Are shelter belts potential inoculum sources for *Neonectria ditissima* apple tree infections?

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Abstract The susceptibility of plants around apple orchards to *Neonectria ditissima* infections in the Tasman region was determined during summer 2013/14. Shelter belt and other neighbouring plants (in the absence of shelter trees) surrounding 20 apple orchards (approximately 51 km shelter length) were identified and compared with known European canker hosts. One-third of all neighbouring plants identified were either species known to be European canker hosts or shared a genus with a known host. Nine non-pomaceous plant species were selected for inoculation studies. Two rasp wounds were created (July 2014) and one was inoculated with *N. ditissima* conidia, the other with mycelium. Symptoms were recorded and the pathogen re-isolated. In February 2015, all symptomless inoculation sites were harvested to determine potential latent infections. *Neonectria ditissima* was reisolated from 38% of inoculations including from symptomless inoculation sites. The fungus could be re-isolated from all species inoculated.

Keywords *Neonectria galligena*, *Nectria galligena*, *Nectria coccinea*, *Cylindrocarpon heteronema*, *Cylindrocarpon mali*, European canker, host.

INTRODUCTION

“The literature on *Nectria* fungi associated with canker of hardwoods in Europe and North America is replete with unavoidably tentative determinations, questionable application of names, inadequate descriptions and many pages of controversial discussion on the specific identity and pathogenicity of forms studied” Lohman & Watson (1943).

The study of *Neonectria ditissima* in association with cankers of pomaceous and hardwood trees needs mention of its highly controversial and varied nomenclature, which has been reviewed by Lohman & Watson (1943), Swinburne (1975) and most recently by Castlebury et al. (2006), to name just a few. Naming was influenced by continent, i.e. Europe versus North

America, and the many hosts. Lohman & Watson (1943) reported that common synonyms used depended on host, year described and country of origin; the names used are *Nectria ditissima* Tul., *Nectria coccinea* Pers. ex Fr. and *Nectria galligena* Bres. The name *Nectria galligena* Bres. had been applied rather consistently to canker of pomaceous hosts until Rossman et al. (1999) further divided the *Nectria* genus into *Nectria* and *Neonectria*. *Nectria* is now restricted to species related to the type species *Nectria cinnabarina* (Tode:Fr.) Fr. with the *Tubercularia* Tode:Fr. anamorphs. The other species have been transferred to *Neonectria* Wollenw. with the *Cylindrocarpon* anamorphs (Castlebury et al. 2006). For the purpose of this manuscript, the teleomorph *Neonectria ditissima* and anamorph *Cylindrocarpon heteronema* are used, as suggested by Castlebury et al. (2006).

European canker caused by the fungus *Neonectria ditissima* is a major disease, producing cankers on twigs and branches, and may cause fruit rot (Zeller 1926; Swinburne 1975). Primary inoculum sources for European canker are infected wood from the same orchard or from surrounding orchards (Swinburne 1975). The fungus produces conidia and ascospores, which spread by aerial rainsplash from tree to tree and rainsplash and runoff within infected trees (Creemers 2014). Apart from the infected wood on trees, cankered prunings left in the tree row and uncovered burn piles can serve as an important source for further infection, producing spores for at least 1–2 years (Swinburne 1975). Besides the sources of inoculum within the orchard, other susceptible species that are grown close to orchards may also act as a source of *Neonectria* inoculum (Flack & Swinburne 1977). The choice of species used to create windbreaks or hedges is therefore important (Creemers 2014). Literature shows European canker has many hosts, and as early as 1889 European canker was observed on beech, oak, hazel, ash, hornbeam, alder, maple, lime, dogwood, wild cherry and apple (Zeller 1926).

From a comparison of known European canker hosts and plants available for purchase in New Zealand, at least 70 species known to be European canker hosts can be found in South Island nurseries. It is therefore likely that some

alternative European canker hosts are present in shelter belts and will be found near orchard trees. The aims of this study were to identify and enumerate currently-used shelterbelt species to provide data on the distribution of known European canker hosts around orchards, and to determine their potential for infection by *N. ditissima* isolates of apple. The longer term goal is to identify their actual risk as alternative hosts based on their susceptibility to infection and sporulation potential in the field.

MATERIALS AND METHODS

Shelter species monitoring

In 2013/14 20 apple growers were randomly selected from Motueka, Upper Moutere and Waimea areas. If the grower had one or two separate orchard areas all perimeters were surveyed. If the grower had more than two separate orchard areas, at least two of these were surveyed. In 2014/15 one large grower property in Motueka with seven independent orchard areas was re-surveyed using all seven blocks and not just two as in 2013/14. Shelter belt and ornamental species adjacent to the apple blocks at the orchard were recorded and quantified by measuring the planted length of row adjacent to the orchard occupied by the plants. Length was estimated by car odometer for larger distances and confirmed using MapMyRun, a program that measures the distance of a route drawn on a map. Single trees were given a length of 1 m. The species found were separated into two groups for analysis: species used as shelter (Shelter) and species found adjacent in the absence of shelter (Neighbouring), which included but was not limited to ornamental species, fruit trees and grass. Shelter and Neighbouring plants were only enumerated if within 10 m of the outer row of apple trees in the block. The likelihood of a species being a European canker host was determined according to literature review for each plant identified. Plants that shared a genus and/or species name with a recorded European canker host were classified as high risk, while other plants were identified as low risk. The following databases have been searched for the host list: CABI (2012); CBS-KNAW

(2014); Cybertruffle (2014); Dingley (1969); Flack & Swinburne (1977) + cited references; Farr & Rossman (2014); Landcare Research (2011, 2013); MPI (2014); MycoPortal (2014); Pennycook (1989); and Systematic Mycology and Microbiology Laboratory Fungus-Host Database (2014). Databases were searched with the following search terms: “European canker”, “*Nectria galligena*” or “*Neonectria ditissima*”.

Inoculation of ten potential host species

From the above field survey, ‘Royal Gala’ trees (Plant & Food Research, Hawke’s Bay) and nine shelter species (Table 1) were selected based on frequency found as a shelter plant. The shelter plants (ten plants each) were purchased from Appeltons Tree Nursery Ltd, Nelson. Upon arrival in June 2014, all plants were potted into PB5 planterbags (Nutrient Film Technique Ltd) using generic potting mix (Bark Processors, Richmond), containing slow release fertiliser. Plants were kept in a shadehouse and watered twice daily with overhead sprinklers for 10 min. In July 2014, plants were inoculated. Plants were small (0.5 to 1 m tall), therefore only two 5–10 mm rasp wounds were created on the main stem, breaking the bark and cambium layers. One rasp wound was inoculated with a mycelial plug (5 mm diameter) from a 3-week-old single conidium isolate Ng47.1 (originally isolated from an apple tree) culture grown on potato dextrose agar (Walter et al. 2014). The mycelium was facing the wound and the plug held in position using Parafilm M® (Bernis Company Inc.). After 14 days the Parafilm M® was removed. The other raspwound was inoculated with a 20 µl droplet of conidial spore suspension (2×10^5 conidia/ml) prepared from field-collected cankers (Amponsah et al. 2014). For the positive controls, to determine that inoculation was successful, ten 1-year-old ‘Royal Gala’ trees were also inoculated. These plants were obtained from Plant & Food Research Hawke’s Bay to ensure they were free of *N. ditissima* infection. Plants were maintained outside on a hardstand, completely randomised, with overhead watering twice daily for 10 min. In December 2014, plants were placed into plastic-lined wooden bins

(2 bins, randomly arranged) with the lining creating an approximately 8 cm high rim allowing the water to pool and thereby creating ‘wet feet’ or waterlogged conditions. This was done to increase plant susceptibility to the pathogen (Swinburne 1975) and potentially accelerate symptom expression.

Plants were regularly assessed for disease symptoms, with a final assessment in February 2015. In December 2014, two plants each of apple, willow, poplar, alder and eucalyptus with visible lesions were selected. One lesion was used for re-isolation and one to induce sporulation in the laboratory in humidity chambers at ambient temperature. At the last assessment, all rasp wounds, with and without symptoms, were harvested for re-isolation. Lesions were surface sterilised for 30 s in ethanol, followed by 1 min in 1% sodium hypochlorite followed by 30 s in 70% ethanol and a rinse under running tap water. Each rasp wound was then cut aseptically into smaller segments (approximately 3–5 mm thick) and three pieces (one from each lesion edge, one from the lesion centre) plated onto water agar containing apple sap (ASAWA medium, Amponsah et al. 2014). For the December isolations, for both the symptomatic and asymptomatic inoculation sites, additional segments up to 44 mm away from the lesion edge were also plated out. The 3–5 mm segments cut were plated sequentially with the cut edge closest to the lesion facing the agar. Plates were incubated on the laboratory bench at 18°C for 2 weeks. Presence or absence of *N. ditissima* was scored based on sporodochia and conidia morphology.

RESULTS

Shelter species monitoring

The literature search resulted in 122 species identified as *Neonectria ditissima* hosts (Appendix 1). Table 1 provides an overview of the grower survey in 2013/14 of Shelter and Neighbouring plant species found surrounding apple orchards representing the Tasman region in New Zealand. The grower property completely re-surveyed in 2014/15 gave similar results and is therefore not presented separately. Most commonly, there were no shelter trees adjacent to

apple blocks, but these were surrounded by road and grass paddocks (approximately 16,700 m). The most common shelter belt species observed were Italian alder (*Alnus cordata*), Leyland cypress (*Cupressus x leylandii*) and Matsudana willow (*Salix matsudana*). Adjacent apple (*Malus* spp.) trees of other growers not separated by a shelter belt (Neighbouring plants) accounted for approximately 10% of total orchard perimeter. Large amounts of pear (*Pyrus* spp.), grape (*Vitis vinifera*), blackcurrant (*Ribes nigrans*) and kiwifruit (*Actinidia* spp.) were found around some orchards while pittosporum (*Pittosporum* spp.) was found at most orchards. Low risk non shelter species, including grass, accounted for 51% of the planted length adjacent to apple orchards.

In summary, one-third of all plants identified were either a species known to be a European canker host or belong to a genus with a known host. Some plants found were not identified beyond genus, because of difficulty identifying uncommon species and differentiating between crosses and clones. Matsudana willow was listed as the species of willow found in shelter belts as appearance, grower records and nursery records indicated it was the most common species of willow planted. However, it may not have been the only willow species found in the shelterbelts observed.

The shelterbelt survey showed that neighbouring apple orchards not separated by shelter were the most frequently recorded group of known European canker hosts and would potentially provide the largest non-shelter

(Neighbouring plant) source of inoculum. Pomeaceous plants are well known for their susceptibility to *N. ditissima* infections (Flack & Swinburne 1977) and this was also reflected in the potted plant assay. The known host black alder (*Alnus glutinosa*) was found at some orchards as a shelter tree, but the Italian alder species occurred more frequently than the black alder. Italian alder was present at the majority of orchards visited, but the susceptibility of Italian alder to European canker has not been previously reported. Based on the potted plant assay Italian alder was classified as high risk. Species of *Populus* are often found as shelterbelts in the Tasman district and are also classified as high risk due to other species and clones within the genus being known hosts. To summarise these data, plants were placed into one of five categories and the percentage of plants found (based on estimated distance) in each category calculated (Figure 1). The categories were “Low Risk Neighbouring” plants, which were predominantly grass; “Low Risk Shelter”, which were predominantly Leyland cypress; “High Risk Apple”, representing neighbouring apple orchards; “High Risk Neighbouring”, which were predominantly pear; and “High Risk Shelter”, which were predominantly alder and willow. High risk was attributed if the literature reports showed a host entry at genus level as listed in Table 1.

Inoculation of ten potential host species

By December 2014, following July inoculation, all inoculated apple rasp wounds expressed

Figure 1 Relative abundance of potential hosts of *Neonectria ditissima* surrounding Tasman apple orchards as surveyed in 2013/14. Plants were placed into one of five categories and the percentage of plants found (based on estimated distance) in each category calculated. High risk was attributed if the literature reports showed a host entry at genus level as listed in Table 1.

Table 1 Shelter and neighbouring plants found around apple orchard blocks for 20 growers, with two or more orchard blocks surveyed for each grower during 2013/14 and 2014/15.

Shelter or neighbouring plant	Common name	Total distance (m)	No. orchard blocks found	Ref. ⁴
Grass species	Grass	16767	25	
<i>Alnus cordata</i>	Italian alder ^{2,3}	7654	18	1
<i>Malus</i> (other grower)	Apple ³	5154	13	
<i>Cupressus x leylandii</i>	Leyland cypress ³	3560	10	
<i>Salix matsudana</i>	Willow ^{2,3}	3164	16	1, 2
<i>Actinidia deliciosa</i>	Kiwifruit	1815	8	
<i>Pyrus</i>	Pear ²	1545	5	1
<i>Vitis</i>	Grape	1070	3	
<i>Pittosporum tenuifolium</i>	Black matipo, kohuhu ³	1024	10	
Non-woody shelter, e.g. flax	Flax	741	2	
<i>Pittosporum eugenoides</i>	Lemonwood ³	689	11	
<i>Allocasuarina</i>	Sheoak	578	6	
Artificial shelter		555	3	
<i>Alnus glutinosa</i>	Alder ^{1,2,3}	487	1	1
<i>Eucalyptus nitens</i>	Eucalyptus ³	468	8	
<i>Populus</i> 'Crow's nest'	Crow's nest poplar ^{2,3}	420	3	1, 2
<i>Alnus</i> sp	Alder ²	430	2	
Unknowns (5 species)		413	5	
<i>Rubus fruticosus</i>	Blackberry	405	2	
<i>Populus</i> pointed	Poplar 636 ²	365	1	
<i>Thuja occidentalis</i> 'Pyramidalis'	Decorative conifer	320	1	
<i>Dodonaea viscosa</i>	Ake ake	275	6	
<i>Cypress japonica</i>	Japanese cypress	270	1	
<i>Cytisus proliferus</i>	Tree lucerne	259	2	
<i>Populus deltoides</i>	Eastern cottonwood	160	2	
	poplar ²			
<i>Populus nigra</i>	Lombardy poplar ²	160	2	
<i>Ulex europaeus</i>	Gorse	160	4	
<i>Cordyline australis</i>	Cabbage tree	137	4	
<i>Leptospermum scoparium</i>	Manuka	134	2	
<i>Humulus lupulus</i>	Hop	130	1	
<i>Coprosma repens</i>	New Zealand laurel	125	1	
<i>Rubus</i> sp.	Raspberry	120	1	
<i>Cupressus</i> sp.		110	2	
<i>Ligustrum</i> sp.	Privet	110	1	
<i>Pinus radiata</i>	Pine	108	3	
<i>Photinia x fraseri</i>	Large photinia	103	3	
<i>Cydonia oblonga</i>	Quince	100	1	
<i>Wisteria floribunda</i>	Japanese wisteria	87	1	
<i>Prunus armeniaca</i>	Plum	82	3	
<i>Amlanchier arborea</i>	Service berry	80	1	
<i>Juniperus virginia</i>	Large juniper	66	2	

Shelter or neighbouring plant	Common name	Total distance (m)	No. orchard blocks found	Ref. ⁴
<i>Podocarpus totara</i>	Totara	56	2	
<i>Pherbalium squamean</i>	Satinwood	55	1	
<i>Picea</i> sp.	Spruce ²	50	1	1
<i>Acacia acinacea</i>	Wattle ²	36	1	1
<i>Cytisus scoparius</i>	Broom	30	3	
<i>Acca sellowiana</i>	Feijoa	27	4	
<i>Nothofagus mensiesii</i>	Silver beech	26	3	
<i>Picea pungens glauca</i>	Blue Spruce ²	20	1	1
<i>Quercus</i>	Oak ²	16	5	1, 2
<i>Pyrus aristocrat</i>	Ornamental pear ²	15	1	1
<i>Corylus avellana</i>	Hazelnut ^{1,2}	12	2	1, 2
<i>Acacia</i> sp.	Wattle 941	10	1	1
<i>Acer x freemanii</i>	Maple hybrid ²	10	1	1, 2
<i>Camellia</i> sp.	Camellia	15	2	
<i>Citrus x paradisi</i>	Grapefruit	10	1	
<i>Sophora microphylla</i>	Kowhai ^{1,2,3}	9	5	3
<i>Bambusa</i> sp.	Bamboo	5	1	
<i>Populus</i> sp.	Poplar ²	5	1	1, 2
<i>Pseudopanax crassifolius</i>	Lancewood	5	1	
Rosaceae: <i>Rosa</i>	Rose ²	4	1	2
<i>Prunus</i> sp.	Red leaf plum	4	1	
<i>Acacia pycnantha</i>	Golden	3	1	
<i>Magnolia grandiflora</i>	Magnolia	3	3	
<i>Ginkgo biloba</i>	Ginkgo	2	2	
<i>Acacia</i> sp.	Wattle	2	2	
<i>Acer circinatum</i>	Vine maple ^{1,2}	1	1	1, 2
<i>Aesculus hippocastanum</i>	Horse Chestnut ^{1,2}	1	1	1, 2
<i>Bambusa</i>	Bamboo	1	1	
<i>Betula pendula</i>	Silver birch ^{1,2}	1	1	1, 2
<i>Callistemon citrinus</i>	Bottlebrush	1	1	
<i>Citrus limon</i>	Lemon	1	1	
<i>Cryptomeria japonica</i>	Japanise cedar	1	1	
<i>Dacrydium cupressinum</i>	Rimu	1	1	
<i>Euonymus europaeus</i>	Spindle	1	1	
<i>Juglans regia</i>	Walnut ^{1,2}	1	1	1
<i>Leptospermum amboinense</i>		1	1	
<i>Melicytus ramiflorus</i>	Mahoe/whiteywood	1	1	
<i>Nothofagus fusca</i>	Red beech	1	1	
<i>Nuytsia floribunda</i>		1	1	
<i>Prunus prunus</i>	Plums, apricots ²	1	1	1, 2
<i>Salvia relfexa</i>	Sage	1	1	

¹Species is a known canker host.²Genus is a known canker host.³Selected for potted plant assay.⁴References used: 1=Farr & Rossman (2014); 2=Flack & Swinburne (1977); 3=Landcare Research (2011).

lesions. For the shelter trees only, some of those inoculated with mycelium formed lesions on the willow, poplar, Italian alder and eucalyptus trees. By February 2015, two lesions also formed in the conidial inoculations, one on Italian alder and one on eucalyptus (Table 2). Re-isolations were not always successful where lesions formed, but *N. ditissima* could be isolated from symptomless inoculation sites (Table 2).

The preliminary December 2014 re-isolations from symptomless and symptomatic tissues (up to 44 mm around the inoculation site) showed different degrees of colonisation among the four host plants tested. For the willow plant, *N. ditissima* was re-isolated 44 mm from the inoculation sites with symptomatic (mycelial inoculation) and asymptomatic (conidial inoculation) infection. For the poplar plant, *N. ditissima* was re-isolated 44 mm from the

inoculation site with symptomatic infection (mycelial inoculation) and 28–32 mm from the asymptomatic conidial inoculation site. For the *Eucalyptus nitans* plant, *N. ditissima* was re-isolated 44 mm from the inoculation site with symptomatic infection (mycelial inoculation) and not at all from the asymptomatic conidial inoculation site. For the Italian alder plant, *N. ditissima* was re-isolated 8–12 mm from the inoculation site with symptomatic infection (mycelial inoculation) and not at all from the asymptomatic conidial inoculation site.

The small subsample of visible lesions collected in December 2014 from apple, willow, poplar, alder and eucalyptus were incubated under high humidity for 3 days to encourage sporodochia formation. These were readily produced in apple and willow, to a lesser degree in poplar and alder but not eucalyptus.

Table 2 European canker symptom development and re-isolation of *Neonectria ditissima* from shelter trees (10 plants each) artificially inoculated with mycelium and conidia in July 2014. Re-isolations were done in February 2015.

Plants used in the bioassay	Number of positive <i>N. ditissima</i> reisolations and number of visible lesions in parenthesis		% lesions formed and positive reisolations of <i>N. ditissima</i> from both conidial and mycelial inoculations	
	Conidia	Mycelium	% visible symptoms	% reisolated
<i>Alnus cordata</i> (Italian alder)	3 (1)	5 (8)	45	45
<i>Alnus glutinosa</i> (black alder)	0 (0)	2 (1)	5	10
<i>Cupressus × leylandii</i> (Leyland cypress)	3 (0)	3 (0)	0	30
<i>Eucalyptus nitans</i>	2 (1)	6 (6)	35	40
<i>Malus × domestica</i> (apple ‘Royal Gala’)	10 (10)	10 (10)	100	100
<i>Pittosporum euginoides</i> (lemonwood)	4 (0)	7 (2)	10	55
<i>Pittosporum tenuifolium</i> (black matipo)	5 (0)	5 (3)	15	50
<i>Populus deltoides</i> × <i>P. nigra</i> × <i>P. nigra</i> (poplar ‘Crows Nest’)	3 (0)	5 (9)	45	40
<i>Salix matsudana</i> (Matsudana willow)	2 (0)	7 (10)	50	45
<i>Sophora microphylla</i> (kowhai)	5 (0)	1 (0)	0	30
Grand total (excluding apple)	27 (2)	41 (39)	23	38

DISCUSSION

The literature search avoided many of the synonyms and anamorph names for the causal organism of European canker. Also, more databanks could have been included, and therefore the search results in Appendix 1 should not be considered a complete list of hosts and country reported. Nonetheless, the list shows many potential hosts including some New Zealand natives such as South Island kowhai, *Coprosma lucida* and *Coprosma areolata*. To our knowledge, a detailed survey on New Zealand native plants has not been conducted. A survey coupled with artificial inoculation of native plantings around apple orchards might see an increase in potential New Zealand native plants being *N. ditissima* hosts. The potted plant assay also indicated that the native host range most likely is larger than reported to date. For example, both species of *Pittosporum* developed symptoms and symptomless infections within 8 months of inoculation, albeit under disease conducive conditions caused by the twice daily overhead irrigation and 'wet feet' in the later month of incubation.

Cross inoculation studies by Flack & Swinburne (1977) with the then named *Nectria galligena* isolated from various hosts surrounding apple orchards showed that the *N. galligena* isolates of ash, hawthorn, poplar, beech and apple could generally cross-infect among these hosts. However, the ash isolate only infected ash and hawthorn. Other studies, as reviewed by Flack & Swinburne (1977), have given similar results with some isolates having a wider host range than others.

Mycelial plug inoculation is a very harsh test and this type of infection would not occur in nature. In the present study both mycelia and conidia were used. Mycelium was included because previous host range studies (Flack & Swinburne 1977) also used mycelial inoculations for *in situ* and/or potted assays. They found that conidia could not establish leaf scar infections in yellow birch and sugar maple using isolates from the hosts. Wounding was found to be important for *N. ditissima* spore infections in non-apple hosts (Lortie 1962, cited in Dubin & English 1974). Pruning wounds are common in shelter trees, providing suitable sites for infection. It is

noteworthy that few authors (Flack & Swinburne 1977) included apple as a host in their cross-infection studies. Generally, assessments in the non-pomaceous hardwood species were for up to 3 years after inoculation. In apple, inoculation and disease expression happens generally within months but infections can remain latent for several years (McCracken et al. 2003). Lesion phenotypes also vary among hosts and potentially the isolates used (Richter 1928; Flack & Swinburne 1977). The long incubation period required for non-pomaceous hosts is an indication that these plants are less susceptible to infection than pipfruit.

The pathogen was reisolated from all species inoculated. The ability to re-isolate from inoculation sites without symptoms suggests that either the pathogen colonised the plant without lesion development or isolation was attempted before the incubation period was complete. Longer incubation and observation periods and *in situ* studies will be required to determine the actual risk of lesion development and spore production on non-apple hosts. Sporodochia formation and spore production in apple, willow, poplar and alder (but not eucalyptus) was observed. These conidia were harvested and rasp wounds of mature 'Braeburn' trees inoculated at the Plant & Food Research orchard, Riwaka. All formed lesions by March 2015 (data not shown). This is an indication that isolates from apple can infect wounds on non-apple host plants, which in turn can produce conidia able to infect apple wounds. Other ongoing work is the inoculation of shelter trees *in situ* (February 2015) using both mycelial plugs and conidia. Trees will be observed for 2–3 years.

Flack & Swinburne (1977) noted that apple trees growing close to a hawthorn hedge had more lesions than those in rows further away. They also concluded that the high susceptibility of poplars renders the genus unsuitable for use as windbreak and recommended the use of grey alder instead. In the present studies, alder was also susceptible to *N. ditissima* infections, with Italian alder more susceptible to infection than black alder (Table 2). This study has identified the potential for infection of New Zealand shelter plant by *N. ditissima*, but their actual risk as an

inoculum source to apple tree infections still needs to be determined. Based on published research, there is a risk that should be considered when planting shelter trees. Hawthorn control around apple and pear orchards is commonly practised as hawthorn also can be a host for fire blight. The wide host range of *N. ditissima* and the potential risk as inoculum source also suggests that shelter management including a fungicide spray programme should be considered, particularly for new plantings and low disease pressure orchards. Once *N. ditissima* is established within an orchard block the disease pressure from within will drive the ongoing epidemic based on the high susceptibility of pipfruit in comparison with other hosts (Table 2). The present work is in agreement with previous research that *N. ditissima* from apple can infect other hosts, including New Zealand native plants. Earlier research (Flack & Swinburne 1977) and these investigations have shown that the reverse is just as likely. The actual contribution of inoculum from shelter trees to *N. ditissima* epidemics in apple orchards potentially is low, but one sporulating lesion will be sufficient to start an epidemic and to re-infect apple orchards.

ACKNOWLEDGEMENTS

We thank the growers, who freely provided access to properties, information and support. Thanks to Plant & Food Research staff and local nurseries for assistance in plant identification. The study was supported by funding from (1) Pipfruit New Zealand Inc. and the Ministry for Primary Industries via Sustainable Farming Fund project SFF 13-040; (2) AGMARDT; (3) Plant & Food Research and (4) Kono Horticulture Ltd. The work was carried out by the summer students Kamla Glaister and Hildegard von Lutz (2013/14) and Nikki Clarke and Zoe Eld (2014/15).

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Appendix 1 *Neonectria ditissima* host list based on a literature search in July 2014.

Name	Common name	Location recorded	Reference ¹
<i>Acacia</i> sp.	Wattle	USA	1
<i>Acer</i> sp.	Maple	Canada, England, Japan, USA	1, 2
<i>Acer circinatum</i>	Vine maple	USA	1, 2
<i>Acer macrophyllum</i>	Oregon maple	USA	1, 2
<i>Acer mono</i> subsp.	Painted maple	Japan	1
<i>Heterophyllum</i>			
<i>Acer negundo</i>	Box elder	Ukraine	3
<i>Acer palmatum</i>	Coral bark maple	USA, Japan	1
<i>Acer pennsylvanicum</i>	Moose bark or striped maple		2
<i>Acer pseudoplatanus</i>	Sycamore	Denmark, Canada, Germany	1
<i>Acer rubrum</i>	Red maple	Canada, USA	1, 2
<i>Acer saccharum</i>	Sugar maple	Canada, USA	1, 2
<i>Acer spicatum</i>	Mountain maple		2
<i>Aesculus</i> sp.	Horse chestnut	England	1, 2
<i>Aesculus hippocastanum</i>	Horse chestnut	Denmark	1
<i>Aesculus turbinata</i>	Japanese horse chestnut	Japan	1
<i>Albizia lebbbeck</i>	Indian Siris	Madagascar	1
<i>Aphidoidea</i>	Aphid	NZ	4
<i>Alnus</i> sp.	Alder	Norway, German	1
<i>Alnus glutinosa</i>	Black alder	Denmark	1
<i>Alnus incana</i>	Grey alder	USA	1, 2
<i>Alnus japonica</i>	Japanese alder	Japan	1
<i>Alnus rubra</i>	Red alder	USA, Canada	1
<i>Amelanchier laevis</i>	Allegheny serviceberry	USA	1
<i>Avena sativa</i>	Oat	Poland	1
<i>Betula</i> sp.	Birch	China, Czech, USA, Germany, England, Norway	1, 2
<i>Betula lenta</i>	Cherry or sweet birch	USA	1, 2
<i>Betula lutea</i> (synonym: <i>alleghaniensis</i>)	Yellow birch	Canada	1, 2
<i>Betula maximowicziana</i>	Monarch Birch	Japan	1
<i>Betula nigra</i>	River or black birch	USA	1, 2
<i>Betula papyrifera</i>	Paper-bark or canoe birch	Canada, USA	1, 2
<i>Betula pendula</i> (syn. <i>verrucosa</i>)	Silver birch	Norway	1, 2
<i>Betula populifolia</i>	Grey birch	USA	1, 2
<i>Betula pubescens</i>	Downy birch	Norway	1
<i>Camellia sinensis</i>	Tea plant	Japan	1
<i>Carpinus</i> sp.	Hornbeam	Czech	1
<i>Carpinus betulus</i>	Hornbeam	Belgium, Denmark, Japan	1, 2
<i>Carya</i> spp	Hickory	USA	1, 2
<i>Carya cordiformis</i>	Bitternut	USA	1, 2
<i>Carya glabra</i>	Pignut	USA	1, 2
<i>Carya ovata</i>	Shagbark hickory		2
<i>Carya tomentosa</i>	Mockernut or Big-bud	USA	1, 2
<i>Carya illinoensis</i>	Pecan	Mexico	1, 2
<i>Castanea dentata</i>	American chestnut	Canada	1

Name	Common name	Location recorded	Reference ¹
<i>Cercis canadensis</i>	East American redbud	USA	1
<i>Citrus sinensis</i>	Orange	Mexico	1
<i>Coprosma</i>		NZ	4
<i>Coprosma areolata</i>		NZ	4
<i>Coprosma lucida</i>	Shining karamu	NZ	4
<i>Cornus</i> sp.		USA	1
<i>Cornus nuttallii</i>	Nuttall's dogwood	USA	1, 2
<i>Corylus avellana</i>	Common hazel	Denmark, Italy, Sicily, Poland	1, 2
<i>Corylus heterophylla</i> var. <i>thunbergii</i>	Asian hazel	Japan	1
<i>Corylus sieboldiana</i>	Japanese hazel	Japan	1
<i>Craetagus</i> sp.	Thornapple	USA	1
<i>Crataegus monogyna</i>	Hawthorn		2
<i>Crataegus oxyacanthoides</i> (syn. <i>oxyacantha</i>)	Midland hawthorn	Germany	1, 2
<i>Eriobotrya japonica</i>	Loquat	NZ	4
<i>Fagus americana</i>	Americana	Canada	1
<i>Fagus crenata</i>	Japanese beech	Japan	1
<i>Fagus grandifolia</i> (syn. <i>americana</i>)	American beech	Canada, USA	1, 2
<i>Fagus</i> sp.	Beech	England, Ukraine, Denmark, Germany	1
<i>Fagus orientalis</i>	Oriental beech	Ukraine	1
<i>Fagus sylvatica</i>	Common beech	NZ, Czech, Belgium, Denmark, England, German, Hungary, Ireland, Japan, Poland, Sweden, Ukraine, France, Slovakia	1, 4, 6
<i>Fagus sylvatica</i> f. <i>purpurea</i>	Copper beech		2
<i>Frangula alnus</i>	Alder buckthorn		5
<i>Fraxinus</i> sp.	Ash	UK, Austria, Norway	1, 4
<i>Fraxinus bungeana</i>	Bunge Flowering Ash	Japan	1
<i>Fraxinus excelsior</i>	Common ash	UK, Denmark, Netherlands, Sweden, Poland	1, 2, 4
<i>Fraxinus mandshurica</i>	Manchurian Ash	China	1
<i>Fraxinus mandshurica</i> var. <i>japonica</i>	Japanese Ash	Japan	1
<i>Fraxinus nigra</i> (syn. <i>sambucifolia</i>)	Black ash	USA	1, 2
<i>Ilex aquifolium</i>	Common holly	USA, Scotland	1
<i>Juglans</i> sp.	Walnut	Norway, USA	1
<i>Juglans cinerea</i>	Butternut or white walnut	USA, Canada	1, 2
<i>Juglans nigra</i>	Black walnut	USA	1, 2
<i>Juglans regia</i>	Common walnut	USA	1
<i>Laburnum anagyroides</i>	Golden chain tree	Denmark	1
<i>Liriodendron tulipifera</i>	Tulip-tree	USA	1, 2, 6
<i>Malus</i> sp.	Apple	England	1

Name	Common name	Location recorded	Reference ¹
<i>Malus communis</i>	Apple	Portugal, Spain	1
<i>Malus sylvestris</i>	Crab apple	NZ, USA, Greece, India, Scotland, South Africa, Sweden, Canada	1, 4
<i>Malus pumila</i>	Paradise apple	NZ, Chile, Canada, USA	1, 4
<i>Malus ×domestica</i>	Apple	NZ, Poland, Australia, Bulgaria, Canada, Ukraine, UK, Ireland	1, 6, 7, 8
<i>Malus ×domestica</i>	Apple 'Aurora', 'Royal Gala', 'Braeburn', 'Granny Smith'	NZ	6
<i>Malus pumila</i> var. <i>domestica</i>	Apple	Japan	1
<i>Nyssa sylvatica</i>	Tupelo or black gum	USA	1, 2
<i>Persea gratissima</i>	Avocado	Malay Peninsula	1
<i>Picea abies</i>	European spruce	Norway	1
<i>Platanus orientalis</i>	Oriental plane	Denmark	1
<i>Populus</i> spp.	Poplar	Ireland, South Africa, canada, Japan, USA	1, 2
<i>Populus alba</i>	Silver polar	Denmark	1
<i>Populus x canadensis</i>	Black poplar	Belgium, Italy, Germany, Netherlands	1
<i>Populus balsamifera</i>	Balsam poplar	Denmark	1
<i>Populus grandidentata</i>	Big tooth aspen	Canada, USA	1, 2
<i>Populus tremula</i>	European aspen	Czech	1
<i>Populus tremuloides</i>	Quaking aspen	Canada	1, 2
<i>Populus wislizeni</i>	Rio Grande Cottonwood	South Africa	1
<i>Prunus</i> spp.	Cherry	Japan	1, 2
<i>Prunus avium</i>	Mazzard cherry	Japan	1
<i>Prunus serotina</i>	Black cherry		2
<i>Prunus salicina</i>	Chinese plum	NZ	9
<i>Prunus ssiori</i>	Japanese Bird Cherry	Japan	1
<i>Prunus subhirtella</i> var. <i>pendula</i>	Weeping cherry	Japan	1
<i>Prunus virginiana</i>	Bitter cherry	Canada	1
<i>Pyrus malus</i>	Pear	Chile, South Africa, Germany	1
<i>Pyrus pyrifolia</i>	Nashi pear	NZ	4, 8
<i>Pyrus pyrifolia</i> var. <i>culta</i>	Nashi pear	Taiwan	1
<i>Pyrus communis</i>	Common pear	NZ, USA, Canada, Chile, Sicily, Mexico, Scotland, South Africa	1, 2, 4, 7, 8
<i>Quercus</i> sp	Oak	China, Czech	1, 2
<i>Quercus alba</i>	American white oak	USA	1, 2
<i>Quercus bicolor</i>	Swamp white oak	USA	1, 2
<i>Quercus borealis</i> (syn. <i>rubra</i>)	Red oak	USA	1, 2
<i>Quercus coccinea</i>	Scarlet oak	USA	1, 2
<i>Quercus garryana</i>	Oregon white oak	USA	1, 2
<i>Quercus glandulifera</i>	Korean Oak	Japan	1
<i>Quercus laurifolia</i>	Laurel oak	USA	1
<i>Quercus mongolica</i> var. <i>grosseserrata</i>	Mongolian Oak	Japan	1
<i>Quercus montana</i>	Chestnut oak	USA	1

Name	Common name	Location recorded	Reference ¹
<i>Quercus robur</i>	English oak	Denmark, Switzerland, Ukraine	1
<i>Quercus rubra</i>	Northern red oak	France	1
<i>Quercus velutina</i>	Black oak		5
<i>Rhus typhina</i>	Staghorn sumac	USA	1, 2
<i>Ribes</i> sp.	Currants	USA	1
<i>Robinia pseudoacacia</i>	Black locust	Japan	1
<i>Rosa</i> sp.	Rose		2
<i>Salix</i> spp	Willow	Canada, USA, Denmark, England, Germany, Japan, Netherlands, Austria	1, 2
<i>Salix alba</i>	White willow	Denmark, Netherlands	1, 2
<i>Salix alba</i> var. <i>vitellina</i>	Golden willow	Denmark	1
<i>Salix alba</i> L. <i>Coerulea</i>	Cricket-bat willow		2
<i>Salix amygdaloides</i>	Peach leaf willow		2
<i>Salix amygdalina</i>	Almond willow	Netherlands	1
<i>Salix cinerea</i>	Grey willow	Belgium	1
<i>Salix nigricans</i>	Black willow	Germany	1
<i>Salix purpurea</i>	Basket willow	England, Japan	1
<i>Sophora microphylla</i>	South Island kowhai	NZ	4
<i>Sorbus</i> sp		Canada	1
<i>Sorbus aria</i>	Whitebeam	Germany	1
<i>Sorbus aucuparia</i>	Rowan or mountain ash		2
<i>Sorbus domestica</i>	True service tree	Poland, Japan	1
<i>Swietenia mahagoni</i>	West Indies Mahogany	USA	1
<i>Tilia</i> sp.	Lime	Czech, Netherlands	1
<i>Tilia americana</i>	American lime or basswood	Canada, USA	1, 2
<i>Tilia cordata</i>	Small-leaved lime	Denmark	1
<i>Ulmus</i> sp.	Elm	Poland, Japan	1
<i>Ulmus americana</i>	American white elm	Canada, USA	1, 2
<i>Ulmus glabra</i> (syn. <i>montana</i>)	Wych elm	Denmark	1, 2
<i>Umbellularia californica</i>	Pepperwood	USA	1
<i>Viola</i> sp.	Violet	USA	1

¹References: 1 = Farr & Rossman (2014); 2 = Flack & Swinburne (1977); 3 = Systematic Mycology and Microbiology Laboratory Fungus-Host Database (2014); 4 = Landcare Research (2011); 5 = CABI (2012); 6 = Landcare Research (2013); 7 = Dingley (1969); 8 = Pennycook (1989); 9 = MPI (2014).