
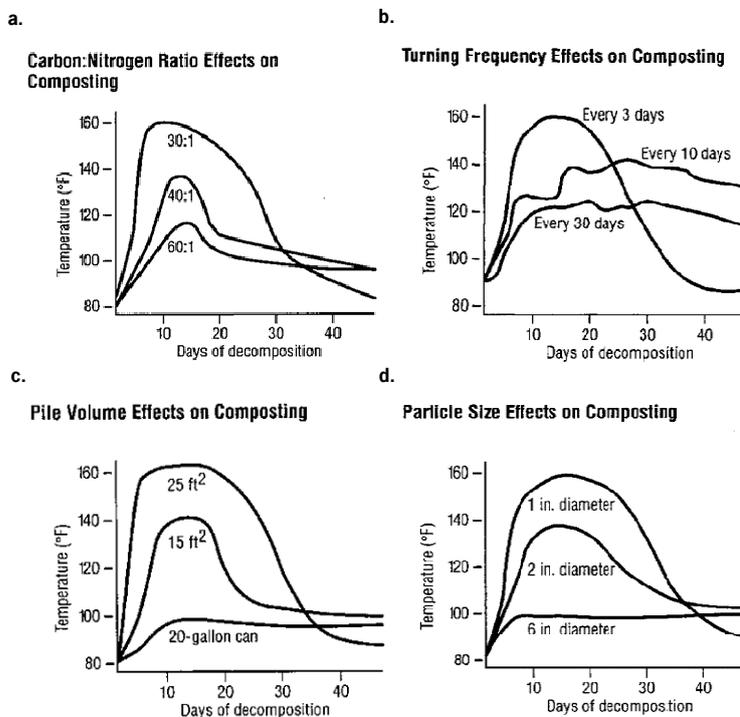
Figure 6.1
The effect C:N ratio (a), turning frequency (b), pile volume (c) and chip size (d) on the rate of composting
(source: wsu.edu: Compost fundamentals).

6.4   Gas and heat treatments

Besides chipping of wood and composting, other treatments may be adequate to reduce the infectious potential of wood and wood chips.
– Addition of gaseous methyl bromide or sulphuryl fluoride in concentrations of 80 g/m^3 during 24 continuous hours at no less than 10° C. This gas treatment must be executed in volumes smaller or equal to 2 m^3.
– (External) heat treatment in which the center of the volume reaches a temperature of at least 70° C during four hours.

Within the EU however, the use of gaseous pesticides is very restricted by regulations and it is to be expected that large scale application after harvest or during transport and storage will be prohibited at any circumstances.

Literature

AEBIOM, 2009. Position Paper: Sustainability of Biomass. Association européenne pour la Biomasse, Brussels.

Alakangas, E., A. Heikkinen, T. Lensu and P. Vesterinen, 2007. Biomass fuel trade in Europe. Summary Report VTT-R-03508-07. *EUBIONET II*. VTT Technical Research Centre of Finland, Jyväskylä.

Beeks, T., 2009. Personal Communication October 2009. (ed. B.S. BV).

Boosten, M., J, Oldenburger, J., Oorschot, M. Boertjes and J. v.d. Briel, 2009. De logistieke keten van houtige biomassa uit bos, natuur en landschap in Nederland: stand van zaken, knelpunten en kansen. Stichting Probos.

Braasch, H., 1996. Studies on the transmissibility of the pinewood nematode *Bursaphelenchus xylophilus* from wood chips to *Pinus* seedlings and stumps. *Nachrichtenblatt des Deutschen Pflanzenschutzdienstes,* 48, pp. 173-175.

CFIA, 2009. Import requirements for non-processed wood and other non-propagative wood products, except solid wood packaging material, from all areas other than the continental United States (U.S.). Canadian Food Inspection Agency. Leaflet D-02-12: 28 pp.

Cram, M. and J. Hanson, (unknown date). How to identify and manage Pine Wilt Disease and treat wood products infested by the Pinewood Nematodes. Leaflet USDA Forest Service.

De Nie, D. and E. Blom, 2008. Feiten over bioenergie in Nederland. Effect op ecosystemen, duurzaamheid en toekomst. IUCN Nederlands Committee. Amsterdam.

Dwinell, L.D., 1986. Ecology of the pinewood nematode in southern pine chip piles. USDA Forest Service *Southeast. For. Exp. Stat., Res. Paper SE-258.*, 14 pp.

Dwinell, L.D. and W.R. Nickle, 1989. An overview of the pine wood nematode ban in North America. *USDA Forest Service. General Technical Report SE-55*, 13 pp.

EPPO, 1996. Archives.eppo.org/EPPOReporting/1996/Rse-9610.pdf.

EPPO, 2008. Guidelines for the management of health risks of biowaste of plant origin. EPPO Bulletin 38: 4-9. PM 3/66 (2).

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

EXFOR: www.spfnic.fs.fed.us/exfor/data/pestreports.

FAO, 2004. Unified Bioenergy Terminology, UBET. FAO Forestry Department, Wood Energy Programme.

Feil, F. and B. Frederiks, 2006. Inzameling snoeihout - Eindrapport. BTG Biomass Technology Group BV, Enschede.

Grontmij, 2008. Grontmij - Sustainable Design and Engineering. Biomassa Forum Beesd, 29 april 2008.

Haack, R.A., F. Hérard, J. Sun and J. Turgeon, 2009. Managing Invasive Populations of Asian Longhorned Beetle and Citrus Longhorned Beetle: A Worldwide Perspective. *Annual Review of Entomology,* 55, 521-546.

Halik, S., 1990. Survival of Bursaphelenchus xylophilus in wood chips in soil and potential for infesting roots of pine seedlings. M.S. thesis, VT, University of Vermont.

Halik, S. and D.R. Bergdahl, 1987. Infestation of wounded roots of Pinus strobus by B*ursaphelenchus xylophilus* from contaminated wood chips in soil. (Abstr.). *Phytopathology,* 77, 1615.

Halik, S. and D.R. Bergdahl, 1992. Survival and infectivity of *Bursaphelenchus xylophilus* in wood chip-soil mixtures. *Journal of Nematology,* 4, 495-530.

Halik, S. and D.R. Bergdahl, 1994. Long-term survival of *Bursaphelenchus xylophilus* in living Pinus sylvestris in an established plantation. *European Journal of Forest Pathology,* 24, 357-363.

Junginger, M., 2009. Around the world in 12 years – An overview of the global wood pellet trade. Trade activities and opportunities for liquid and solid biofuels in the SE Asian region and implications for policy. Joint Task 40 / ERIA workshop. Tsukuba Japan. Copernicus Institute, Utrecht University.

Kiyohara, T. and Y. Tokushige, 1971. Inoculation experiments of a nematode, *Bursaphelenchus sp.*, onto pine trees. *Journal of Japanese Forestry Society,* 53, 210-218.

Kofman, P., 2008. Cursusmap Cursus Biomassa, hout voor energie. Van bos naar installatie. Houten. Algemene Vereniging Inlands Hout.

Kuiper, L. and S. de Lint, 2008. Binnenlands biomassapotentieel. Biomassa uit natuur, bos, landschap, stedelijk groen en houtketen. Ecofys Netherlands B.V.

MAF, 2003. Import health standard sawdust, wood chips, wood shavings, and wood wool from all countries. Version 1.2. New Zealand Ministry of Agriculture and Forestry. 11 pp.

McCullough, D.G., T.M. Poland, D. Cappaert, E.L. Clark, I. Fraser, V. Mastro, S. Smith and C. Pell, 2007. Effects of chipping, grinding, and heat on survival of emerald ash borer, Agrilus planipennis (coleoptera: Buprestidae), in chips. *Journal of Economic Entomology,* 100, 1304-1315.

Mercader, R.J., N.W. Siegert, A.M. Liebhold and D.G. McCullough, 2009. Dispersal of the emerald ash borer, Agrilus planipennis, in newly-colonized sites. *Agricultural and Forest Entomology,* 11, 421-424.

Mininisterie van LNV, 2008. Intentieverklaring 'biomassa uit bos, natuur, landschap en de houtketen'. Ministerie van LNV, Platform Hout Nederland & Bosschap. 14 februari 2008.

Mushrow, L., A. Morrison, J. Sweeney en D. Quiring, 2004. Heat as a phytosanitary treatment for the brown spruce longhorn beetle. *The Forestry Chronicle,* 80, 224-228.

Noble, R., J.G. Elphinstone, C.E. Sansford, G.E. Budge and C.M. Henry, 2009. Management of plant health risks associated with processing of plant-based wastes: A review. *Biosource Technology,* 100, 3431-3446.

Noble, R. en S.J. Roberts, 2004. Eradication of plant pathogens and nematodes during composting: a review. *Plant pathology,* 53, 548-568.

Panesar, T.S., F.G. Peet, J.R. Sutherland and T.S. Sahota, 1994. Effects of temperature, relative humidity and time on survival of pinewood nematodes in wood chips. *European Journal of Forest Pathology,* 5, 287-299.

ProcedeBiomassa, 2009. Ontwikkelingen in de beschikbaarheid van biomassa voor bij- en meestook in Nederlandse kolencentrales. Tussenrapportage in het kader van het project 'Inventarisatie beschikbare biomassa voor energietoepassingen'. DENB086018.

Roberts, D.L. and J. Kuchera, 2006. The Survival of EAB in Wood Chips: Does Size Matter? *The Landsculptor*, 19-21.

Ryckeboer, J., J. Mergaert, K. Vaes, S. Klammer, D.D. Clercq, J. Coosemans, H. Insam and J. Swings, 2003. A survey of bacteria and fungi occuring during composting and self-heating processes. *Annals of Microbiology,* 53, 349-410.

Sathyapala, S., 2004. Pest Risk Analysis. Biosecurity Risk to New Zealand of Pinewood Nematode *(Bursaphelenchus xylophilus) MAF Biosecurity Authority Forest Biosecurity group*, 37 pp.

Spijker, J., H.W. Elbersen, J.J. de Jong, C.A. van de Berg and C.M. Niemeijer, 2007. Biomassa voor energie uit de Nederlandse natuur. Alterra, Wageningen UR.

Steierer, F., A. Fischer-Ankern, M. Francoeur, J. Wall and K. Prins, 2007. Joint Wood Energy Enquiry. (ed. UNECE/FAO).

Swaan, J. and S. Melin, 2008. Wood Pellet Export: History-Opportunities-Challenges. Wood Pellet Association of Canada.

Taylor, R.A.J., T.M. Poland, L.S. Bauer and R.A. Haack, 2006. Is Emerald Ash Borer an obligate migrant? Emerald Ash Borer Research and Technology Development Meeting, 26-27 September 2005, Pittsburgh, Pennsylvania.

Tomminen, J., S. Halik and D.R. Bergdahl, 1991. Incubation temperature and time effects on life stages of *Bursaphelenchus xylophilus* in wood chips. *Journal of Nematology,* 23, 477-484.

USDA, 2008. New Pest Response Guidelines, Asian Longhorned Beetle *Anoplophora glabripennis*. (ed. APHIS-PPQ), 37 pp.

USDA, 2009. Emerald Ash Borer Program Manual, *Agrilus planipennis* (Fairmaire) (ed. A.-P.-E.a.D.P.-E. Planning). Riverdale, Maryland.

Wang, B., V.C. Mastro and W.H. McLane, 2000. Impacts of chipping on surrogates for the longhorned beetle Anoplophora glabripennis (Coleoptera: Cerambycidae) in Logs. *Journal of Economic Entomology,* 93, 1832-1836.

Description of model species

Appendix 1 Insects

Agrilus planipennis - **Emerald Ash Borer (EAB)**

This beetle (Buprestidae) is a phloem-feeding insect native to Asia. The insect was discovered in 2002 in the USA and Canada. The larvae reach a length of 26-32 mm and feed in the phloem of ash trees (*Fraxinus* sp.) from late summer through early fall. Most larvae overwinter as prepupae in individual cells excavated in the thick, outer bark of large trees or in the outer sapwood on smaller trees with thin bark. Pupation occurs in spring, and adults emerge from May through August.

The rate of natural dispersal by adult flight of EAB is difficult to estimate. Flight mill studies suggest that female beetles may be physiologically capable of flying 1.5 km/day for at least a few consecutive days (Taylor et al., 2006). The beetles are strong flyers. Flight under laboratory conditions suggests that a mated female may fly more than 20 km (USDA, 2009). Evaluating EAB dispersal in the field is difficult because trees with low densities of larvae typically exhibit no external symptoms. It was demonstrated that larval densities rapidly declined with distance and that most larvae (88.9 and 90.3%) were on trees within 100 m of the emergence point of the adults at each site (Mercader et al., 2009).

In certain US states, federal quarantines prohibit transport of ash trees, logs, or unprocessed wood. Although phloem in cut logs eventually becomes too dry to support the Emerald Ash Borer (EAB) development, at least some beetles can emerge from ash material that died or was cut during the preceding twelve months (McCullough et al., 2007).

Effects of wood chipping on survival of EAB

Mechanical destruction of infested trees with grinders or chippers has previously been used as a regulatory treatment for wood infested by wood-boring or phloem-feeding insects. Larvae that are still feeding in ash phloem between the outer bark and sapwood, are more vulnerable to exposure, injury, and desiccation resulting from bark separation during grinding or chipping (McCullough et al., 2007). However, effectiveness of grinding or chipping infested ash material in winter and early spring, when most of the insects are prepupae, is very important. Infested ash wood should be chipped preferably before May every year because adults will still emerge in the spring and summer from ash wood which was cut the previous winter (Haack et al., 2009). The prepupae are folded into oval cells within the sapwood or thick bark, where they may be somewhat protected from desiccation or injury during processing. Moreover, prepupae require no additional feeding and uninjured individuals could potentially complete development without intact host material. In some studies it was focused on the high-risk prepupal stage, when EAB is least vulnerable to desiccation or injury associated with chipping or grinding and most likely to complete development in processed material (McCullough et al., 2007). In the US, many of the infested ash trees with high-density EAB populations have been processed in large horizontal grinders. Some chips from infested ash trees are used locally for products such as compost or mulch, but many loads of chips have been burned at electricity plants. Grinders, which smash and crush large pieces of wood into smaller pieces, rely on a screen or grate to control the maximum particle size. Fine material may be undesirable for burning in electricity plants because of the difficulty of forcing sufficient air through very fine particles (McCullough et al., 2007). Processing infested ash material with the chipper was more effective than grinders. In experiments, some prepupae in the chips survived the winter, but no evidence was found that EAB adults emerged from the chip piles (McCullough et al., 2007).

Figure 7.1

Some wood chips do not meet 2.5 cm specifications. In some larger parts, larval galleries are visible
(Roberts and Kuchera, 2006).

Figure 7.2

A comparison of two '2.5 cm' wood chips with adult Emerald Ash Borers. The smaller chip is about
2.5 cm square. The larger chip is about 2.5 cm on two sides (Roberts and Kuchera, 2006).

Figure 7.3
An ash bark chip harboring an intact live Emerald Ash Borer that survived the grinding operation
(Roberts and Kuchera, 2006).

It cannot be excluded that prepupae of the Emerald Ash Borer may survive in untreated chips larger than 2.5 cm. Otherwise the material could be re-chipped, converted into pellets, heat treated, composted or burned in a non-quarantine area (e.g. Roberts and Kuchera, 2006).

The import of suspicious non-treated (gas, chemicals, heat) woodchips partly larger than 2.5 cm in all directions should be rejected. Otherwise the material could be re-chipped, converted into pellets, heat treated, composted or burned in a non-quarantine area (Roberts and Kuchera, 2006).

In a series of studies, the effects of grinding and chipping on survival of EAB prepupae in ash material were evaluated. Heavily infested ash bolts containing roughly 8,700 prepupae, were processed by a horizontal grinder with either a 2.5- or 10-cm screen. There was no evidence of EAB survival in chips processed with the 2.5-cm screen, but eight viable prepupae were recovered from chips processed with the 10-cm screen (McCullough et al., 2007).

Are larvae of EAB able to move from one wood chip to another?

The question may arise if it is possible that larvae may invade from one wood chip to another. If that would be possible, complete larval development in a pile of chips could not be excluded. Several insect species, especially beetles, tunnel into the wood during their larval or pupal stages. Some species spend much of their time as larvae between bark and wood in living trees, before they burrow into the wood for pupation. So, the young larval stages need living material which they cannot find in a pile of chips. However, we were not able to find literature on that. In superficial experiments, transferring vital larvae of the poplar clearwing moth

Paranthrene tabaniformis, the cambium miner fly *Phytobia cambii* and the oak buprestid beetle *Agrilus biguttatus*, larvae failed to penetrate into fresh non-infested pieces of wood (Moraal, pers. comm).

Effects of heat treatment and composting on EAB

The effects of heat treatments on prepupal survival were also studied. The survival was consistently higher in wood chips than bark chips at 40° C, whereas no prepupae survived exposure to 60° C for eight or more hours. In a second study, prepupae in wood chips were exposed to 40, 45, 50, 55, or 60° C for 20 or 120 minutes. Some prepupae survived 20 minutes of exposure to all temperatures. No prepupae survived exposure to 60° C for 120 minutes, but 17% survived exposure to 55° C for 120 minutes. This suggest that some fraction of the population may survive within the internationally recognised phytosanitary standards (ISPM-15) for treatment of wood packing material (McCullough et al., 2007).

Compost piles must be a minimum of ca 150 m^3 and the internal temperature at a depth of ca 45 cm must reach 60° C for four continuous days. Use a bulldozer to remove the outer layer of the compost and bring it to the core. Other material including wood waste (living, dead, cut or falling) including stumps, roots, branches of *Fraxinus* spp. chip or mulch to less than 2.5 cm in at least two dimensions is an approved method (USDA, 2009). Heat treatment of ash logs and lumber are described in respect to infestations by the Emerald Ash Borer in quarantine areas. These heat treatment procedures may employ steam, hot water, oven or any other method that raises the temperature of the center of the log to the minimum temperature of 71.1° C during 75 minutes. Also fumigation with methyl bromide is regarded to be effective. These methods are described in the USDA Treatment Manual (USDA, 2009).

Anoplophora glabripennis and A. chinensis - Asian Longhorn Beetle (ALB)

The Asian Longhorn Beetle *Anoplophora glabripennis* and *A. chinensis* (ALB) is one of the most serious insect pests on poplar (*Populus* spp.) in China. Adult beetles feed on the bark of small twigs, and occasionally on petioles and leaves. Females lay their eggs individually under the bark of host trees by chewing distinctive oviposition sites in the bark surface. Oviposition sites may be found on the main trunk, large limbs, and even exposed roots. After hatching, the larvae (5-60 mm long) feed on the vascular cambium and phloem throughout the second or third instars. Late instars usually move into the xylem, creating tunnels as they feed. Mature larvae cut pupal chambers in the xylem and then pupate (length of pupa, 30-37 mm). Adults emerge through a circular hole (10 mm diameter) cut through the xylem and bark. Normally, 1-2 year is required for the beetle to complete its life cycle. The species is native to China, Korea and possibly Japan (Wang et al., 2000).

In a test, plastic worms were used as surrogates for larvae of the beetle. Plastic worms of different sizes were placed in holes drilled in logs of sugar maple, *Acer saccharum*. In another test, in addition to plastic worms, different instars and pupae of gypsy moth, *Lymantria dispar,* are used. Although chipping did not result in an obvious damage to all plastic worms, it did kill all larvae and pupae of insects placed in holes of maple logs. All recovered insects were severely damaged after chipping logs and we could not determine recovery rates. Results of the two tests indicate that chipping wood from infested trees without incineration of the resulting chips provides a highly effective method for destroying wood inhabiting insect pests such as *A. glabripennis.* The elimination of incineration saves considerable resources while effectively eliminating risks associated with movements of wood containing living wood-boring insects (Wang et al., 2000).

Figure 7.4
Damage of surrogate worms of different sizes after logs were chipped (Wang et al., 2000).

Eradication programs are being conducted in the USA and some European countries. When infestations of the Asian Longhorn Beetle in the Netherlands should occur, the felled trees can be removed by chipping (max. 2.5 cm in all dimensions) the wood on-the-spot. The inner wood might still be used for lumber (after inspection). The most suitable time is during the larval or prepupal stage. The knives of the chipping machines should kept sharp to keep the chip size right. During the beetle's flight season, the trees are preferably chipped early in the morning or in the evening when temperatures are still low thus minimising beetle dispersal. The removal of trees is preferably done from the outside to the centre. It is recommended that the chips are used for compost (at sufficient high temperatures) or for biofuel to eliminate any remaining living insect.

Larger chips should be incinerated promptly. An eradication plan requires that all trees with ALB oviposition pits or exit holes must be cut and chipped. The need to burn chips after infested trees were cut and chipped was eliminated because mortality was expected to be high from chipping alone (Haack et al., 2009). Nursery stock in the regulated area is subject to inspection. Any infested host material found in the nursery trade is required to be chipped (USDA, 2008). It is recommended that infested host material removal occurs within three days of detection when beetles are active. It is recommended that the roots of host material be removed to a minimum of 25 cm below ground level. Any above ground roots of 1.5 cm or more in diameter should also be removed. Host material should be chipped or burned. Chipped material must be no larger than 2.5 cm in three dimensions. Host material that is not chipped may be moved to an approved burning site with proper safeguards: vehicles must be tarped or covered to prevent spillage and host material may be held no longer than 24 hours at the burn site prior to burning (USDA, 2008).

Appendix 2 Nematodes

Bursaphelenchus xylophilus - **Pine Wood Nematode (PWN)**

Introduction

Pine wilt is a disease of *Pinus* spp. caused by the Pine Wood Nematode (PWN), *Bursaphelenchus xylophilus*. The PWN is native to North America and is not considered a primary pathogen of native pines, but is the cause of pine wilt in some non-native pines. In countries where the PWN has been introduced, such as Japan, China and Portugal, pine wilt is an important non-native disease. The PWN is transmitted to conifers by cerambycid beetles of the genus *Monochamus*, either when the beetles feed on the bark and phloem of twigs of susceptible live trees (primary transmission) or when the female beetles lay eggs (oviposition) in freshly cut timber or dying trees (secondary transmission). Nematodes introduced during primary transmission can reproduce rapidly in the sapwood and a susceptible host can wilt and die within weeks of being infested if conditions are favorable to disease development. In living trees, PWN was still present in living, healthy looking pines, six years after inoculation (Halik and Bergdahl, 1994). The PWN can be transferred from wood chips to healthy trees by: 1) Vector routes for transfer of Pine Wood Nematode; and 2) Non-vector routes for transfer of Pine Wood Nematode.

Vector routes for transfer of Pine Wood Nematode

In the Netherlands, the cerambycid beetles *Monochamus sutor* and *M. galloprovincialis* are occurring in some areas. Some experiments have been done on the elimination of the cerambycids *Tetropium fuscum* and *Tetropium cinnamopterum*. They died after the wood was exposed to 50° C for 30 minutes or to 55° C for 15 minutes (Mushrow et al., 2004). Beetles of *Monochamus* spp. could fly up to three km to find a host tree for the maturation feeding or oviposition, therefore surveillance for *Monochamus* spp. in high risk areas such as ports, sites processing containers, timber yards, and parks and nurseries, is considered essential for the early identification of the presence of PWN. The surveillance for *Monochamus* spp. could be included in a wood boring bark beetle surveillance system for high risk sites (Sathyapala, 2004). The process of chipping wood will kill the majority of *Monochamus* spp. that may be present in the wood. Any vectors that survive the initial chipping process will be unlikely to complete development because the wood will tend to be too small to support the full larval and pupal gallery. There is therefore very low risk of vector transfer with wood chips (Evans et al., 1996). There is ample evidence that PWN reproduces successfully in wood chip piles and could be present in larger numbers at the end of transportation than at the start (Dwinell 1986; Halik and Bergdahl 1992; Panesar et al., 1994). Wood chips therefore represent a significant inoculum source for potential transfer to European forests. Dauer-larvae have been demonstrated to occur in wood chips and to increase as a response to abrupt changes in temperatures. Non-specific potential vectors such as *Rhagium* sp. and *Hylobius abietis* and *Hylastes* sp. have been reported to be attracted to heaps of sawdust and, occasionally, thousands of individuals may be present. It is possible that chips could act in a similar way, leading to contamination of any beetles trapped in nematode-infested chip piles. The fact that these beetles also breed in freshly dead trees points to possibilities of nematode transmission during oviposition. The possibilities of vector transport from chips after they have arrived in Europe cannot therefore be ruled out (Evans et al., 1996). If introduced without an insect vector, or with no insect vector already established, PWN could still establish itself in a suitable host by means of non-vector transfers. The likelihood of establishment however, would be low. In this case, the long-term survival of PWN depends on finding a native or established vector (Halik and Bergdahl, 1992).

Figure 7.5

Interactions of the Pine Wood Nematode with sawyer beetles and bark beetles to cause pine wilt disease

(from: Cram and Hanson, unknown date).

Non-vector routes for transfer of Pine Wood Nematode

PWN has a number of characteristics that indicate that its introduction to Europe by means of any type of imported untreated wood would, over time, be a highly probable event, even in the absence of specific insect vectors. It can survive in wood for long periods of time after entry and it is capable of moving (by its own means) out of pieces of wood into wounds of trees. The unrestricted import of infested wood could therefore lead to a potentially dangerous situation in which pieces of wood of many types (sawn wood, off-cuts, wood chips, sawdust) carrying nematodes would be transported throughout the region and would offer multiple occasions for transfer to native trees (Evans et al., 1996). There is some experimental evidence for transfer of nematodes from wood chips to susceptible trees when chips are buried among wounded or unwounded tree roots (Kiyohara and Tokushige, 1971; Halik and Bergdahl, 1992). However, these experiments have been carried out in a disputable way. In an experiment with mulched seedlings with PWN-infested chips, the nematode was not transmitted to Scots pine roots through the soil (Dwinell and Nickle, 1989). To determine if the nematode was capable of infesting wounded roots, infested and uninfested chips were mixed with soil in pots with white and Scots pine seedlings. Trees were maintained at 20 and 30° C and harvested at mortality or after twelve weeks. Nematodes appeared to enter roots primarily through cortex and phloem, either intercellularly or via resin canals and were observed infesting all woody root tissues. Parenchyma cell contents were granular and stained brown or were completely destroyed (Halik, 1990). White pine (*Pinus strobus*) wood chips were inoculated with an isolate of PWN from that host. Wounds were made at three locations on the

roots of 24 (twelve per treatment) five-year-old white pines by scraping the bark to expose xylem tissue. Seven of twelve seedlings treated with nematode-infested chips wilted and PWN was extracted from roots and stems. Histological studies showed PWN only in tissues of inoculated seedlings (Halik and Bergdahl, 1987). Pine wood chips experimentally contaminated with PWN were brought into contact with unwounded seedlings of 4-year old *Pinus sylvestris*, and with stumps either freshly cut or cut two months before the trial. The results showed that the nematode could only be extracted from stumps, and only if fresh wounds were present. Nematodes were not found on intact seedlings or on stumps cut two months before the trial. It is concluded that, in principle, PWN can be transmitted from contaminated wood chips to freshly wounded stumps (Braasch, 1996; EPPO, 1996).

Effects of heat treatment and composting on PWN
The development of micro-organisms in chip piles is mainly governed by temperature. The temperature in a chip pile depends on the ambient temperature, the size and compaction of the pile, and the fines and bark content of the chips. Regardless of the ambient temperature, the interior of the pile rapidly rises to 60° C. Within a few days, the living sapwood cells die and there is a 50% loss in monoterpenes. After three days, piled fresh pine chips do not longer attract Monochamus spp. Wood chips of *Pinus strobus* inoculated with PWN were incubated at 3, 12, 30 or 40° C during intervals of 47, 82 and 130 days to determine the effects of incubation temperature and time on total number of nematodes and occurrence of each life stage. Nematodes did not survive at 40° C (Tomminen et al., 1991). The temperature of the outer layer of the pile is usually lower. The initial spontaneous heating in piled wood chips is attributed primarily to heat released by respiration in living sapwood cells. Since the living cells in fresh sapwood chips retain their viability only about two weeks at 21° C, the Pinewood nematode is largely dependent on fungi in chips for nutrition and lives saprophytically in these chips for longer periods. PWN-populations increased in the outer layers (temperature 35-40° C, but there was a complete mortality in the interior of the pile (Dwinell, 1986)). The spontaneous heating of the interior chips caused by oxidation is sufficient to kill all nematodes. The optimum temperature range for the reproduction of the pinewood nematode in southern pine chips was 35 to 40° C. At temperatures above 45° C, the population densities of the nematode in pine chips rapidly declines. Unfortunately, it may not be economically feasible to use such a high temperature to control the pinewood nematode in wood chips. It is doubtful whether pine chips could serve as a source of inoculum for the establishment in countries that import them. Unless the nematode is transmitted by a vector, it is destined to be digested in the pulping process. The basic biological requirements of vectors (*Monochamus* spp.) can not be found in wood chips (Dwinell, 1986). So, the risk of the nematode being vectored from wood chips appears to be extremely low (Dwinell and Nickle, 1989).

The population dynamics of the PWN in wood chips was studied during transport by ship from USA to Sweden. Samples indicated that the population of the PWN increased significantly during the Trans-Atlantic voyage. The reason was that the temperature of the cargo reached the PWN optimum temperature of 35° C. The nematodes reproduced on fungi that invaded the wood (Dwinell and Nickle, 1989). In wood chips, PWN was able to survive in low numbers at 20-22° C for up to forteen months (Panesar et al., 1994), it could therefore survive shipment to Europe from any source (Evans et al., 1996).

Appendix 3 Bacteria

Erwina amylovora (Fireblight)

Hosts

The principal hosts are in the sub-family Pomoideae of the family Rosaceae. The most susceptible tree forming hosts that are common in the Netherlands are *Crataegus* (most species), *Cotoneaser salicifolius*, *Pyrus* spp. (various cultivars), *Malus* spp. (various cultivars), *Sorbus* (most species).

Biology and dispersal

The Fireblight pathogen overwinters in infected host plants. Hold-over cankers are the most important source of primary inoculum for blossom infection in the spring. Bacteria carried by insects or by wind-driven rain enter the plant through the blossom, natural openings (stomata, lenticels, hydathodes) or wounds.

Natural dispersal by insects or rain only disseminates *E. amylovora* locally, though migrating birds have been considered to carry infectious bacteria over longer distances. The Fireblight pathogen can mainly be transmitted over long distances by transporting material of diseased host plants. The possibility that aerosols may play a significant role in the spread of the pathogen over long distances cannot be excluded.

Geographical distribution

E. amylovora is native to North America and was introduced into northern Europe in the 1950s to 1960s. Presence in the EPPO region: Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Egypt, France (except south-east), Germany, Greece, Hungary, Ireland, Israel, Italy, Kosovo, Lebanon, Luxembourg, Macedonia, the Netherlands, Norway, Poland, Romania, Serbia (north, west, south), Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, UK (absent from Northern Ireland) and Ukraine.

Phytosanitary risks

E. amylovora is one of the most important pests on the EPPO A2 list. It is also considered as a quarantine pest by numerous countries around the world in which the disease is not yet present (e.g. Australia, Japan). It presents a risk to the pear and apple industries as well as to the nursery trade, since many ornamental species are susceptible hosts.

All countries, even those where the disease exists, have imposed restrictions to the import or introduction of susceptible host plants. All plant organs except seeds are considered as potential sources for disseminating the pathogen.

There is no adequate chemical or other treatment for the elimination of the pathogen from plant material without destroying the plant tissues.

(Source: EPPO)

***Pseudomonas syringae* pv *aesculi* (Bark Bleeding Disease of Horse chestnut)**

Hosts
Aesculus hippocastanum and *A. x carnea* and their cultivars are the most susceptible common hosts which show disease symptoms. *A. flava* and *A. pavia* have shown only minor symptoms thus far.

Biology and dispersal
Many facets of the biology of *P. syringae* pv. *aesculi* are not yet understood in detail. The bacterium has been identified and described earlier in Mediterranean regions, but so far only as a pathogen that causes necrotic lesions on the leaves of a tree. It cannot be excluded that a new, more aggressive strain of this fungus has developed meanwhile, but this also has to be confirmed. The bacteria usually can be found as endophyte on the bark and other plant parts of trees that are still healthy, but the factors that may predisposit the infection are not yet known. Once the bacteria enter the bark, necrotic bark lesions develop that eventually may girdle stems or thicker branches. It is suggested that infection may occur via small wounds such as leaf scars or by mechanical wounds. Even wounds made by bark cell sucking insects are suggested to serve as points of entrance, but this hypothesis still has to be confirmed. Fresh bleeding symptoms only occur during the growing season, indicating the trees reaction to wall off the pathogen with the new periderm and cork tissue. Once a tree is infected, the bacteria overwinter in the bark and from there may extent further in healthy bark tissue the next growing seasons. Trees react with formation of wound callus to overgrow the necroses, but new callus tissue also may be prone to new infections. The efficiency of walling off the necrosis together with the tolerance for the disease seems to be under individual genetic control, but this still has to be confirmed.

Geographical distribution
Severe outbreaks of the disease were observed in the Netherlands from 2002 on. Since that time the disease also was observed in Belgium, France, Germany, Italy and the UK. In the UK the bacterium definitely was identified as *Pseudomonas syringae* pv *aesculi*.
Presence in the EPPO region: Belgium, France, Germany, Italy, the Netherlands and the UK.

Phytosanitary risks
This is a serious and harmful disease whose pathways of spread together with the factors that may favor spread or may be predisposing infection are not yet known. However it is suggested that transport of infected material is the most likely factor to introduce the disease in areas that are not yet infested by the disease.
The disease could presumably be as damaging in other part of Europe where horse chestnuts are used as ornamental trees. It presents a risk to the urban forest as well as to the nursery trade.
P. syringae pv. aesculi is not yet present on an EPPO list of quarantine pests although its distribution seems to extent to regions where the occurrence of the disease never has been reported before. It is not yet officially considered as a quarantine pest by any other regional plant protection organisation.

(Source: EPPO)

Pseudomonas syringae pv *persicae* (Bacterial Dieback of peach)

Hosts

Peaches and nectarines are the only hosts which show disease symptoms. *Prunus salicina* has shown some symptoms on artificial inoculation.

Biology and dispersal

P. syringae pv. *persicae* enters shoots in autumn and winter through leaf scars to cause bark lesions whose development leads a few months later to dieback symptoms. Pruning wounds also provide a means of entry, particularly those made in winter on susceptible tissues and with pruning tools carrying the pathogen.

In spring, the bacterium spreads to young shoots and passes into an epiphytic phase. Leaf lesions provide abundant inoculum in spring. However, it is the epiphytic population on the leaves in autumn that constitutes the inoculum for infection via leaf scars. Natural spread is most unlikely to occur over long distances. The main path for long distance spread would be on infected planting material.

Geographical distribution

The bacterium was first observed in France. There have been unconfirmed reports from former Yugoslavia. In France, the departments of Drôme and Ardèche in the Rhône-Alpes region are essentially those affected, with a few foci just beyond their borders. There is no evidence of the presence of the bacterium in any other European country apart from former Yugoslavia.

Presence in the EPPO region: France, Yugoslavia (unconfirmed).

Phytosanitary risks

This is a serious disease whose spread has been favoured by a combination of circumstances: highly susceptible cultivars predisposing effects of climate and soil, ease of transmission by pruning. In the central Rhône valley, numerous trees are destroyed every year, although only the Ardèche and Drôme departments are seriously affected in this way. The disease could presumably be as damaging in other peach-growing areas in Europe.

P. syringae pv. *persicae* is an EPPO A2 quarantine pest in view of its very limited distribution in the EPPO region. It is not considered as a quarantine pest by any other regional plant protection organisation.

(Source: EPPO)

Xanthomonas arboricola pv *pruni* (Bacterial Leaf Spot)

Hosts

X. arboricola pv. *pruni* attacks only *Prunus* spp., and particularly the fruit crops almonds, peaches, cherries, plums, apricots and *P. salicina*. Other exotic or ornamental species of *Prunus* attacked include *P. davidiana* and *P. laurocerasus*. Cultivars of the Sino-Japanese group (*P. japonica* and *P. salicina*) are generally more susceptible than European plums.

Biology and dispersal

On peach, *X. arboricola* pv. *pruni* overwinters primarily in the intercellular spaces of the cortex, phloem and xylem parenchyma towards the tips of twigs produced during the preceding season. On plum and apricot, summer cankers formed in one season continue developing the following spring, so providing a source of inoculum at this time. Plum buds and fallen leaves have also been reported as overwintering sites.

In the spring, before host division starts, the bacteria in the intercellular spaces multiply and cause the epidermis to rupture, so initiating a visible lesion referred to as a spring canker. Inoculum from these cankers

is disseminated in rain and wind and infects new leaf growth via stomata. Lesions developing on the leaf exude bacteria which bring about secondary infections. It is suggested that the bacterium may migrate systemically from twigs to leaves. Pruning operations will also transmit the disease. Insects which damage plum bark, such as *Cicada* spp., also provide points for entry. Following foliage infection, summer cankers develop in the green tissue of the shoot, but usually become sealed off by a periderm layer and, as cankers tend to dry out during the course of summer, the viability of bacteria therein is largely reduced; thus, except in certain localities, summer cankers in plum and peach are of no importance as overwintering sites for the bacterium, or in initiating infections the following spring. In general, it is the late infections of shoots, occurring during rains just before and during leaf fall in the autumn, when the host resistance mechanism of producing a periderm barrier is reduced, which constitute the primary inoculum source for the following spring.

A warm, moderate season with temperatures of 19-28°C and with light, frequent rains accompanied by fairly heavy winds and heavy dews is most favorable for severe infection. The disease tends to appear and spread in the spring, then makes little progress through the summer, but late infections occur in the autumn. The disease is not usually found in arid regions.

Strain differences have mostly not been noted in *X. arboricola* pv. *pruni*, but differential virulence to peach, plum and apricot cultivars has been observed.

X. arboricola pv. *pruni* has a limited capacity for local dispersal by rain splash in orchards. In international trade, it is likely to be carried on plants for planting (except seeds) of host species, including bud wood.

Geographical distribution

X. arboricola pv. *pruni* was first described in North America. It is not clear whether it has spread from there or naturally has a wider range.

Presence in the EPPO region: Austria (unconfirmed), Cyprus (unconfirmed), Lebanon, Moldova, the Netherlands (unconfirmed), Switzerland (unconfirmed), Ukraine. Locally established in Bulgaria, Italy, Romania, Russia (European, Far East), Slovakia (unconfirmed) and Slovenia.

Phytosanitary risks

Greatest damage arises from severe defoliation resulting in weakened trees. Heavily infected trees (plum) gradually become uneconomic.

X. arboricola pv. *pruni* is listed as an A2-quarantine pest by EPPO. The disease is rated as of little economic importance by the EPPO countries where it currently occurs, but it is absent from several major countries producing *Prunus*. Its behaviour elsewhere in the world suggests that it would be likely to establish more widely in the EPPO region although, in general, the bacterium would not present a threat to arid regions.

(Source: EPPO)

Appendix 4 Fungi

Ceratocystis fagacearum **(Oak wilt)**

Hosts
C. fagacearum attacks *Quercus* spp. No North American oak is known to be immune. Red oaks (subgenus *Erythrobalanus*) usually die within a few weeks of infection. White oaks (subgenus *Lepidobalanus*) are more resistant. They may recover from the disease. If they die, it is usually over a period of several years. *Pseudopityophthorus* spp. serve as important vector for the disease are mainly found on *Quercus* although other hardwood hosts have been recorded. In Wisconsin (USA), *P. minutissimus* was found to be common in red oaks but absent from white oaks.

Biology and dispersal
Ceratocystis fagacearum C. fagacearum is a classic vascular wilt pathogen, with the fungus confined to the vessels of the outermost xylem ring until the tree becomes moribund. In a diseased red oak, passive movement of spores within the transpiration stream usually results in the fungus being transported to all parts of the tree. When a red oak dies, growth of the fungus out into the inner bark can lead to the production of sporulating mats, although this may be prevented by high summer temperatures and competition from other fungi. Mats produce endoconidiophores initially, and then perithecia, if fertilisation is effected by the introduction on insects of the other mating type of the fungus. Antagonistic fungi hasten the degeneration of the mat and the pathogen usually disappears from the above-ground parts of a dead tree within a year of wilting. Survival in the root system may be more prolonged, especially if the roots are grafted to those of neighbouring trees.
In a diseased white oak, distribution of the fungus in xylem of the current annual ring is much more restricted than in red oaks. If the tree recovers, the infected ring will be buried under new xylem and is most unlikely to constitute a significant source of inoculum. In many parts of its range, the most important means of dispersal is through the transportation of spores of the fungus across root grafts as a result of the movement of water to transpiring healthy trees from non-transpiring diseased ones. In parts of the disease range, all the oaks are grafted together. Under these conditions disease centres can enlarge rapidly. Thus a radial rate of 7.5 m per year occurs in *Q. ellipsoidalis* in Minnesota and 11-16 m per year in *Q. fusiformis* in Texas (USA). Elsewhere functional grafts are much more infrequent and underground spread is slower and more erratic.
Above-ground spread is a relatively rare event. In the north of the disease range, it occurs principally through the activities of sap-feeding nitidulid beetles which disseminate spores from the sporulating mats to fresh wounds on healthy trees. In some areas further south, the oak bark beetles *Pseudopityophthorus minutissimus* and *P. pruinosus* (see below) are thought to be more important as vectors, chiefly because sporulating mats are rarely produced. However, in Texas, at the extreme south of the disease range, mats are commonly produced on *Q. texana* and nitidulids are considered important as vectors in this state.
There are only a few instances where it is suspected that the movement of diseased materials by man has resulted in the appearance of a new disease outbreak. Nevertheless, knowledge that sporulating mats can be produced on logs from diseased trees has greatly influenced European attitudes towards the disease.
Pseudopityophthorus spp. Two generations of beetles occur per year through most of the oak wilt range. In states such as Ohio (USA), all stages successfully overwinter except the pupae. Further north in Wisconsin however, where only *P. minutissimus* is present, the larger larvae are the only winter-resistant stage. These emerge as adults in May. Young adult beetles commonly make deep feeding wounds in the twig crotches, leaf axils, bud axils and immature acorn axils of both red and white oaks. Fresh feeding wounds can be found

from early spring onwards and it has been established that the wounds are capable of acting as infection courts when inoculated with the oak wilt fungus. The percentage of young adult beetles carrying the fungus is very variable. As many as 30% of beetles emerging from some trees with oak wilt can carry the fungus but a more typical figure is between 0.4 and 2.5%.

It also seems possible that parent beetles transmit the disease in spring. They may make a gallery system in a diseased tree, emerge to feed on twigs of healthy trees, and then breed again in a healthy tree.

C. fagacearum normally spreads rather slowly by root grafting and more rarely above ground by insect transmission. International spread on planting material, or vectors carried on it, is presumably possible although the disease is in practice reported from forest trees rather than from nursery plants. Thus, oak wood carrying sporulating mats of the fungus is the main practical pathway which has been envisaged for international spread. If the wood carries bark, oak bark beetles are more likely to be present and provide an immediate pathway for transmission.

Geographical distribution

Ceratocystis fagacearum C. fagacearum is indigenous to North America and has not spread to other continents.

Presence in the EPPO region: absent.

Pseudopityophthorus spp.

Presence in the EPPO region: absent.

Phytosanitary risks

The white oaks *Q. robur*, *Q. petraea*, *Q. suber* and *Q. ilex* are very important forest and plantation trees in the EPPO region. North American red oaks such as *Q. rubra* have been extensively planted in some countries, e.g. France.

C. fagacearum is an A1 quarantine pest for EPPO. It is perceived to constitute a very real threat to the EPPO region because of the lack of adaptation to the pathogen in the oak species to be found there, and also because of the occurrence of insects which appear to have the potential to be highly effective vectors, e.g. the European bark beetle (*Scolytus intricatus*)). The entry in the EPPO A1 list includes the vectors of *C. fagacearum*, without specifically naming them, while the EU Annex names *Arrhenodes minutus*, *Pseudopityophthorus minutissimus* and *P. pruinosus*. There is no foundation for considering *A. minutus* (oak timber worm) as a vector. In particular, the duration of the larval stage (2-4 years) is too long for an effective link with *C. fagacearum* in a dead tree to be established. Although the *Pseudopityophthorus* spp. certainly are vectors, it is not certain that it is useful to mention them specifically as quarantine pests, because they are not important in their own right as pests, because they play a relatively minor role in dissemination (less than the presumed potential role of the European *S. intricatus*), because they are not the only species involved and because the measures taken against *C. fagacearum* will exclude them in any case, together with other vectors.

(Source: EPPO)

Ceratocystis fimbriata f. sp. *platani* (Canker stain of plane)

Hosts
Platanus spp. are the only hosts of this *forma specialis*, especially *P. x acerifolia* (widely planted as an amenity tree in most parts of Europe) and its parents *P. occidentalis* and *P. orientalis.*

Biology and dispersal
The fungus may be transmitted by root contact. Anastomosis between roots of *Platanus* trees is possible and the pathogen can infect the uninfested tree. It is certainly transmitted by contaminated pruning tools and terracing machinery which causes damage to the roots. The fungus can survive for 7-15 days on the surface of a wound. Penetration only occurs through wounds, and the fungus colonises the bark and also the wood. Longitudinal spread can be rapid (50-100 cm per year). The fungus can reach the heart of the tree, along the medullary rays.
There is apparently no incubation period. The fungus can survive for more than 105 days in soil during the winter but temperatures of 35-40° C are lethal to the pathogen in soil. Sawdust from diseased trees is highly infective.
Natural spread is very slow and most unlikely to occur over long distances (there are no natural vectors). Terracing machinery may carry infested soil and contaminate healthy areas. The fungus could be spread in *Platanus* wood in countries where this is used. The most probable means of international spread is by trade in infected plants.

Geographical distribution
The organism was introduced from the USA to several Southern European ports at the end of the Second World War and spread rapidly in Italy and more slowly in France. The rate of spread in France seems to have accelerated in recent years. Only the western part of Vaucluse is severely affected. Eradication measures are proving effective in Marseille.
Presence in the EPPO region: France, Italy (including Sicily), Spain (unconfirmed), Switzerland.

Phytosanitary risks
In the eastern USA, before 1950, Canker stain attacked 3.8% of the trees, and up to 80% in some towns. However, the disease appears to have lost importance. In south-east France, *C. fimbriata* f.sp. *platani* has caused serious losses to shade trees. In Marseille, after a first phase of infection starting in 1945, 1850 *Platanus* trees of average age 110 years were killed between 1960 and 1972 (about 13% of the initial population). The disease spread out of the city and into the next department (Vaucluse). Infected trees died in 3-7 years. In Italy, the fungus invaded the north of the country in a few years and killed many trees, especially in young row plantings.
C. fimbriata f.sp. *platani* is an EPPO A2 quarantine organism. *Platanus* is the key amenity tree species for the urban environment in temperate climates. In view of the speed of spread of the disease and the extent of damage, it must be considered a serious threat to many EPPO countries. The disastrous European experience with *Ceratocystis ulmi* (Dutch Elm Disease) should serve as an example.

(Source: EPPO)

Chalara fraxinea **(Ash dieback)**

Source: EPPO Alert List

Hosts
Fraxinus excelsior (European ash). No data is available on the susceptibility of other *Fraxinus* species.

Biology and dispersal
Data is lacking on the biology of *C. fraxinea*. It was isolated from diseased twigs and branches, as well as in dead roots of living ash trees.
Although data is lacking on the biology of the fungus, it seems likely that plants for planting and wood of *F. excelsior* could be pathways for spreading the disease over long distances.

Geographical distribution
Presence in the EPPO region: Austria, Finland, Germany**,** Hungary, Lithuania, Norway, Poland, Slovenia and Sweden (*C. fraxinea* has been identified in these countries). On the basis of symptoms, the disease has also been observed in Denmark, Estonia, Latvia and Switzerland.

Phytosanitary risks
Because Ash dieback could represent a serious threat to forest, amenity and nursery ash trees, the EPPO Secretariat decided to add *C. fraxinea* to the EPPO Alert List in 2007. Further studies carried out in 2008 in Poland revealed that *C. fraxinea* was the anamorph of an already described species, *Hymenoscyphus albidus,* which is considered as non-pathogenic, native and widespread in Europe. Therefore, the emergence of a new disease caused by this species is difficult to explain, and it is acknowledged that further studies are needed to better understand the taxonomy and biology of the *H. albidus/C. fraxinea* complex. *Fraxinus* are widely grown across the EPPO region both for forestry and amenity purposes. Although data is still lacking on the exact role of *C. fraxinea* in ash dieback, EPPO member countries should be warned that Ash dieback is emerging in Europe and that there may be a risk in moving diseased *F. excelsior* plants across the region without any precaution. Further studies are obviously needed on the etiology of Ash dieback, its geographical distribution and economic impact.

Cronartium ribicola **(Blister rusts)**

(American species: *C. coleosporioides; C. comandrae; C. comptoniae; C. fusiforme*)
(Source: EPPO)

Hosts
The main aecial hosts are two- and three-needled *Pinus* spp. Such as (depending on the *Cronartium* species), jack pine (*P. banksiana*), lodgepole pine (*P. contorta)*, and western yellow pine (*P. ponderosa*). Also Scots pine *P. sylvestris* is more or less susceptible for some of the *Cronartium* species and sometimes also the Austria pine (*P. nigra*).
The telial hosts are also depending on the *Cronartium* species, but all together they consist of a wide variety of plant genera and species. Some of them can also be found in Europe which makes that some of the Cronartium species certainly will find hosts and alternative hosts once introduced in Europe.

Biology and dispersal

The biology of all the heteroecious North American *Cronartium* spp. is broadly the same. Pycnia and aecia are produced on the *Pinus* hosts in the spring and early summer, one to several years after infection. Aeciospores can be carried over long distances in the wind and infect the alternate (telial) host; they cannot reinfect *Pinus*. About two weeks after infection, uredinia appear on the alternate hosts. Successive production of uredinia and reinfection throughout the summer result in high levels of infection on the alternate host. Telia are produced in late summer, and *Pinus* hosts become infected via the first-year needles by the wind-borne basidiospores which arise from germination of teliospores; the telial host cannot be reinfected by basidiospores. Basidiospore infection, which occurs in summer and autumn, is usually limited to an area within 1.5 km of the alternate host, owing to the spores being delicate and short-lived. Infection of *Pinus* by basidiospores completes the life cycle, the duration of which varies between species. The fungal mycelium of these rusts may overwinter in bark and galls of *Pinus*

Cronartium spp. can be carried considerable distances as wind-borne aeciospores and can survive considerable periods in the airborne state. More importantly, these rusts can also be carried to new areas on plants for planting of the coniferous aecial hosts, as has occurred in parts of the USA. The alternate hosts of *Cronartium spp.* often are wild plants which are extremely unlikely to be traded internationally. Similarly, there is no risk in movement of *Pinus* seeds or pollen.

Geographical distribution

Natural distribution: North America and Canada
Presence in the EPPO region: absent

Phytosanitary risks

The *Cronartium* rusts cause very important diseases in North America, resulting in malformation, reduced vigour and death of trees and seedlings. However, their abundance does depend primarily on the abundance and localisation of the alternate host.

C. coleosporioides is one of the non-European *Cronartium* spp. of the EPPO A1 list. The danger presented by these fungi to the EPPO region is classically exemplified by reference to the quarantine pest *C. ribicola*, which has made it almost impossible to grow *P. strobus* commercially in most areas in Europe and North America to which the fungus was introduced from Asia. However, it should be stressed that the potential risk from introduced *Cronartium* spp. is much affected by the status of the alternate hosts concerned. While the *Ribes* hosts of *C. ribicola* are widespread cultivated plants, the telial hosts of some *Cronartium* species are wild plants which do not occur in Europe, and there is only a possibility that related European wild plants might also be infected. In this case there is only a moderate risk for the EPPO region. But, on the other hand, when alternative hosts are present (such as *Quercus rubra* for *C. fusiforme*) and in addition, European *Pinus* spp. Are severely broady infected by the *Cronartium* species, not apparently infected, then the risk for the EPPO region may be high.

Cryphonectria parasitica (Chestnut blight)

Hosts

Chestnuts (*Castanea* spp.), particularly *C. dentata*, *C. mollissima* shows resistance but may also become infected. Also *Quercus* spp., *Castanopsis*, *Acer*, *Rhus typhina* and *Carya ovata*. Within the EPPO region, *Castanea* spp. (especially *C. sativa*) are the main hosts.

Biology and dispersal

Conidia and ascospores of *C. parasitica* are spread in wind and rain, but are also transmitted by beetles (*Agrilus* spp.) and birds. Entry into wood is via wounds produced by the insect vectors. Spread within the host is rapid unless cankers form which temporarily restrict the fungus. The fungus can exist as a saprobe on broad-leaved trees beyond its parasitic host range. Fan-shaped, buff-coloured mycelial wefts form in the inner bark and cambium. Reddish perithecia are produced in groups. Long, coiled tendrils of conidia exude from pycnidia in wet weather.

On fruits, the fungus is associated only with the nutshell and apparently does not affect seed germination or seedling growth.

Although insect vectors are not thought to play a very important role in the transmission of the disease, it is noteworthy that Chestnut blight cankers have a very large and diverse fauna. In trapping experiments in the USA, 495 insect species were captured on old blight cankers. A considerable number of insects spent parts of their life cycle on cankers and nearly 69 species were found to carry inoculum of *C. parasitica*. In international trade, the fungus may be carried by host plants or on wood or bark. There is a small risk of transmission by fruits or seeds.

Geographical distribution

C. parasitica was introduced into North America from the Far East at the end of the nineteenth century and spread within the next five decades throughout all the main chestnut areas. In 1938, the pathogen was first discovered in Europe as an isolated focus near Genova, Italy. Once again, the fungus spread very rapidly and at the end of the 1960s most parts of southern Europe where chestnuts are cultivated were affected by the pathogen.

Presence in the EPPO region: Austria, Belgium, Bosnia-Herzegovina, Croatia, France, Germany, Greece, Hungary, Italy, Macedonia, Poland, Portugal, Russia (Black Sea coast (widespread), Caucasus), Slovakia, Slovenia, Spain, Switzerland, Tunisia, Turkey, Ukraine and former Yugoslavia.

Phytosanitary risks

Between 1904 and 1950, *C. parasitica* caused almost complete destruction of *Castanea dentata* in the eastern USA. There has also been extensive spread on *C. sativa* in Europe from Italy since 1938. However, there is evidence that the pathogen is behaving less virulently in Europe than in the USA; new and healthy coppice shoots arising from stumps originally attacked indicate recovery from the disease. This has been explained by the occurrence in Europe of hypovirulent strains which are vegetatively compatible with virulent strains.

Strains of *C. parasitica* may show vegetative incompatibility, i.e. they may not form hyphal anastomoses. Hypovirulent strains have lost their ability to cross wound periderm before suberisation. Hypovirulence can be transmitted by hyphal anastomosis to virulent strains of the same vegetative compatibility group. In Europe, relatively few compatibility groups of *C. parasitica* have been observed, thus leading to a wide distribution of single compatibility groups which favors the spread of hypovirulence. In the USA the situation is reversed. There, over 70 compatibility groups have been identified, limiting the distribution of hypovirulent strains.

The fungus is indigenous on species of *Castanea* in China and Japan, where it does little harm.

C. parasitica is an A2 quarantine organism for EPPO.

Spread of *C. parasitica* from the southern part of the EPPO region into more northern areas could cause considerable losses. Since the occurrence of relatively low strain variability has limited the losses in infected areas, the introduction of new strains might disturb the European balance between virulent and hypovirulent strains and could have a devastating effect on the remaining chestnut areas of southern Europe.

(Source: EPPO)

Gibberella circinata (Fusarium circinatum) (Pitch canker of pine)

Hosts

G. circinata infects only *Pinus* spp. In North America, its main native hosts are *Pinus elliottii*, P*inus palustris*, *Pinus patula*, *Pinus radiata*, *Pinus taeda Pinus virginiana*. It has also been recorded on over 30 other *Pinus* spp., including the European and Mediterranean species *Pinus halepensis*, *Pinus pinaster* and *Pinus sylvestris*, various North American species planted in Europe such as *Pinus contorta* and *Pinus strobus* and various Asian species (e.g. *Pinus densiflora*, *Pinus thunbergii*). There is an isolated record on *Pseudotsuga menziesii*, not apparently associated with any damage.

Biology and dispersal

G. circinata infects the branches of pine, causing a bark canker. Since perithecia have not been observed in nature, it is presumed that ascospores are not of great importance for infection of the host. Most infection is by macroconidia and /or microconidia, carried by wind or insects. Bark-feeding insects (e.g. *Pityophthorus, Ips, Conophthorus*) commonly breed in affected branches and emerging adults commonly carry the pathogen. These insects may also provide a wound suitable for infection.

Moisture is required for an infection to occur, and infections appear to be associated with locations or seasons where atmospheric moisture is readily available and temperatures are relatively warm, such as in the south-eastern USA during summer thunderstorms. In California, the disease is most severe in close proximity to the coast. The distribution of the disease also suggests that cooler temperatures are restrictive.

G. circinata can infest pine seeds internally or be present as a superficial contaminant but it is not known how this infestation occurs. Seed-borne inoculum can infect and kill pine seedlings.

G. circinata is spread locally by wind and insects, but its rate of spread in newly infested areas does not appear to be very high. Over long distances, it can be carried by consignments of pine seeds, or by plants for planting of pine. In principle, it could

be carried by infected wood, but this is most likely for particle wood made from small branches and their bark, in which spores of the fungus can survive. Round wood and sawn wood, especially if debarked, are less likely to carry the fungus. In view of the substantial trade in pine wood, and the limited distribution of the fungus, it seems unlikely that this has been a significant pathway in practice.

Geographical distribution

The origin and spread of *G. circinata* seems obscure. Older records from various parts of the world may be based on inadequate identification. Outside America, records in Japan and South Africa are considered to result from introduction.

The fungus is probably native in North America, but some US states (and Mexico) record its introduction.

In any case, until 2005, there have been no reliable records in the EPPO region.

Presence in the EPPO region: Italy (unconfirmed), Spain.

Phytosanitary risks

G. circinata is a chronic problem in the south-eastern USA, where it affects production in plantations, nurseries and seed orchards, but does not significant impact on native forests. It regularly adds to the cost of production but does not result in large financial losses in most years. Most southern pines are affected to some extent, including *P. taeda*, which typically sustains only minor damage and *P. elliottii*, which can be more severely affected. However, the use of less susceptible genotypes and changes in silvicultural techniques have greatly reduced the impact since that time.

Since *G. circinata* was introduced into California in 1986, it has caused damage and mortality of *P. radiate* in urban plantings and in native forests. Costs of tree removal and replacement may eventually amount to several million USD in severely affected areas. Other *Pinus* spp. are also affected. Since its introduction into South Africa, *G. circinata* has caused serious problems in seedling nurseries. It could readily be further spread

by international movement of infected *Pinus* seeds. Unconfirmed records in the EPPO region may indeed be associated with the import of infected seeds, from which the disease did not establish. The areas to which it has spread have Mediterranean-type climates, so that, within the EPPO region, the Mediterranean area is clearly at risk since *Pinus* spp. Are widely planted there. The disease probably presents the greatest danger to forest nurseries. Damage to plantations or native forests seems more likely to arise in a warmer and more humid climate than exists anywhere in the EPPO region.

(Source: EPPO)

Gymnosporangium spp.

(American and Asian species: *G. asiaticum, G. claviceps, G. globosum, G. juniperi-virginianae, G. Yamadae*)
(Source: EPPO)

Hosts
The most important aecial hosts are Rosacaea of the subfamily Pomoidea such as, depending on the species of Gymnosporangium): pear (Pyrus pyrifolia, P. communis), quince (Cydonia oblonga), apples (Malus pumila), species of Amelanchier, Aronia, Chaenomeles, Crataegus, Mespilus, Photinia and Sorbus.

The telial hosts are Juniperus spp., depending on the species of Gymnosporangium: Juniperus chinensis, Juniperus virginiana, J. communis.
Sometimes a Gymnosporangium species is found on Cupressus.

Biology and dispersal
Gymnosporangium spp. are heteroecious in that they require *Juniperus* and rosaceous hosts of subfamily Pomoideae to complete their life cycle. Telia are produced on stems and leaves of *Juniperus* in the spring. In moist conditions, the telia germinate *in situ* and produce basidiospores which are dispersed and are able to infect nearby rosaceous hosts. Infection of *Juniperus* by *Gymnosporangium* may persists for more than one year.
Infection from basidiospores gives rise to pycnia borne on the upper surface of the rosaceous host its leaves; they are visible from late spring to early summer. Later, aeciospores are produced inside tubular protective sheaths (peridia) on the underside of the leaf. The aeciospores are released when the peridium ruptures and are capable of being wind-borne over long distances to *Juniperus*. After germinating on *Juniperus* an overwintering latent mycelium is produced. Infection of the rosaceous host does not persist after infected leaves have fallen. The telial state appears on *Juniperus* in the spring to begin the life cycle again.
Under natural conditions, spread of *Gymnosporangium* is by basidiospore dispersal to rosaceous hosts, and by wind-borne aeciospores to *Juniperus*. Rosaceous hosts trees within 100 m of a *Juniperus* tree are at high risk of infection, and up to 1,000 m in windy situations. In international trade, plants of *Juniperus* (especially Bonsai plants) are liable to be infected. *Gymnosporangium* can be latent during winter (the probable importing period) and may not be detectable at pre-export phytosanitary certification. Infection may also have remained latent on the plants in the previous growing season.
Introduction of *Gymnosporangium* on commercial importations of rosaceous host plants is very unlikely as infection is not persistent in the dormant stage. Fruits are not infected.

Geographical distribution

Natural distribution: North America or Asia
Presence in the EPPO region: absent

Phytosanitary risks

Gymnosporangium is reported to be a serious pathogen in its natural distribution area. It is also, on its alternate host, one of the most important and widely distributed fungal pests of urban ornamentals. Non-European *Gymnosporangium spp.* are listed as A1 quarantine organisms by EPPO. Other *Gymnosporangium* spp. already occur on pears in Europe, e.g. *G. sabinae* with *Juniperus sabina* as alternate host. The severity of *G. sabinae* infection on pear is determined by the proximity of infected *J. sabina* and, in practice, *G. sabinae* is only of rather moderate importance, in southern Europe only. In favour of the quarantine pest status of Non-European *Gymnosporangium* is the fact that they it could very probably establish in Europe (since non-European *Juniperus* species do occur) and that it does appear to be a more damaging species, on its main host ouside Europe than its European counterpart in the EPPO region. Against it is the fact that European rosaceous hosts often do not appear to suffer significant damage and that in commercial orchard juniper-rust is easily controlled. Nevertheless however, the disease can be detrimental for *Juniperus* spp. on which control is difficult.

Phytophthora lateralis (Root rot of *Chamaecyparis*)

Hosts

The main host of *P. lateralis* is *Chamaecyparis lawsoniana* (Lawson's cypress). *Taxus brevifolia* (Pacific yew) has also been reported as a host. *P. lateralis* is thought to have been introduced, from an unknown origin, into North America, where it encountered the native *C. lawsoniana*; if this is so, it may have a native host, as yet unknown, in its area of origin (possibly another *Chamaecyparis* sp. or other member of the *Cupressaceae*). Although there are isolated records of infection of other *Chamaecyparis* spp. (*C. formosensis*, *C. obtusa*), it seems clear, from the absence of any published information, that these plants, which are also widely cultivated, do not suffer significant damage or loss due to *P. lateralis.* There are reports of *P. lateralis* naturally infecting other hosts, including in particular other conifers, ornamental *Ericaceae*, and *Actinidia* spp. These are all considered to be misidentifications of other *Phytophthora* spp., notably *P. gonapodyides.*
Artificial infection has been obtained in inoculation experiments with *Rhododendron* spp., *Pseudotsuga menziesii* and *Chamaecyparis nootkatensis.* This opens the possibility that *P. lateralis* might be carried latently by, and survive on, plants which are not natural hosts.

Biology and dispersal

P. lateralis parasitises roots in the same way as other *Phytophthora* spp. In an established infection on a root of *C. lawsoniana*, *P. lateralis* is present as mycelium, from which sporangia are formed. Under suitable conditions (i.e. available moisture and temperatures of 10-20° C), the sporangia release zoospores that can swim a few cm autonomously, or also be carried by natural movement of soil water. The zoospores make contact with and attach to susceptible host rootlets, germinate and infect. They may also encyst, and the cysts may be further transported by water and have a further opportunity to infect a susceptible root. *P. lateralis* mycelium spreads through the inner bark and cambium of the root system to the root collar, which can result in the eventual death of the host. Infection can occur at temperatures of 3-25° C but temperatures of 15-20° C are optimal. The foliage of *C. lawsoniana* is sometimes infected, if it comes into contact with the ground. Infection spreads upwards in an irregular triangle. Under favourable conditions, the pathogen produces sporangia on the foliage, and aerial spread is possible. The mycelium of *P. lateralis* forms chlamydospores which persist in the soil and in leaf or root debris, ensuring the long-term survival and overland movement of the pathogen. *P. lateralis*, which is homothallic, sometimes also produces oospores, which can similarly survive. In buried pot tests, *P. lateralis* was recovered at a low frequency after seven years,

but the pathogen was killed in days when infected roots were exposed to the sun on the soil surface. The other known host, *T. brevifolia*, is less susceptible. Surveys have shown that *T. brevifolia* is only killed by *P. lateralis,* where it was growing along streams in close association with dead or dying *C. lawsoniana.* This suggests that a high level of zoospore inoculum is needed to obtain infection of this host.

Natural short-distance dispersal can be plant-to-plant, aerial, or through soil and water. Below-ground movement is primarily by zoospores, which may be carried down slopes by water movement. Plant-to-plant contact can be above or below ground. Cases are known where C. lawsoniana has undergone abundant intraspecific root grafting, which has served as a path for vegetative spread of P. lateralis. Above ground, foliage infection can be transmitted through contact between adjacent foliage. Aerial spread is thought to be primarily through zoospores, as mature sporangia remain attached to the sporangiophores and infection coincides with temperatures conducive for zoospore release (10 to 20° C). P. lateralis spread slowly through the Pacific states of the USA over several decades, and its progress was monitored throughout this period.

A comprehensive study of the disease in Southwest Oregon and Northwest California concluded that dispersal by vehicles had the greatest effect in spreading the pathogen to uninfested areas. Trees in areas crossed by roads were more likely to be infected than those not crossed by roads. Vehicles on roads also spread inoculum further than foot traffic (both animal and human). Waterways were also pathways of spread, since hosts at sites with large or persistent streams were more likely to become infected.

Long-distance movement of inoculum, particularly human-mediated movement of infested soil, mainly involves chlamydospores and oospores. Zoospores are more important for short-distance dispersal. In international trade, the most likely pathways for *P. lateralis* would be plants for planting of *C. lawsoniana*, or plants for planting of non-host plants with contaminated soil attached, or contaminated soil as such.

Geographical distribution

Presence in the EPPO region: France (found but not established), the Netherlands (found but not established).

Phytosanitary risks

P. lateralisis a serious pest of C. lawsoniana, which is one of the most valuable commercially harvested conifer timbers in the world, commanding up to ten times the price of Pseudotsuga menziesii wood from the same site. The greatest loss in commercial forestry results from the death of young trees at the lower size limits of merchantability. Presently, the disease continues to kill trees in forestry plantations but also hedgerow and landscape trees in the Pacific states of the USA and has resulted in the loss of wood export markets especially to Japan. Trees of C. lawsoniana in parks in British Columbia generally experience significant annual losses due to root rot caused by P. lateralis, and the cost of replacing them has become prohibitive. P. lateralis is thought to have nearly destroyed the multi-million dollar industry for production of ornamental *C. lawsoniana* in Northwest Oregon and Western Washington. In addition to social impacts through loss of business in nursery and forestry sectors, tourism and fishing have been affected due to forest closures. In addition, *P. lateralis* has destroyed large numbers of *C. lawsoniana* within the natural range of the species, where it grows in riparian habitats with large trees providing shade and long lasting structure to waterways.

P. lateralis is extremely damaging to *C. lawsoniana* in nurseries, plantations and natural vegetation in the Pacific regions of USA and Canada where it has been introduced and spread. The disease takes the form of a root and crown rot leading to extensive tree mortality.

In the EPPO region, the endangered area is mainly the Atlantic parts of Western Europe, having a wet maritime climate, but extends to conifer nurseries in any part of the region. The phytosanitary risk mainly concerns *C. lawsoniana,* which is grown as a valued ornamental, produced and sold by nurseries, especially as semi-dwarf cultivars for parks and gardens. It is one of the most important ornamental conifer species for the nursery trade. In contrast to the situation in North America, *C. lawsoniana* is infrequently grown as a timber tree in the EPPO region, though there are plantations in Northern Spain and Portugal which would be at risk. In practice, the risk of introduction of *C. lateralis* into the EPPO region is reduced, because the endangered area mainly falls within the European Union, which prohibits the import

of plants of *Chamaecyparis*, and also restricts the import of growing medium, and of trees and shrubs generally, from non-European countries. Although it is recognised that *T. brevifolia* is also a (less susceptible) host of *P. lateralis*, this species exists only in botanical collections in the EPPO region, and has no commercial importance in production or trade.

(Source: EPPO)

Phytophthora ramorum (Sudden oak death)

Source: EPPO Alert list

Hosts
Sudden oak death has been observed on: *Lithocarpus densiflorus* (tanoaks), *Quercus agrifolia* (coast live oak) and *Q. kellogii* (black oaks), *Q. parvula* var. *shrevei*. These oak species are native to California. The pathogen was found on *Vaccinium ovatum* causing twig dieback. In California, *P. ramorum* has been found in rhododendron plants adjacent to infested oaks. The pathogen was also isolated from *Sequoia sempervirens* and *Pseudostuga menziesii*. Symptoms were limited to young and small branches and no mortality of mature trees was observed. *P. ramorum* was also isolated from *Acer macrophyllus, Aesculus californica, Arbutus menziesii, Arctostaphylos manzanita, Heteromeles arbutifolia, Lonicera hispidula, Rhamnus californica, Rosa gymnocarpa* and *Umbellularia californica*, although its pathogenicity has not been yet demonstrated on these species. More recently, the following species were reported as hosts in USA: *Quercus chrysolepis, Toxicodendron diversilobatum, Rubus spectabilis, Rhamnus purshiana, Corylus cornuta, Pittosporum undulatum, Trientalis latifolia*. In Europe, *P. ramorum* is mainly found on *Rhododendron* and *Viburnum,* but recently it was also isolated from *Arbutus, Camellia, Hamamelis, Kalmia, Leucothoe, Magnolia, Pieris* and *Syringa*. An isolated finding on one *Quercus falcata* tree was reported by UK in November 2003, and shortly after on a few trees of *Fagus sylvatica, Quercus ilex, Q.cerris, Castanea sativa* and *Aesculus hippocastanum*. In the Netherlands, one infected tree of *Q. rubra* and two *Fagus sylvatica* have also been identified. These trees were all located near infected *Rhododendron*.

Biology and dispersal
Infection would occur through zoospores, sporangia and chlamydospores. As for other *Phytophthora*, it is likely that the disease can be transmitted by infected plants and soil. However, it has also been observed that sporangia of the pathogen are deciduous which opened the possibility that they could be transported by air currents but this has not been demonstrated. Bark beetles and ambrosia beetles are commonly found on diseased trees but their potential role of vectors has not been studied yet. Plants for planting, wood, bark of *L. densiflorus* (tanoaks), *Q. agrifolia* (coast live oak) and *Q. kellogii*, soil from areas where the disease occurs. Plants for planting of ornamental hosts (e.g. *Rhododendron, Viburnum*) and of *Vaccinium ovatum* from areas where the disease occurs.

Geographical distribution
North America: Sudden oak death has only been reported in USA, in central coastal areas of California and one county in Oregon In ornamental nurseries, infections have reported in several states. In Canada, it was detected in 2003 on one *Rhododendron* plant in a nursery (British Columbia), under eradication.
Presence in the EPPO region: *P. ramorum* has been found mainly on *Rhododendron* and *Viburnum* in nurseries in Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Lithuania, the Netherlands, Norway, Poland, Serbia, Slovenia, Spain (Asturias, Galicia, Islas Baleares: Mallorca), Switzerland, Sweden, United Kingdom.

Phytosanitary risks

Sudden oak death came to attention as significant tree mortality has been observed on several oak species in California (US). A new species *Phytophthora ramorum* was found associated with the disease and considered as the primary causal agent. *P. ramorum* was also found in Europe on nursery plants (mainly *Rhododendron, Viburnum*) causing twig dieback but has never been found causing extensive damage in forests. Genetic studies have shown that USA and European populations belong to the same species *P. ramorum*. At first, different mating types were found in Europe (A1) and North America (A2), but in 2003 the occurrence of a few isolates belonging to A1 and A2 mating types was respectively reported in North America and Europe.

It is hypothetised that the pathogen was separately introduced into these two regions from a third area which remains unknown.

Oaks are important forest and amenity trees in the EPPO region. In USA significant oak tree mortality is observed, but not in Europe. Studies have been initiated on the susceptibility of European oak species to the disease, but no conclusion can be given yet. Nursery plants such as *Rhododendron, Viburnum,* are widely grown in the EPPO region and *P. ramorum* affects their quality. From experience with other *Phytophthora* diseases, control is difficult in practice. As a consequence of tree mortality, it was felt in the USA that the disease could also have a negative impact on the biological diversity of forests and lead to environmental problems (enhanced fire risk and damage to water catchments).

Appendix 5 Viruses and viroids like pathogens

Plum pox potyvirus (Sharkavirus)

Hosts
The main woody hosts are the fruit-producing species of *Prunus*, including apricots (*P. armeniaca*), peaches (*P. persica*) and plums (*P. domestica* and *P. salicina*). PPV infection of cherries is still considered extremely unusual, being practically unknown throughout most of Europe.
PPV infects most wild or ornamental species of *Prunus*, such as *P. cerasifera*. Numerous cultivated or weedy annual plants can carry potential inoculum, but natural transmission between such herbaceous plants and *Prunus* has never been demonstrated.
Susceptible *Prunus* spp. are widely grown for fruit production (varieties and rootstocks) throughout all European parts of the EPPO region. Wild woody and herbaceous hosts are also widespread and are potential reservoirs of the disease.

Biology and dispersal
Infected *Prunus* trees are the major source of inoculum. The virus is transmitted from them either by grafting or non-persistently by the aphid vectors *Aphis spiraecola* and *Myzus persicae*. Other aphids have been shown to transmit at lower frequency than the two main vectors. The number of trees becoming infected in an orchard is directly related, in a given season, to numbers of winged aphids. These aphids probe or feed on infected leaves, then fly to other trees where they again probe or feed. Aphids spread the disease not so much to immediately adjacent trees, as to trees several rows away. In summer, the aphids may also migrate to various herbaceous species present in orchards and come back to the fruit trees to lay their winter eggs. The capacity for vector transmission varies considerably between strains. After inoculation, the incubation period may last several months and systemic spread may take several years. Accordingly, the virus may be distributed very irregularly in the tree. Various strains of PPV were originally distinguished (necrotic, intermediate, yellow) on the basis of symptoms obtained by inoculation of herbaceous indicator plants. More recently, it was found that they could be consistently grouped into the two major types (D and M).
The disease appears randomly in orchards. After 2-3 years, infection begins to spread from the first infected trees. Graft transmission can contribute significantly to spread in infected areas if certified virus-free material is not used. Movement of the virus between areas or countries is most often with uncertified plants for planting.

Geographical distribution
PPV has its origin in eastern Europe (Bulgaria) and has spread from there to most of the continent.
Presence in the EPPO region: PPV is present, or has occurred, in practically all contries. In the central and eastern countries PPV spread relatively early and levels are generally high: Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Moldova, Poland, Romania, Serbia, Slovakia, Slovenia and Ukraine). In the Mediterranean countries spread is recent and there is a high risk of further spread: Albania, Cyprus, Egypt, Greece, Italy, Portugal, Spain, Syria and Turkey. In the northern and western countries levels of PPV are very uneven: fairly widespread in Austria, Germany and the UK (England), very localised in Belgium, France and Luxemburg, eradicated in Denmark, the Netherlands and Switzerland.

Phytosanitary risks
Sharka disease is particularly serious in the fruit-producing areas of central and eastern Europe. Virus infection can lead to considerable yield losses, reaching 100%. European plums may show premature fruit drop, while Japanese plums and peaches show ring-spotting on fruit, and apricots show serious fruit deformation.
PPV is an EPPO A2 quarantine pest. In the EPPO region, it represents a major risk to apricots, plums and peaches in many countries where it is still absent or very localised. In addition, its presence in a country creates difficulties for export of certified planting material.

(Source: EPPO)

Peach rosette mosaic nepovirus

Hosts
The principal host is the American grape species *Vitis labrusca*. Some cultivars of *V. vinifera* and French-American *Vitis* spp. hybrids are also susceptible. Peach rosette mosaic nepovirus (PRMV) is also an important pathogen of peaches (*Prunus persica*) and has experimentally caused disease in *Vaccinium corymbosum*. In addition, several weed species have been shown to be hosts for the virus but the experimental herbaceous host range is rather narrow. Some species of Chenopodiaceae, Cucurbitaceae, Fabaceae and Solanaceae are infected by mechanical inoculation with sap from infected grapes or peaches.

Biology and dispersal
Several nematode species have been recorded as vectors. PRMV was shown to be seed-borne in grapevine cv. Concord at a level of 9.5% from an average of two experiments. It was also shown to be seed-borne in *Taraxacum officinale.* PRMV is also transmitted through seed of *Chenopodium quinoa.*
The nematode vector *X. americanum* transmits the virus from infected vines, infected grape seedlings and certain weed hosts, such as *Taraxacum officinale*, to healthy grapevines or peach trees. However, spread from infection foci (usually circular in shape) is only at the rate of about one m per year radially. Diseased grape seed may be present in pomace that growers sometimes spread in the vineyard. In international trade, PRMV is only liable to be carried in infected propagating material; accompanying soil may harbour infective seeds and the nematode vector.

Geographical distribution
PRMV is one of the North American nepoviruses of fruit trees, and has not extended its range to any other continent.
Presence in the EPPO region: absent.

Phytosanitary risks
A 50-fold yield reduction has been measured in grapevine cv. Concord infected for several years. In 1980, at the annual meeting of the International Council for the Study of Viruses of the Grapevine, held in Canada, New York and Michigan, the group as a whole unanimously agreed, upon seeing PRMV-diseased vines, that PRMV causes the worst symptoms in grapevine of any virus disease in the world.
PRMV has recently been added to the EPPO A1 list, but has not been considered as a quarantine pest by any other regional plant protection organisation. Its present distribution in North America indicates that it could well establish and produce symptoms in most of central Europe. The crops at risk would be peach and grapevine. However, in order for it to become a serious problem it would need to establish a relationship with an efficient vector. Because of the doubts about the information on transmission, it is difficult to provide a realistic assessment of the risk of such a relationship being established. Two of the nematodes mentioned as vectors (*Macroposthonia xenoplax* and *Longidorus elongatus*) are already present and quite widely distributed in the EPPO region, but these are of dubious status and in any case not considered to be capable of a high rate of

transmission. On the other hand, the major vector in North America, *X. americanum*, is not present in the EPPO region, and has already been considered as an A1 quarantine pest by EPPO on the basis of its vector potential for tomato ringspot nepovirus. The other reported non-European vector, *L. diadecturus,* is of rather doubtful status. It does not seem of sufficient importance for the EPPO region to be considered as a quarantine pest.

(Source: EPPO)

Cherry rasp leaf nepovirus

Hosts
The principal hosts are cherries and peaches, and also apples. The rootstock species *Prunus mahaleb* is also susceptible. Raspberries are also attacked.
Weeds have also been found naturally infected, but without symptoms (e.g. species of *Taraxacum*, *Plantago* and *Balsamorhiza*). A wide range of herbaceous test plants has been successfully inoculated in the laboratory, including *Chenopodium* spp., cucumbers, *Nicotiana* spp., *Phaseolus vulgaris* and cowpeas.
In the EPPO region, the main potential hosts would be cherries, peaches and apples.

Biology and dispersal
CRLV is a nepovirus, transmitted by the nematode vector *Xiphinema americanum.* Since the form of *X. americanum sensu lato* found in western USA is now known as *X. californicum*, this is the vector in practice. CRLV is readily transmitted by sap inoculation. Seed transmission has been shown to occur in some herbaceous hosts. Virus has been detected in pollen from infected cherry trees, but transmission by pollen has not been confirmed. Spread of the virus in the field is generally slow due to the slow movement of the nematode vector.
CRLV is spread only slowly by its nematode vector, and the most likely means of international movement is in infected propagating material. It could possibly be carried by the nematode vector in soil accompanying plants. The virus has been intercepted several times in imported plant material from North America.

Geographical distribution
CRLV is native to western North America: Canada (British Columbia, Ontario, Quebec), USA (California, Colorado, Idaho, Montana, New Mexico, Oregon, Utah, Washington).
Presence in the EPPO region: absent.

Phytosanitary risks
In North America, CRLV causes serious stunting in peaches, and fruit yield and quality reductions in cherries and apples. Young trees and seedling rootstocks are sometimes killed. Because of its slow spread, the disease is mainly a nuisance in nuclear stock propagation. However, it can reach high levels of infection in older orchards. Trees planted on previously infected sites often become infected.
CRLV could be troublesome in nuclear stock propagation, probably throughout the EPPO region. Rootstocks and some scion cultivars may not show obvious symptoms. None were seen on raspberries known to be infected.
CRLV is considered to be an A1 quarantine organism for EPPO. The potential of CRLV in the EPPO region depends on the introduction of its nematode vector *Xiphinema americanum* or on the possibility of its transmission by related nematode species. The A2 listing of *X. americanum* by EPPO is to a large extent based on the virus risk, rather than on any direct risk from the nematode.

(Source: EPPO)

Peach mosaic closterovirus

Hosts

Peach mosaic closterovirus affects only *Prunus* spp.: peach (*Prunus persica*), nectarine (*P. persica* var *nectarina*), almond (*P. dulcis*), apricot (*P. armeniaca*), *P. besseyi*, *P. serrulata* and several species of plum. Cherries are not hosts of the disease. Peaches and nectarines are the main economically affected hosts, as the disease on susceptible cultivars deforms the fruit so that it becomes unsalable. Cultivated European and Japanese plums *(P. domestica* and *P. salicina*) are highly susceptible to the disease but express only the leaf symptoms described for peach. In apricot, some susceptible cultivars (e.g. Blenheim) develop leaf discoloration patterns and distortion and stubby twig symptoms. Trees are less vigorous, produce less fruit and have more sunburned fruit than healthy trees. Almond trees generally show mild foliar and fruit symptoms, with a reduction in yield or nut quality.

Biology and dispersal

Peach mosaic closterovirus is easily graft-transmissible to healthy peach using fruit, leaf, root, or bud tissues and a contact period as short as two days. The vector of the disease is the peach bud mite *Eriophyes insidiosus*. This mite feeds and reproduces on developing leaf primordia within the bud. In areas of the USA where it infests freestone peaches, it is usually limited to adventitious buds on the trunk or on the lower scaffold branches. Infested buds are swollen and reddened, growth remains retarded, and buds may eventually die. A single infectious mite can transmit the disease to a healthy tree. *E. insidiosus* has been found on peach and on several American species of plum in south-western USA. In Mexico, *E. insidiosus* was observed in buds of wild *Prunus munsoniana* in Chihuahua and in buds of criollo peaches (clingstone peaches with various colors of flesh grown in Mexico for hundreds of years) in the central highland areas where peach is grown. On criollo peaches, the mites were seen in unopened buds along small branches distributed throughout the canopy of the trees. Natural transmission is ensured by the mite vector. The main means of movement is in infected propagation material

Geographical distribution

American peach mosaic was first observed in 1931 in Texas (US) and soon after that in Colorado and southern California (limited to areas south of the Tehachapi mountains). The disease was then reported throughout the peach-growing states of Arizona, Arkansas, New Mexico, Oklahoma and Utah. It must be stressed that in the USA, because of the implementation of strict quarantine programmes, the disease is now rare. The disease is considered important in Mexico, where many symptomatic trees are currently being observed. Apparently, there are no records outside North America for peach mosaic closterovirus.

Presence in the EPPO region: absent.

Phytosanitary risks

In the USA, the economic consequences in affected peach orchards have been considerable in the past. However, the disease is currently of very minor importance in USA, but much more important in Mexico. Fruits from affected trees, especially peaches and nectarines, are generally unmarketable. EPPO originally considered peach American mosaic as an A1 quarantine pest. After a period of confusion on the identity of the pathogen it is again now clear that there is a North American probable closterovirus which causes a mite-transmitted mosaic disease of peach, which is unknown in the EPPO region. Although the virus can readily be excluded from commercial plantations using healthy planting material, and the vector *E. insidiosus* is not known to occur in Europe, the introduction of this virus into the EPPO region would create a significant additional constraint for peach production, justifying its retention on the A1 list. Other eriophyid mites existing relatively harmlessly on *Prunus* in Europe could possibly act as alternative vectors.

(Source: EPPO)

Plum American line pattern ilarvirus

Hosts
The main hosts are plums and other *Prunus* spp. such as peaches and *P. serrulata*. Isolates of APLPV have been transmitted mechanically to 85 species in eight families. Furthermore, the purified virus can be transmitted to various other Rosaceae. In practice, for the EPPO region, *Prunus* spp. are the potential hosts.

Biology and dispersal
Certain ilarviruses are known to be transmitted by pollen, but so far no vector has been demonstrated for APLPV. The virus is easily transmissible in tree hosts by bark patch grafting, budding and mechanical means, but is not seed-borne. *Cuscuta campestris* transmitted the virus from *Nicotiana megalosiphon* to *Petunia*, but other trials with different *Cuscuta* spp. and other plants have failed. The virus is unstable in crude sap and has a thermal inactivation point in diluted sap of 66° C for 10 minutes.
The means of natural spread is not exactly known, but if this is limited to transmission by infected pollen grains the risk of natural spread over long distances should be very small. The virus is not seed-borne. International spread is most probable by means of infected planting material.

Geographical distribution
Presence in the EPPO region: absent.

Phytosanitary risks
Although of negligible importance on its own, APLPV appears to act synergistically with other viruses such as prune dwarf ilarvirus. APLPV is considered to be an EPPO A1 quarantine pest, but is not of quarantine significance for any other regional plant protection organisation. The lack of research on this virus during recent years may indicate that its importance has declined. It may be adequately covered by normal virus-free certification.

(Source: EPPO)