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BS1847: Spotted lanternfly, *Lycorma delicatula* (White 1845) review: biology, ecology and pest management with reference to kiwifruit

Mauchline N, McKenna C

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Report approved by:

Nicola Mauchline
Scientist/Researcher, Applied Entomology
March 2019

Libby Burgess
Science Group Leader, Applied Entomology – Bioprotection
March 2019

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EXECUTIVE SUMMARY

BS1847: Spotted lanternfly, *Lycorma delicatula* (White 1845) review: biology, ecology and pest management with reference to kiwifruit

Mauchline N, McKenna C
Plant & Food Research Te Puke

March 2019

Spotted lanternfly (SLF), *Lycorma delicatula* (White 1845), is native to China with a distribution throughout Asia and several Pennsylvanian counties (United States of America). This invasive planthopper has become a significant economic threat to horticultural crops, hardwoods, ornamentals and natural ecosystems due to feeding damage caused by this insect (oozing wounds, sooty mould growth, wilting, whole or part plant death). This is exacerbated by its broad host plant range, indiscriminate egg laying behaviour and its ability to repopulate areas soon after insecticides have been applied.

SLF develops through six life stages: egg, four nymphal stages and an adult stage. In China, Korea and Pennsylvania SLF adults lay eggs from late autumn through to winter, the eggs overwinter and nymphs hatch from late winter into early spring. Adults first appear in autumn, and begin to disperse and mate. The adults are active until winter. It is uncertain whether SLF has more than one generation each year in areas where the climate is warmer, particularly throughout winter. SLF is known to aggregate in the nymph and adult stages.

SLF can complete its life cycle on *Ailanthus altissima* (common name tree-of-heaven), greatly preferring it over other plant species. Evidence suggests early instar nymphs are polyphagous, but fourth instar nymphs and adults have a strong preference (or requirement) for one or few plant species, particularly *A. altissima. Ailanthus altissima* is present in New Zealand, distributed from Auckland to Dunedin, and is classified as an unwanted organism. Cytotoxins sequestered from host plants, such as *A. altissima,* and the sugar content of a host plant play a role in host selection. It is believed the insect uses defensive chemicals, including sequestered cytotoxins, among other strategies to protect itself from natural enemies.

SLF management

Aspects of SLF biology and ecology make this a difficult pest to manage. Visual surveys are used to identify and monitor the presence of SLF, and host trees banded to trap and eliminate SLF nymphal populations. The insect is susceptible to a range of broad-spectrum insecticides including pyrethroids, carbamates, organophosphate and neonicotinoids. Though many insecticides appear to be effective, delivering the insecticide to the pest in a cropping environment is difficult. Recommendations to overcome this include using a combination of systemic and contact insecticides, applied as tree injections or bark sprays, and foliar and soil drench applications.

A variety of cultural methods exist that are deemed crucial in managing populations of SLF including winter pruning of host plants to remove egg masses, the use of trap trees with a subsequent insecticide application, egg mass scraping, and the prevention of SLF movement through the destruction or disinfecting of any material found to be harbouring this insect.

Natural enemies of SLF in its native China include a solitary egg parasitoid, *Anastatus orientalis*, and two ecto-parasitoids, *Dryinus browni* and *D. lycormae.* In North America, an egg parasitoid, *Ooencyrtus kuvanae* and generalist predators have been recorded as natural enemies of SLF. It is unclear to what extent natural enemies can impact populations of SLF.

Damage to kiwifruit

Kiwifruit is reported as a host of SLF and in many Chinese provinces SLF is regarded a pest of kiwifruit. In Korea damage from nymphal feeding has been reported on *Actinidia chinensis* where SLF have been observed feeding on the leaves, canes and trunks of kiwifruit vines, resulting in the growth of sooty mould. Nymphs cluster on the underside of kiwifruit leaves and canes where they cause damage. This is believed to result in the deformation of the vine. Adults lay eggs on the canes, trunk, fruit, and on the support structures such as wooden beams.

Management of SLF on kiwifruit in New Zealand

SLF has the potential to stifle the kiwifruit supply chain and severely impact the industry's ability to export due to the accumulation of sooty mould on fruit and/or the presence of egg masses on the fruit surface. SLF would most certainly result in significant market access restrictions due to the current global distribution.

SLF will require a high degree of control to meet the requirements of Zespri's kiwifruit export markets. The management of SLF will require a combination of Zespri® Crop Protection Programme (CPP) permitted insecticides, cultural methods including host plant removal, new technologies such as lure and kill, and biological control, with monitoring playing a crucial role.

Of the active ingredients identified as efficacious against SLF, most are not permitted within the CPP because of EU reductions in maximum residue limits (MRLs). The use of unpermitted active ingredients would impede the kiwifruit industry's access to export markets and social licence to operate, as well as disrupt the current IPM programme. Of the insecticides tested offshore, bifenthrin, thiacloprid, pyrethrum and spinosad could be applied against SLF as these are currently permitted within the CPP at certain periods in the cropping cycle. However of these products, only bifenthrin has shown good activity against SLF. As such, cultural controls (e.g. host plant and egg mass removal, banding, use of trap trees and nets) will be important for managing SLF.

Some control methods would be relatively easy to adopt in a short period of time (less than three years), including surveying, tree banding, the use of insecticides currently permitted in the CPP, winter clean-up, egg mass removal, host plant removal, and the use of trap trees. Other methods will take longer to implement because of current knowledge gaps and the lack of available technologies. The most significant gaps include the absence of efficacious and safe insecticides for use against SLF, a lack of knowledge on SLF biology that could be used to develop lure and kill technologies, and a lack of biocontrol agents. It is likely that successful management of SLF will only be achieved when these are knowledge gaps have been addressed.

For further information please contact:

Nicola Mauchline
Plant and Food Research Te Puke,
412 No. 1 Road, RD2, Te Puke 3182, NEW ZEALAND
Tel: +64 7 928 9800, DDI: +64 928 9812, Fax: +64 7 928 9801
Email: nicola.mauchline@plantandfood.co.nz

1 BIOLOGY AND ECOLOGY

1.1 Classification and nomenclature

Lycorma delicatula (White 1845)

Class:	Insecta
Order:	Hemiptera
Suborder:	Auchenorrhyncha
Family:	Fulgoridae
Genus:	*Lycorma*
Species:	*delicatula*
Subspecies:	*jole* (Stål 1863) and *operosa* (Walker 1858) (Bourgoin 2018).

Other scientific names

Aphaena delicatula (White 1845), *Lycorma delicatulum* (White 1845). *L. delicatulum was* deemed incorrect spelling of *L. delicatula* (Bourgoin 2018).

Common names

English:	spotted lanternfly (Barringer 2014), Chinese blistering cicada (Dara 2014), spot clothing wax cicada (Han et al. 2008; Lee et al. 2011), red-winged flower cicada (Park et al. 2009)
French:	fulgore tacheté
Chinese:	chu-ki, hong-liang-zi, hua-gu-liang, ban-yi-la-chan
Korean:	ggot-mae-mi (Han et al. 2008; Lee et al. 2009).

This species was first recorded and described as *Aphaena delicatula* by White (1845) based on a sample collected from Nakin, China, and in 1863 was renamed as *L. delicatula* (Bourgoin 2018). Three other *Lycorma* species exist, *L. imperialis* (White 1846), *L. meliae* (Kato 1929) and *L. olivaceae* (Kato 1929) (Bourgoin 2018).

1.2 Geographical distribution

1.2.1 Endemicity

The spotted lanternfly (SLF) is native to northern China and is believed to have been present in China since 500BC (Liu 1939). SLF was originally found in Shandong, Shanxi and Hebei, and was more abundant in the North than in the Southern areas of China (Liu 1939, Kim et al. 2013).

SLF is now widespread throughout China (Figure 1), present in Anhui (Li et al. 1997), Beijing (Choi et al. 2014), Chongqing (Chen et al. 2010), Fujian (Yu 2011), Gansu (Zheng et al. 2009), Guangdong (Li et al. 1997), Guangxi (Zhang and Zhao 1996), Guizhou (Li 2011), Hainan (Zhang and Zhao 1996), Hebei (Choi et al. 2014), Henan (Cai and Wu 2013, Ding et al. 2006), Hubei (Kim et al. 2013; Ding et al. 2006), Hunan (Zhou 1992; Chen et al. 2010), Jiangsu (Li et al. 1997), Jiangxi (Peng et al. 2004), Jilin (Zhang and Zhao 1996; Liu et al. 2015), Liaoning (Zhang and Zhao 1996; Wang 2012), Ningxia (Zheng 2015), Shaanxi (Choi et al. 2014), Shandong (Choi et al. 2014), Shanghai (Kim 2013), Shanxi (Wang et al. 2000; Ding et al. 2006), Sichuan (Li et al. 1997), Tianjin (Choi et al. 2014), Xinjiang (Forest Pest Control and Quarantine Bureau of Xinjiang Uygur Autonomous Region 2014), Xizang ((Tibet) Zhang and Zhao 1996), Yunnan (Wang et al. 2000; Ding et al. 2006), Zhejiang (Li et al. 1997). The only provinces where SLF is not recorded are Heilongjiang and Inner Mongolia (Figure 1).

Figure 1. Distribution of spotted lantern fly, *Lycorma delicatula*, throughout China. Spotted lanternfly (SLF) has not been recorded in the Heilongjiang and Inner Mongolia provinces; light grey. (Source EPPO (2016) Pest risk analysis for *Lycorma delicatula*. EPPO, Paris; http://www.eppo.int/)

The status of SLF is not consistent within the literature. Some sources refer to SLF as native to China, India, Japan and Vietnam (e.g. Chou et al. 1985; Barringer 2014), however evidence of its native status can only be found for China (Liu 1939). Kim et al. (2013) compared regional isolates of SLF from locations in China, the Republic of Korea and Japan, providing increased understanding pertaining to the endemicity of SLF. All Korean and Japanese isolates were found to be genetically identical to those collected from China, specifically Beijing, Tianjin, Qingdao and Shanghai; local haplotypes have been identified in the Zhejiang province (China).

1.2.2 Global distribution

Outside of its native China, SLF has spread to the Republic of Korea, Japan, Vietnam, Taiwan and Northern United States of America (USA) (EPPO 2019) (Figure 2, Table 1).

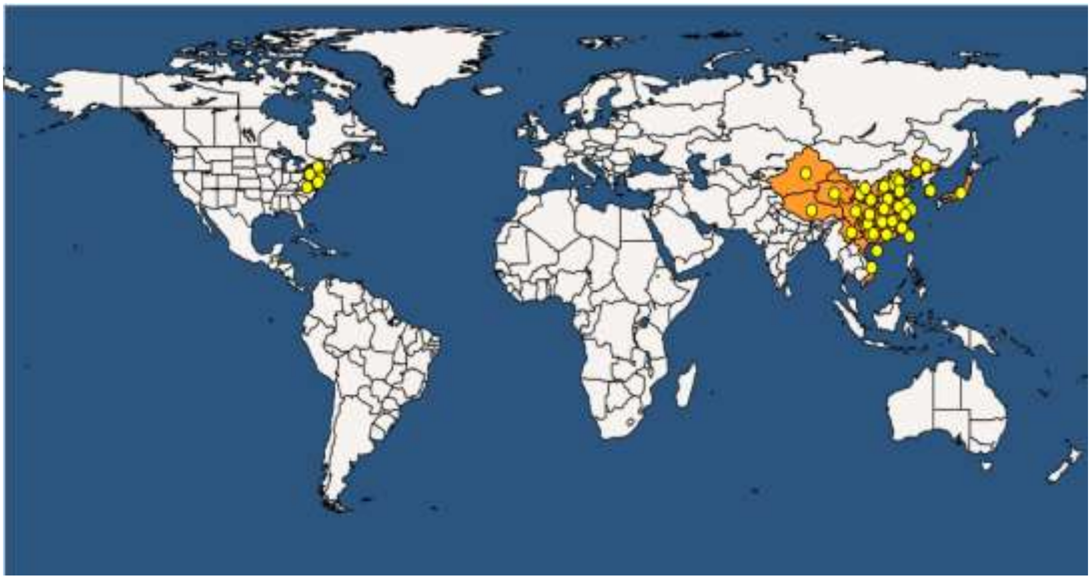

Figure 2. Global distribution of spotted lantern fly, *Lycorma delicatula*. (Source EPPO Global Database, last updated 15 October 2018; https://gd.eppo.int/).

The Republic of Korea

SLF was first reported in Korea in early 1932, but it is now understood this was a misidentification of *Limois emelianovi* (Han et al. 2008; Choi et al. 2002). SLF was found in 2004 at Cheonan (Kim and Kim 2005), but within five to seven years it had spread throughout the mainland from the West to the South and East, including northeast (Han et al. 2008; Kim et al. 2011a; Kim et al. 2013; Park et al. 2013; Lee et al. 2014). The populations of SLF in Korea show evidence of a low but significant genetic differentiation, indicating the presence of at least three genetically unique populations (Park et al. 2013).

Japan

SLF was first found in 2009 in Ishigawa Prefecture, Komatsu city (Tomisawa et al. 2013) and has since spread to neighbouring Fukui Prefecture (Umemura et al. 2013). There is uncertainty regarding the distribution in other Japanese regions and whether SLF was actually present in Japan before 2009 (Han et al. 2008; Kim et al. 2013).

Vietnam and Taiwan

The distribution of SLF in unclear in Vietnam but it is thought that it ‘could be present/spreading in North Vietnam’ (Pham 2009). SLF is present in Taiwan, but details of its first report and distribution are not recorded (EPPO 2019).

Cambodia, India (Assam) and Laos

No distribution records or unreliable records exist for SLF in Cambodia, India (Assam) and Laos (Pham 2009; EPPO 2019).

Table 1. Distribution of spotted lanternfly, *Lycorma delicatula*, outside of China.

Continent/ Country/ Region	Distribution	Reference(s)
Asia		
Cambodia	Absent, unreliable record	Pham 2009; EPPO 2019
India	Absent, unreliable record	EPPO 2019
Assam	Absent, unreliable record	EPPO 2019
Japan	Present	Kim et al. 2013; EPPO 2019
Honshu	Present	Han et al. 2008; Kim et al. 2011a; Kim et al. 2013; Tomisawa et al. 2013; Umemura et al. 2013; EPPO 2019
Korea, Republic of	Widespread	Han et al. 2008; Kim et al. 2011a; Kim et al. 2013; Park et al. 2013; Lee et al. 2014; EPPO 2019
Laos	Absent, unreliable record	Pham 2009; EPPO 2019
Taiwan	Present	EPPO 2019
Vietnam	Present	Pham 2009; EPPO 2019
North America		
USA	Restricted distribution	EPPO 2019
Delaware	Present, few occurrences	EPPO 2019
New Jersey	Present, few occurrences	EPPO 2019
New York	Present, few occurrences	EPPO 2019
Pennsylvania	Present	Barringer et al. 2015; Dara et al. 2015; EPPO 2019
Virginia	Restricted distribution	EPPO 2019
Maryland	Single adult found	Maryland Department of Agriculture 2018

USA

Pennsylvania, USA (new continental record)

SLF was found in Pennsylvania, Berks County, on *A. altissima* (tree of heaven) in 2014. At the time of discovery the infestation was believed to be two to three years old (Barringer et al. 2015; Dara et al. 2015). It is now present in 13 counties including Berks, Bucks, Carbon, Chester, Delaware, Lancaster, Lebanon, Lehigh, Monroe, Montgomery, Northampton, Philadelphia and Schuylkill (EPPO 2019). The pathway accepted as being the most likely to have enabled entry was from a shipment of stone products from China contaminated with SLF egg masses (EPPO 2016).

- Delaware

SLF was found in 2017 in New Castel County and is currently under eradiation (EPPO 2019; Delaware News 2017).

New Jersey

SLF was first found in July 2018 in Warren County and then in the Mercer and Hunterdon counties (EPPO 2019; Maher 2018).

New York

A dead SLF was found in November 2017, followed by the discovery of a single adult in September 2018 in Yates County and a single adult found in a vehicle in Albany (EPPO 2019; Orr and Schuhmacher 2018).

Virginia

SLF was found in January 2018 in Frederick County (EPPO 2019; Virginia Department of Agriculture and Consumer Services 2018).

Maryland

A single adult SLF was found in October 2018 in Cecil County near the border of Pennsylvania and Delaware (Maryland Department of Agriculture 2018)

The potential global distribution of SLF has been forecast using CLIMEX modelling software (Jung et al. 2017) (Figure 3). In this simulation, SLF has a high eco-climatic index and therefore a potential for survival throughout South America, parts of Europe, the east coast of Australia and the North Island of New Zealand.

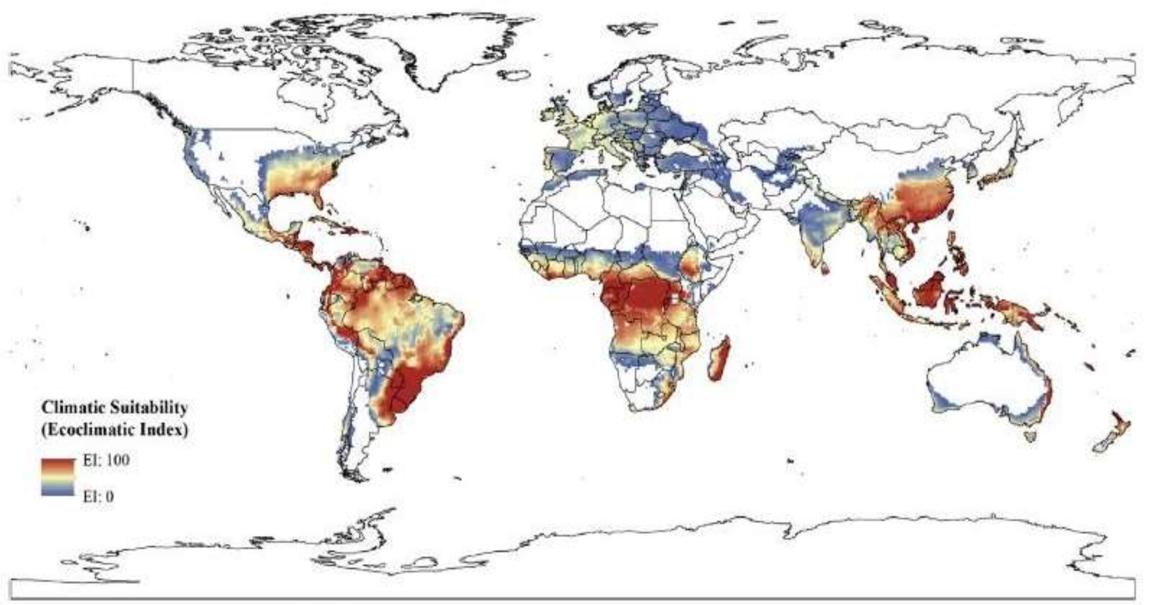

Figure 3. Predicted potential global distribution of *Lycorma delicatula* by CLIMEX. Ecoclimatic index (EI) values from 0 to 100 are represented by color ramp. The deeper red color represents the more favorable location for *L. delicatula* establishment, whereas deeper blue color represents the unfavorable region.

Figure 3. The potential global distribution of spotted lanternfly, *Lycorma delicatula*, using CLIMEX modelling software (Source Jung et al. 2017).

1.3 Description

SLF is a planthopper belonging to the family of fulgorid insects. Fulgorids tend to be large in size compared to other planthoppers and have reticulate wing venation of the hindwings and forewings (Bartlett et al. 2014; Kim et al. 2013). As a univoltine species, SLF develops through six life stages: egg, four nymphal stages and adult, and overwinters in the egg stage.

1.3.1 SLF eggs

Each egg is ovoid in shape with a rounded side and flattened front (Figure 4), and a stem-like structure at one end (Pennsylvania Department of Agriculture 2018a). Vertical columns of eggs are laid side by side, with each batch covered with an ootheca (protective case) (Figure 4). The ootheca has a brownish putty-like appearance containing 30–50 eggs, and has a length of approximately 25 mm (Dara et al. 2015; Barringer et al. 2015).

Figure 4. Egg masses of spotted lanternfly (SLF), *Lycorma delicatula.* Left = vertical columns of individual eggs, right = an SLF ootheca (Photo source Lawrence Barringer, Pennsylvania Department of Agriculture).

1.3.2 SLF nymphs

Nymphs develop through four instars. The first three instars (early nymphs) are black with white spots, and the fourth instar (late nymph) is red with white spots and black stripes, and distinctive wind pads (Figure 5) (Dara et al. 2015). Early nymphs are 6–10 mm in length, with late nymphs up to 13 mm in length (Leach et al. 2018).

Figure 5. Nymphs of the spotted lanternfly, *Lycorma delicatula*; left image is of an early nymph, right image is of a late nymph (Photo source State of NJ Department of Agriculture).

1.3.3 SLF adult

Adult SLF are easily detectable as they are large and have distinctive colouring (Figure 6). Adults have light brown forewings with black spots, and the base colour darkens along the wing tips. It is thought that the colouration of the forewings allows for SLF to conceal itself on the trunk of a tree (Frantsevich et al. 2008). In flight, SLF displays red hind wings with black spots on the proximal third, a white section in the middle of the wing, and a solid black wing tip. The abdomen is yellow with black, with white areas present on the top and bottom. The hindwings are brightly coloured, red with black spots. A white area separates the red from the black ends of their hindwings (Dara et al. 2015).

Female SLFs have a body length of 20 to 25 mm, with the male body measuring 17 to 20 mm in length (Barringer et al. 2015). When measured from the head to the tip of the wings, length ranged from 21 to 27 mm and 21 to 22 mm, for female and male respectively (Dara et al. 2015). Females have longer legs, ranging from 18 to 22 mm, with the male leg length ranging between 15 to 18 mm (Barringer et al. 2015).

Figure 6. Adult spotted lanternfly, *Lycorma delicatula* (Photo source Lawrence Barringer, Pennsylvania Department of Agriculture).

1.4 Host plants

SLF nymphs and adults have been observed feeding on a variety of host plants including woody trees, fruit trees, ornamental trees and vines. Their host range includes economically important plants such as *Vitis vinifera* (common grape vine), pipfruit (*Malus* spp.) and kiwifruit (*Actinidia* spp.) (Appendix 1) (EPPO 2019; Dara et al. 2015).

1.4.1 Primary host plant

Ailanthus altissima, commonly known as the ‘tree-of-heaven’ or the ‘Paradise tree’, is a primary host plant in the lifecycle of SLF (Chou 1946; Park et al. 2009; Tomisawa et al. 2013; Barringer et al. 2015; Ca and Wu 2013) (Figure 7). *A. altissima* is native to northeast and central China, and is present in countries and counties were SLF have been identified (Figure 8). SLF can complete its life cycle on *A. altissima,* greatly preferring it over many other plant species, and therefore is likely to establish where *A. altissima* is present (EPPO 2016).

Figure 7. *Ailanthus altissima*, commonly known as the 'tree-of-heaven'; a primary host of the spotted lanternfly, *Lycorma delicatula*.

A. altissima is present in New Zealand (Figure 9). This tree species is distributed from Auckland to Dunedin and exists in a variety of environments including coastal, forest and shrub land (Breitwieser et al. 2019a). The species is regarded as invasive and is classified as an unwanted organism by Biosecurity New Zealand.

Although *A. altissima* is a primary host plant of SLF, Li and Tao (1980) claimed that SLF is a generalist and does not live solely on *A. altissima*. It appears that early instar nymphs are polyphagous, but a strong preference for one or a few species of tree, in particular *A. altissima,* is apparent once SLF reaches fourth instar and adult. Observations made in both Korea and Pennsylvania indicate that the number of individuals captured on non *A. altissima* trees decreased and numbers captured on *A. altissima* increased as the insect reached fourth instar or adult (Kim et al. 2011c; Dara et al. 2015). In Korea, adults were collected only on *A. altissima* and *Tetradium daniellii* trees in September, and by November adults were found exclusively on *A. altissima* trees (Kim et al. 2011c). As part of a field-based host plant study performed at Pennsylvania State University in 2015–2016 researchers observed that fourth instar nymphs moved from other host plants and congregated on *A. altissima*, and during the time adults were present, SLF was not observed on any other species of host plant (Setliff 2016).

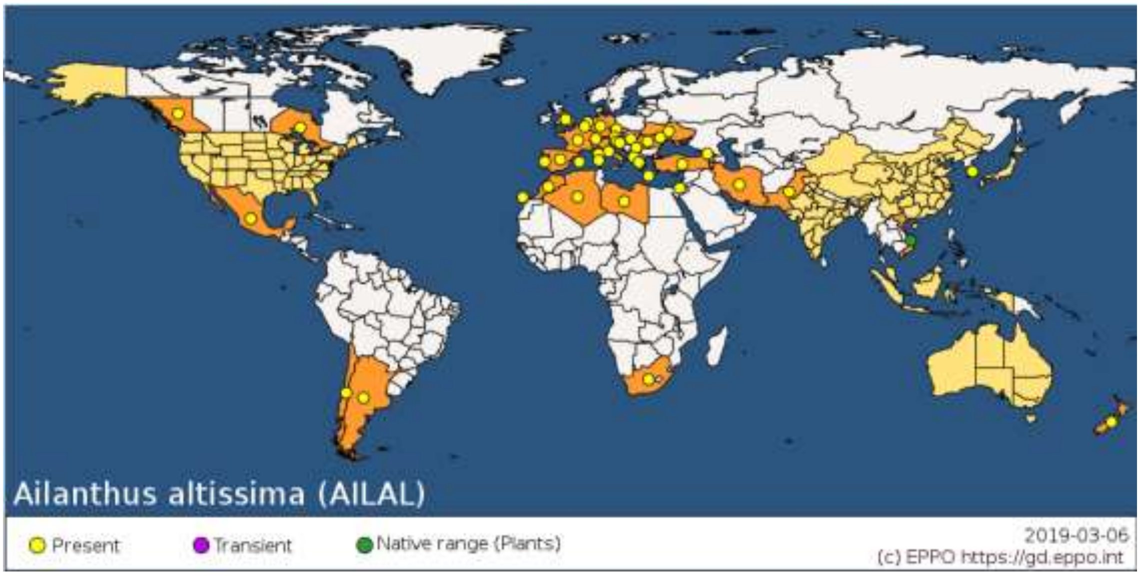

Figure 8. Countries where *Ailanthus altissima* is present (Source EPPO Global Database; last updated 6 March 2019, https://gd.eppo.int/taxon/AILAL/distribution). Countries in yellow indicate presence, counties in orange indicate presence but no details available.

Figure 9. Distribution of the tree-of-heaven, *Ailanthus altissima,* within New Zealand (Source Breitwieser et al. 2019a).

1.4.2 Secondary host plants

SLF has been found in association with over 100 plant species, with feeding recorded on 38 host plants; a complete host plant list and associated references are provided in Appendix 1. SLF has a preference for Chinaberry (*Melia azedarach*), wild and cultivated grapes (*Vitis spp.*) and Korean Euodia (*Tetradium daniellii)* (EPPO 2016; Park et al. 2009; Dara et al. 2015).

Chinaberry is present in New Zealand, and distributed from North Auckland to Wellington (Breitwieser et al. 2019b). Chinaberry leaves and fruit are poisonous to humans and the leaves have natural insecticidal properties (Russell et al. 1997). There are three other species in the Meliaceae, or mahogany family, listed as host plants of SLF (Appendix 1). According to Breitwieser et al. (2019b), there are three Meliaceae species present in New Zealand, including one endemic (*Dysoxylum spectabile)* and two exotic (*M. azedarach* and *Toona sinensis*).

Other secondary host plants where feeding has been recorded include the Amur cork tree *(Phellodendron amurense*), apple (*Malus* spp.), apricot (*Prunus* spp.), birch (*Betula* spp.), black locust (*Robina pseudoacacia*), cherry (*Prunus* spp.), Chinese juniper (*Juniperus chinensis*), Chinese mahogany (*Toona sinensis),* Chinese thuja (*Platycladus orientalis*), dogwood (*Cornus* spp.), food wrapper plant (*Mallotus japonicus*), fragrant snowbell (*Styrax obassia*), Japanese silverberry (*Elaegnus umbellata*), Japanese snowbell (*Styrax japonicus*), hops *(Humulus lupulus)*, (maple (*Acer* spp.), kiwifruit (*Actinidia* spp.), peach (*Prunus* spp.), pears (*Pyrus* spp.), plum (*Prunus* spp.), pomegranate (*Punica granatum*), Virginia creeper *(Parthenocissus quinquefolia)*, walnut (*Juglans* spp.), willow (*Salix* spp.) and *Zanthoxylum bungeanum* (EPPO 2016; Dara et al. 2015).

Recent reports of SLF finds in soybeans, alfalfa, corn, basil and cucumber have been made in Pennsylvania, with feeding resulting in the death of basil and cucumber plants (Malinoski 2018); this extends to reports of damage on basil, blueberry, cucumber and horseradish (Pennsylvania Department of Agriculture 2018b).

SLF has been recorded on several herbaceous plant species; this appears to be related to the living and feeding habits of early nymphal instars which cause the insects to fall and climb on nearby plants; late nymph instars and adults have not been recorded on herbaceous species (Lieu 1934; Park et al. 2009; Wang et al. 2000; Chou et al. 1985).

Increasing evidence suggests that any given secondary host plant alone may not be sufficient for completion of the SLF life cycle, therefore SLF may need to feed on more than one plant species during its lifecycle (Park 2015) when *A. altissima* is not present. This was expressed in Tomisawa et al. (2013), who mentioned that only *A. altissima* and *Melia spp.* are 'hosts', citing others as 'not hosts but adults depend upon'. Preference for feeding on certain plants is not fully understood and different hypotheses have been made, e.g. relating to sugar content of the plant (Lee et al. 2009) and the presence of cytotoxic alkaloid chemicals (Kim et al. 2011c; Ohmoto et al. 1981; Anderson et al. 1983).

1.4.3 Impacts on native flora and fauna

New host species have been identified from locations where SLF has been introduced, including the addition of 24 North American tree species to the putative host plant list (Setliff 2016; EPPO 2016). The impact on native flora and fauna has not been quantified in any countries where SLF has been found.

It is likely that damage occurs to a variety of native plants as a result of insect feeding, and by the accumulation of sooty mould both on the plant itself and on neighbouring plants. Impacts on native flora and fauna in the USA are currently being minimised through the removal of *A. altissima*, to slow the spread of SLF, and through various measures to control SLF; this is discussed in section 2.

1.5 Damage

As vascular feeders, SLF nymphs and adults use their haustellate (sucking) mouthparts to feed on phloem (Hao et al. 2016; Ding et al. 2006). Feeding is concentrated on trunks, branches and stems; SLF do not typically feed on foliage or fruit but they have been observed sitting in clusters in such areas seeking warmth.

Oozing wounds are created on the plant as a result of feeding, and when a large number of individuals are present on a plant, wilting, localised death of leaves and branches and even plant death can result (Han et al. 2008; Chou 1946; Ding et al. 2006).

The insect excretes a sugary substance known as honeydew as a byproduct of feeding (Figure 10) (Ding et al. 2006). This sugary liquid falls onto the plant, and sometimes onto plants nearby, and provides a food source for fungi such as sooty mould. Heavy infestations result in the build-up of honeydew and sooty mould which can decrease photosynthesis of the plant by blocking sunlight from the surface of the plant (Dara et al. 2015). The production of honeydew has been known to attract ants, bees and wasps to areas with SLF infestations, creating an indirect problem.

Figure 10. The build-up of sooty mould resulting from the feeding of spotted lanternfly, *Lycorma delicatula* (Photo source Lawrence Barringer, Pennsylvania Department of Agriculture).

1.5.1 Damage to kiwifruit

Kiwifruit is a reported host of SLF (Appendix1) and in many Chinese provinces is regarded as a pest of kiwifruit (Wu 2012; Pei and Wang 2001; Feng 2000). In Korea damage from feeding nymphs has been reported on *Actinidia chinensis* (Park et al. 2009).

Nymphs and adults have been observed on 'Hayward' and 'Xiuxiang', and on an experimental variety known as 'University Gold' in Yangling, China, where they were observed congregating on the trunks and canes (Gonzalo Avila, pers. comm.) (Figure 11). SLF were observed mainly on the lower trunks and not in the canopy in an organic 'Hongyang' block in China in 2018 (Shane Max, pers. comm.).

Figure 11. Spotted lanternfly adults, *Lycorma delicatula*, on kiwifruit vines in Yangling, China (Photo source Gonzalo Avila, Plant and Food Research).

The feeding of SLF (nymphs and adults) on kiwifruit has been recorded by multiple sources (Du et al. 2010; Pei and Wang 2001; Zhang et al.1994; Dai 2012; Wu 2012; Zhao et al. 2001; Feng 2003; Feng 2000; Hong and Li 1994; Mi et al. 2007; Du et al. 2011). SLF have been observed feeding on the leaves, canes and trunks of kiwifruit vines, resulting in the growth of sooty mould (Wu 2012; Pei and Wang 2001). This is believed to result in the deformation of the vine (Feng 2000). Nymphs cluster on the underside of kiwifruit leaves and canes where they cause damage (Pei and Wang 2001).

Adults lay eggs on the canes, trunk, fruit and the kiwifruit support structures (Wu 2012). Egg masses have been observed on kiwifruit canes in Yangling, China (Gonzalo Avila, pers. comm.) (Figure 12). The management of SLF in kiwifruit orchards in China is discussed in Section 2.

Figure 12. Spotted lanternfly, *Lycorma delicatula*, egg masses laid on a kiwifruit vine in Yangling, China (Photo source Gonzalo Avila, Plant and Food Research).

1.6 Pest status

SLF is widely regarded as an invasive insect pest capable of causing significant damage to a variety of plant species, including plants of economic importance.

Only in its native China is SLF not generally regarded as a major pest (EPPO 2016). However moderate damage has been reported on crops such as apple, grapevine, kiwifruit, pomegranate, peach, apricot, plum and cherry, and on *A. altissima* (Wang 2008; Zheng et al. 2009; Zhai et al. 2014; Qi et al. 2007).

In Korea SLF is regarded as a serious pest, known to attack 67 host species including grapes, apples and stone fruit. SLF is subject to a variety of control measures, particularly as it is known to cause substantial economic damage to grapevines (Kim et al. 2013).

This pest has a reportable/actionable status from the United States Department of Agriculture, with a quarantine order in place for parts of Pennsylvania. SLF is a significant threat to Pennsylvanian agriculture, landscapes and natural ecosystems, including grape (where heavy damage has already been recorded), fruit trees, hardwood and nursery industries, which collectively are worth approximately $18 billion to the state's economy. The insect has the potential to result in significant economic impacts from restrictions on commerce within quarantine zones (PennState Extension 2019).

The primary risk pathways for the introduction of SLF into new countries and counties include woody plants, wood, sawn wood, bark, stone, packaging material as well as man-made items and inert objects; these objects can harbour SLF egg masses (EPPO 2016).

1.6.1 Pest status in kiwifruit

The economic impacts on kiwifruit in both China and Korea are not understood, and so for the purposes of this review the pest status of SLF in kiwifruit is restricted to observations. In some orchards in China the proportion of the crop attacked can be significant whereas in other orchards damage can be very patchy. Pei and Wang (2001) reported SLF infestations of greater than 90% in some orchards.

Simon Cook (NZKGI, KVH director) visited Pennsylvania recently to assess the impacts of brown marmorated stink bug and SLF and after his observations he said, 'I have seen orchards suffer 20–30% fruit loss because of PVH (passionvine hopper), I can see this resulting in fruit loss of 80–90% with SLF'. Scientists and growers in the state feel SLF is the most damaging and greatest threat of all invasive species the area has seen.

If SLF was to establish on kiwifruit in New Zealand, significant economic loss would be inevitable. SLF would be classified as a production pest due to the accumulation of sooty mould on the fruit and the presence of egg masses on the fruit surface. SLF would also cause significant market access restrictions because of its oviposition habits (refer Section 1.7) and/or residues from potential chemical inputs required for its control.

1.6.2 Impacts on general public

Impacts on the general public have the potential to be varied and widespread. Firstly from damage to, and the death of, a variety of plant species that occur in national parks, recreational areas and home gardens. Secondly, the nuisance caused by SLF entering houses (Han et al. 2008), honeydew accumulation and subsquent growth of sooty mould, and the attraction of wasps, bees, and ants into areas where large quantities of honeydew may be present.

The Pennsylvania Department of Agriculture has classified SLF as a "public nuisance" as it poses a danger to forests, ornamental trees, orchards and grapes (Pennsylvania Department of Agriculture 2017). Thirteen counties within the state are under quarantine order which requires all property owners within the quarantine zone to control or eliminate SLF found on their property. The quarantine order also places restrictions and strict guidelines on the movement of any material or object that may carry or spread SLF. Examples of such materials include wood, grapevines, vegetation, packaging material, vehicles, trailers and mobile equipment (Pennsylvania Department of Agriculture 2017).

In a recent webinar, Dana Rhodes of the Pennsylvania Department of Agriculture stated that SLF infestation could affect property values and quality of life, tourism and assets such as the state's park system, the state's natural ecosystem, and new business initiatives (Rhodes 2018).The impact could also extend to companies dependent on these state assets, many of which are small local businesses.

1.7 Biology and ecology

1.7.1 Life cycle

In China, South Korea and Pennsylvania, SLF has one generation per year. SLF adults lay eggs from late autumn through to winter, the insect overwinters as an egg (Dara et al. 2015), with egg hatch occurring in late winter through to early spring. SLF develops through four nymphal instars from late winter/early spring to early autumn. Adults first appear in autumn, when they begin to disperse and mate, and are active until winter (Figure 13, Table 2) (Park et al. 2009; Park et al. 2012; Dara et al. 2015).

Figure 13. The life cycle of spotted lanternfly, *Lycorma delicatula*, in Pennsylvania, USA (Source Pennsylvania Department of Agriculture).

It is uncertain whether SLF has more than one generation per annum in areas where the climate is warmer, particularly throughout winter. It has been hypothesised that the increase in winter temperatures may be factor in the recent occurrence and range expansion of SLF in Korea (Lee et al. 2011). There are large gaps in the understanding of SLF biology including a lack of in-depth understanding of alternate hosts, reproductive requirements, nutritional requirements, pheromone communications, dispersal, diapause requirements and other biological aspects, much of which is now being studied as part of a research programme to improve the biological understanding of SLF (Urban 2018). The literature suggests that SLF was not widely studied until it emerged as a pest in Korea in 2006.

Table 2. The life cycle of spotted lanternfly, *Lycorma delicatula* in South Korea (Information sourced from Park et al. 2009).

Stage	Dec-Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Egg	■	■	■				■	■	■
1st instar		■	■	■					
2nd instar			■	■	■				
3rd instar				■	■				
4th instar				■	■	■			
Adult					■	■	■	■	

1.7.2 Adult

Adults first appear in autumn, and begin to disperse and mate through to the onset of winter (Park et al. 2009; Park et al. 2012; Dara et al. 2015). Adults are diurnal, and are present for three months or more under field conditions (Tomisawa et al. 2013). Longevity of six and seven days was recorded when adult SLF were inoculated onto *A. altissima* and *V. vinifera* respectively under laboratory conditions, and less than three days when SLF were inoculated onto other host species (Lee et al. 2009).

SLF has piercing-sucking mouthparts adapted to feeding from plant cells. The mouthparts are located under the front of the head and consist of a cone-shaped tubular labrum. There is a deep longitudinal channel along the dorsal surface containing the stylet fascicle (mouthpart used to pierce the surface of the plant). Like other hemipterans, the stylet fascicle comprises four parts, two mandibular and two maxillary stylets (Hao et al. 2016).

This insect uses its cryptic forewings, defensive chemicals, and various defence behaviours including rapid jumping, a sudden display of its conspicuous hindwings and abdomen, and death feigning to protect itself from natural enemies. Kang et al. (2017) report seasonal differences in post-attack defences, individuals were more likely to jump away in the early season, whereas feigning death was more frequent in the late season.

SLF use cytotoxins as chemical defences to deter predators (Barringer and Smyers. 2016). These are acquired through feeding from host plants, mainly the tree of heaven, *A. altissima*. Song et al. (2018) provided the first report of quassinoid sequestration by SLF after feeding on *A. altissima* and the first evidence that Simaroubaceae plants provide defensive chemicals to insects. Birds were shown to avoid SLF collected on *A. altissima* but not those collected from secondary hosts. This highlights the links between timing of defence sequestration, timing of host and the plant preference shifts. Although grapevines do not have toxic metabolites like the other preferred hosts of SLF, *A. altissima* and Korean Evodia (Bebe tree), studies conducted in South Korea have shown the sugar content of the host plant also appears to play a role in the selection of host, with plants containing high sucrose and fructose preferred (Lee et al. 2009).

Wang et al. (2018) suggest that development in the structure of antennal sensilla from 1st instar nymph to adult could enable the sensory capability for specific functions such as host plant recognition. For instance, specialised sensilla placodea start to develop on the antenna pedicel in the 2nd instar, enabling dispersion behaviour for the species. SLF is a diurnal species and it may rely on visual cues for orientation. Domingue et al. (2019) evaluated adult movement after physical disturbance and inferred a preference for greater intensity of ambient light for flight orientation. It had been previously reported that SLF prefers to move toward shorter UV and blue light wavelengths (Jang et al. 2013). Greater amounts of these wavelengths within a sunlit field versus the shaded forest may be the cue used to direct the flight of both SLF adults and nymphs.

Adult SLF can fly but they tend to jump more than fly and their wings often remain closed. Recorded flying distances are limited to 2 m at a time (Tomisawa et al. 2013), seldom beyond 3.3 m (Chou 1946). Based on the biology of the pest, it is also not excluded that emerging adults may be able to fly longer distances to find food. Observations in the field in Pennsylvania revealed that flying was observed mainly from mid to late September, flying from 10–80 meters. They would disperse over longer distances by successive movements during their lifetime (EPPO 2016).

This species possesses specialised tarsal adhesive pads (arolia), which allow strong climbing and jumping characteristics (Frantsevich et al. 2008). SLF can jump 1 to 1.3 m (Chou 1946) to escape predation if a predator is unperturbed by their coloration (Frantsevich et al. 2008).

SLF are known to aggregate both as nymphs and as adults. It is thought that adults use vibrations through the substrate and semiochemicals to communicate to find partners for mating, as is the case for many other planthopper species. In Pennsylvania, aggregation has been observed on *A. altissima* and in some cases, large aggregations have occurred in urban areas (Figure 14). Researchers have found 39 antennally active compounds, with 8 of them found to be attractants for SLF. Those 8 have been incorporated into a blend that is highly attractive to SLF (TWG 2017).

Figure 14. An aggregation of spotted lanternfly, *Lycorma delicatula*, in an urban area in Pennsylvania, USA (Photo source Lawrence Barringer, Pennsylvania Department of Agriculture).

Copulation and oviposition are observed from dusk into the evening in mid-September to November. Mating behaviour was observed for the first time this autumn in Pennsylvania. The courtship consisted of the male and female sitting still side-by-side on the trunk for several hours followed by 2–4 h of coupling (TWG 2017). The male reproductive organs have been studied by Jiang et al. (2011), the primary morphological characteristics include a distinctly inflated ejaculatory duct near the terminal, a well-developed accessory gland, and the seminal vesicle is sheathed by a membrane.

SLF will lay their eggs on plant and non-plant surfaces with a preference for *A. altissima*. There has been no egg-laying recorded on some plants where adult feeding has been recorded (Barringer et al. 2015; Kim et al. 2011c), and there are many plants on which egg-laying have been recorded but not feeding (Appendix 1). In Pennsylvania, it has been observed that egg-laying is strongly associated with *A. altissima*, although when SLF numbers are high, females may lay eggs on other plants or materials (EPPO 2016). In China, eggs are observed on other plants and materials close to *A. altissima,* also in situations of low population density (EPPO 2016).

Variation in wing morphometrics have been observed in populations of SLF from Korea, China, and Japan (Kim et al. 2013). Similarities were found in individuals from Korea and the northern area of the Yangtze River (China), while individuals from Seoul and Buan were very similar to those from Shanghai. The Japanese individuals had a large wing size relative to individuals from Korea and China.

1.7.3 Nymph

Nymphs hatch from eggs in late winter and into spring, and develop through four instars before eclosion, as described in Section 1.3.2. In Korea, eggs hatch in May, with nymphs ascending up the host plant after emerging in the early morning (Han et al. 2008). As nymphs emerge, they start climbing up potential host plants until they reach a food source where they feed by sucking sap from vascular bundles from within the host plant. Earlier instars have been observed most commonly on leaves, young shoots and stems, moving to branches and trunks in later instars (Kim et al. 2011c). Although SLF has been recorded on herbaceous species, this may be due to the fall-ascend cycle of the early instars, this cycle becomes longer and the nymphs fall less frequently as the arolia (adhesive pads) on the tarsi develop (Kim et al. 2011c; Frantsevich et al. 2008). It is possible that the falling-ascending behaviour may be a strategy to select host plants, or they may be dislodged by physical obstacles, the wind or other individuals (Choi et al. 2012).

Earlier nymphal instars seem to feed indiscriminately on many plant species, with 1st to 3rd instars having a wider host range than 4th instar nymphs (Kim et al. 2011c). The literature suggests 1st instar nymphs feed on most plants that they encounter on the ground, indicating that SLF is a broad generalist at this development stage, only showing preferences for specific host plants as they develop. Nymphs aggregate on the host plant to feed. When the density of nymphs on a host plant is high, it is more likely that aggressive behaviour between nymphs will occur as they compete for feeding locations (Choi et al. 2010). During antagonistic encounters, it is most likely for the original nymph to maintain control over its feeding space rather than the new nymph taking control. Studies revealed that prior residence was a significant factor in the outcome, not body size (Choi et al. 2010).

Jung et al. (2016) assessed the use of harmonic radar tracking as a new tool to study the dispersal and behaviour of SLF. The results of this study indicate that this can be applied successfully to 4th instars without changing their mobility and survivorship.

When 3rd instar nymphs were inoculated onto seven host plant species, significant variations in nymph longevity and ecdysis rate were recorded (Table 3) (Lee et al. 2009). When 3rd instar nymphs were inoculated onto *A. altissima* and *V. vinifera,* longevity of 15 days and a 63% ecdysis rate was recorded for both host species, whereas when inoculated onto all other species, longevity was less than 6 days.

Studies performed by Park et al. (2009) and Park (2015) recorded a mean nymphal development time of 83 days when developed on *Parthenocissus quinquefolia* at room temperature (Table 4). The number of development studies performed for SLF are limited.

Table 3. The development of spotted lanternfly, *Lycorma delicatula* (Source Lee et al. 2009). Please note permission would be required from the journal if Zespri were to reuse this content outside the scope of this report, e.g. in a presentation, brochure, website.

Table 2. Survivorship of *Lycorma delicatula* when inoculated 3rd instar and adult on 7 species plants and 3 species fruits

Plants	Type	n	Part	Longevity (mean±SD, day)				Ecdysis rate (%)[d]
Ailanthus altissima	Nymph[a]	110	Branch	15.0	±	1.0	A[c]	63.3
	Adult[b]	110		6.8	±	0.6	a[c]	-
Vitis vinifera	Nymph	105	Branch	15.4	±	3.0	A	63.0
	Adult	105		6.1	±	0.7	a	-
Pinus densiflora	Nymph	51	Branch	4.5	±	1.5	B	5.9
	Adult	51		2.2	±	0.5	b	-
Hibiscus syriacus	Nymph	51	Branch	5.6	±	1.2	B	7.8
	Adult	51		2.5	±	0.4	b	-
Malus pumila	Nymph	51	Branch	5.3	±	0.4	B	17.7
		50	Fruit	1.2	±	0.3	B	0.0
	Adult	51	Branch	2.4	±	0.3	b	-
Pyrus calleryana	Nymph	54	Branch	6.0	±	2.1	B	9.3
		50	Fruit	1.7	±	1.4	B	0.0
	Adult	54	Branch	2.1	±	0.4	b	-
Prunus persica	Nymph	50	Branch	5.5	±	1.1	B	0.0
		50	Fruit	1.6	±	1.0	B	0.0
	Adult	50	Branch	2.9	±	0.3	b	-

[a] Longevity until 3rd instar to death; [b] Longevity until adult to death; [c] Means followed by same letter(capital letter for nymph and small letter for adult) are not significantly different at P=0.05 by Tukey's Studentized Range Test (SAS Institute, 2003); [d] Ecdysis of 3rd to 4th instar.

Table 4. Spotted lanternfly, *Lycorma delicatula*, nymph development (based on data from Park et al. (2009) and Park (2015)).

Instar	Development time (days)*	Day degrees**
1st instar	18.8	271
2nd instar	20.9	492
3rd instar	20.8	620
4th instar	22.2	908

* Developed on *Parthenocissus quinquefolia* at room temperature.
** Thermal constant for peak population on *Ailanthus altissima.*

1.7.4 Egg

In China, Korea and Pennsylvania, SLF eggs are laid in late autumn to early winter, overwinter in an ootheca, before hatching in late winter and early spring (Table 2) (Dara et al. 2015). In a study performed in Korea, Kim et al. (2011c) observed most eggs hatched between 0500 h and 0800 h, with all eggs within an ootheca hatching simultaneously.

Eggs are laid on woody trees, in particular *A. altissima* (Dara et al. 2015; Han et al. 2008), however eggs have also been found laid on numerous other plant species (Appendix 1). Egg masses (each containing 30–50 eggs) are laid on tree bark and under loose bark, and are covered in a brown waxy deposit (described in Section 1.3.1). In Korea, an average of 3.4 egg masses have been observed on a tree at a time, with up to 197 egg masses per tree observed in Pennsylvania (Lee et al. 2014; Dara et al. 2015).

This insect has been frequently observed laying eggs at 1–1.5 m above ground on woody trees with a diameter larger than 15 cm (Barringer 2014; Kim et al. 2011c). Observations from surveys in Pennsylvania similarly found that woody plants greater than 15 cm diameter (at 1 to 1.5 m) were preferred for egg laying but eggs were also found on trunks and branches down to 1 cm diameter when the population of SLF was very high (EPPO 2016).

SLF tend to lay their eggs in the lower portion of a tree (Tomisawa et al. 2013), however eggs have been observed 1 to 3 m up the tree and are laid as far up as 13 m on *Prunus* trees with rough lower bark (Kim et al. 2011c). Tomisawa et al. (2013) observed egg masses at various heights on branches and trunks of large trees (>10 m), but most were located in the lower half. In Pennsylvania, egg masses were not present on the lower trunk on larger trees with rougher bark, rather in the upper trunk and branches. Smaller smooth-barked trees had egg masses laid from the ground to the crown (EPPO 2016).

In addition to woody plants, SLF eggs are laid on other ‘smooth’ materials or surfaces such as dead plants, bricks, stones, decks, houses, outdoor equipment, rocks and buildings (Barringer 2014; Zhai et al. 2014). A wide variety of inert objects that may carry egg masses are mentioned in the literature, from buildings (Umemura et al. 2013; Zhai et al. 2014) to cables near tree crowns (Cai and Wu 2013). Smooth surfaces that are more vertically oriented, stable, and red/brown/grey in colour seem to be preferred as egg laying substrates for SLF.

Egg development and survival is significantly affected by temperature. In South Korea, Lee et al. (2011) reported that egg mortality increased as minimum winter temperature decreased. Choi et al. (2012) evaluated egg hatching at three incubation temperatures: 15°C, 20°C, and 25°C. Time to hatch was 55.9, 26.8 and 21.6 days respectively, with hatching rates of 61.9%, 57.8% and 30.4%. A total of 355.4 day degrees was required to reach 1^{st} instar nymph.

The minimum temperature that will kill SLF eggs has been estimated between -3.4°C and -12.7°C (Lee et al. 2011), with a temperature threshold of -11°C modelled for the survival of overwintering eggs (Lee et al. 2014). This estimate contrasts with SLF having survived the much colder winter temperatures experienced in Pennsylvania in 2014, where temperatures fell as low as -22.2°C. In Jilin province in China, the coldest temperature recorded was -44°C, in an area where SLF occurs (Changbaishan Mountain) (EPPO 2016). It is likely the exposure time to minimum temperatures is an important factor. Park et al. (2011) reports on experiments on overwintered eggs exposed to -15, -20 and -25°C for different exposure times (12 h, 24 h, 3 d, 5 d, 7 d). Eggs were collected, chilled at 5°C, exposed to low temperatures, and then kept at room temperatures. Some eggs exposed at -20°C for 12h or 24 h hatched. They concluded that -25°C is around the critical temperature (no hatching obtained for any exposure time).

Shim et al. (2015) studied embryonic diapause with the results indicating that diapause termination in SLF eggs requires a chilling period; this period is also believed to facilitate post diapause development.

1.8 Natural enemies

Natural enemies of SLF in its native China include a solitary egg parasitoid, *Anastatus orientalis*, and two ecto-parasitoids, *Dryinus browni* and *D. lycormae.* In North America, an egg parasitoid, *Ooencyrtus kuvanae* and generalist predators have been recorded as natural enemies of SLF (Table 5).

The egg parasitoid, *A. orientalis,* (Hymenoptera: Eupelmidae) was discovered in northern China and is regarded as an important natural enemy as parasitism rates can reach up to 80% in some regions (Xiao 1992; Zhang 1993) (Figure 15). This species was recently surveyed in four provinces in China, the highest egg mass parasitism rate recorded was 69% and the highest rate of egg parasitism within an egg mass was 33% (Choi et al. 2014).

This species is considered to be an important biocontrol agent in China and is being investigated both in the Republic of Korea and the USA as a potential biological control agent because of high rates of parasitism of eggs (Choi et al. 2014). Another *Anastatus* sp. has also been reported parasitising overwintering SLF masses in grape vineyards in South Korea (Kim et al. 2011b).

Dryinus browni (Hymenoptera: Dryinidae) is a nymphal ecto-parasitoid native to China. Late-stage parasitoid larvae exit the host into a protective sac under the wing pad of the nymph and once mature spin a cocoon, overwinter and emerge the following summer. Reported parasitism rates are up to 40% (Yan et al. 2008). *Dryinus lycormae* has also been found parasitising SLF (Dong 1987; Yang 1994).

The egg parasitoid, *O. kuvanae,* (Hymenoptera: Encyrtidae) was discovered in surveys within a Pennsylvanian quarantine zone in 2016 and is currently under investigation (Liu and Mottern 2017) (Figure 16). This species is native to Asia and was introduced into the United States as a biological control agent against gypsy moth, *Lymantria dispar* (L.) in 1908. Liu and Mottern (2017) reported 7% parasitism of egg masses sampled and 20% parasitism of the eggs within the masses.

Table 5. Natural enemies found in association with spotted lanternfly, *Lycorma delicatula*.

Species name	Type	Life stage	Present in New Zealand
Anastatus orientalis	parasitoid	Egg	No
Dryinus browni	ectoparasitoid	Nymph	No *D. koebelei* present (parasitoid of 2 Flatidae species)
D. lycormae	ectoparasitoid	Nymph	No
Ooencyrtus kuvanae	parasitoid	Egg	No
Arilus cristatus	predator	Generalist	No
Apoecilus cynicus	predator		No

Predation of adult SLF by the wheel bug, *Arilus cristatus* (Hemiptera: Reduviidae) was observed in 2015 in Berks County, Pennsylvania (Barringer and Smyers 2016) (Figure 17). The predatory stink bug, *Apoecilus cynicus* (Hemiptera: Pentatomidae) has also been observed feeding on SLF adults in Berks County (Barringer and Smyers 2016). Some common insect predators, such as spiders and praying mantises, have been found to attack SLF in North America, however, these are unlikely to reduce their population to a manageable level.

Figure 15. *Anastatus orientalis,* an egg parasitoid of spotted lanternfly, *Lycorma delicatula* (Photo source Yang et al 2015b).

The role of entomopathogens as natural enemies of SLF remains unexplored. A report of a fungus found infecting SLF in North America was made last year, but the fungus is yet to be identified (TWG 2017).

The wet weather experienced in Berks County, Pennsylvania, recently has resulted in the growth of fungi that may kill SLF, according to Emelie Swackhamer, an educator with the Penn State Extension in Montgomery County. "Several different types of fungi, we believe, are starting to affect and kill them," she said. Researchers plan to study fungi as a potential control tool (Reading Eagle 2019).

SLF is equipped with natural defences to warn off potential natural enemies. It has been proposed that the cryptic forewing of SLF is an adaptation to blend into its surroundings while the rapid opening of the brightly coloured hindwings serves as an aposematic function, warning of unpalatability (Kang et al. 2011).

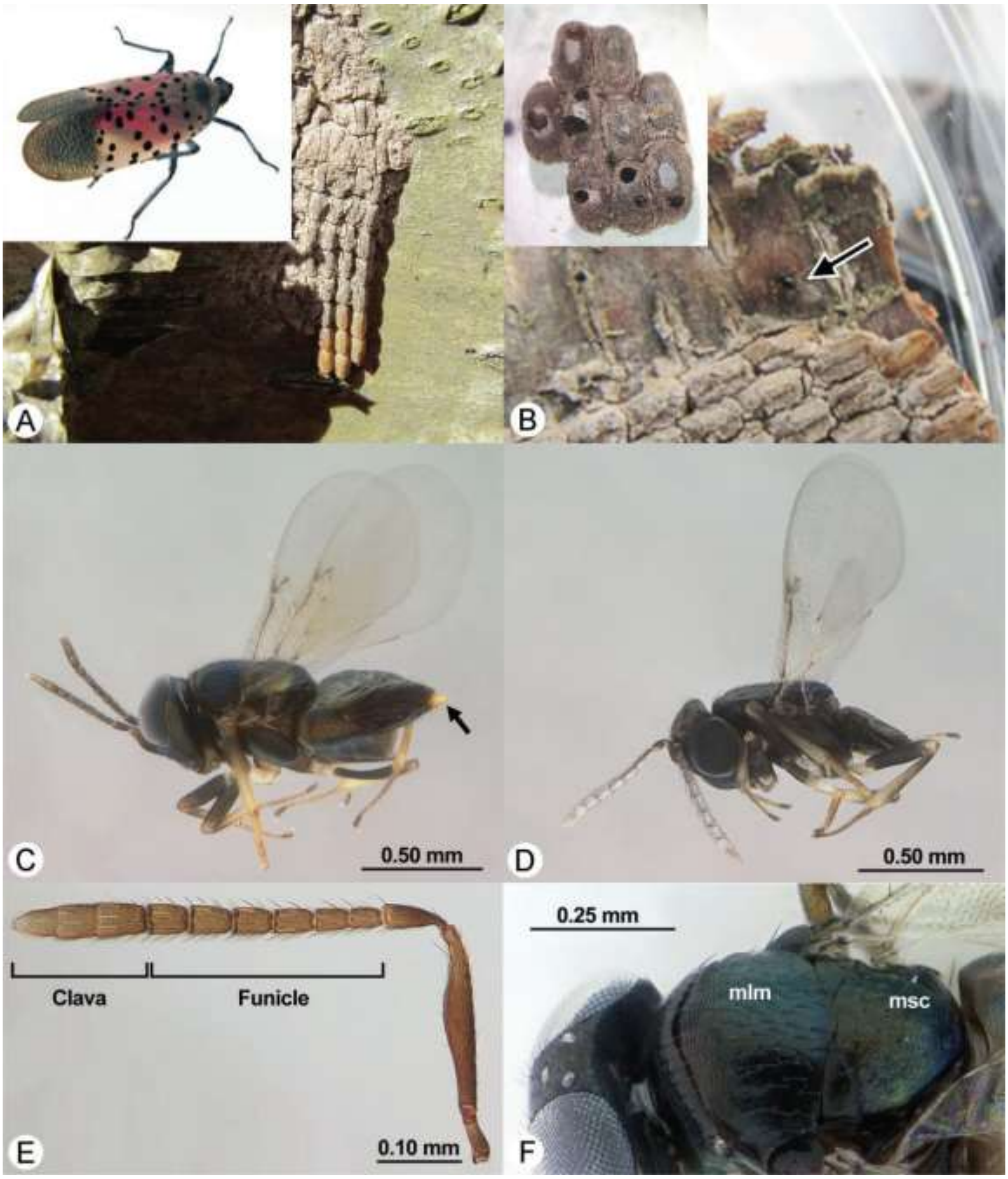

Figure 16. ***Ooencyrtus kuvanae,*** **an egg parasitoid of spotted lanternfly,** ***Lycorma delicatula*** **(A) SLF egg masses on bark of sweet birch; inset showing SLF adult. (B) SLF egg mass with arrow indicating with parasitoid emergence holes. (C)** ***Ooencyrtus kuvanae*****, female habitus. Arrow indicating exposed portion of ovipositor sheath. (D)** ***Ooencyrtus kuvanae*****, male habitus. (E)** ***Ooencyrtus kuvanae*****, female antenna. (F)** ***Ooencyrtus kuvanae*****, female showing relative sculpture of the midlobe of the mesoscutum (mlm) and the mesoscutellum (msc) (Sourced from Liu and Mottern (2017).**

Figure 17. The wheel bug, *Arilus cristatus,* a predator of spotted lanterfly, *Lycorma delicatula.*

It is also thought that the toxic metabolites sequestered by the SLF during feeding deter natural enemies (Xue and Yuan 1996). A survey of egg masses parasitised by *A. orientalis* found the parasitism rate was lowest when laid on *A. altissima* (27.4%) and much higher when laid on *Toona sinensis* (64.3%) (Choi et al. 2014). Kang et al. (2011) reported observing birds vomiting after eating SLF.

It is unclear to what extent natural enemies can control SLF. The natural enemies identified to date have the potential to be important biocontrol options for SLF in Asia and North America, with research underway on the species described above.

2 PEST MANAGEMENT

SLF is a difficult insect to manage primarily due to the diversity of egg laying surfaces, its host range, and its ability to repopulate areas soon after insecticides have been applied. In South Korea and northern America SLF is managed using a combination of cultural methods, host removal and insecticides, with monitoring playing a crucial role in identifying populations. In this section the literature was reviewed for existing management methods and associated information, this is discussed with reference to kiwifruit. A summary of both the current and potential management techniques is provided in Table 7 at the end of this section.

2.1 Monitoring techniques

Visual surveys are an essential method used to identify and monitor the presence of SLF, the locations where feeding damage has occurred, and areas where *A. altissima* and other preferred host plants are present (PDA 2018; TWG 2017; Pugh et al. 2015).

Tree banding is regarded as an effective method for monitoring and trapping SLF (Dara 2018) (Figure 18), for example, more than 1.7 million SLF were trapped using sticky bands in Pennsylvania in 2017 (Dara 2018). Choi et al. (2012) tested three colours of sticky traps and found that brown traps were the most attractive in trapping nymphs and adults. Though SLF can be found on many types of plants, they strongly prefer *A. altissima* and banding these trees is regarded as an effective method for monitoring SLF (Dara 2018). Tree bands tend to be most effective against young nymphs as they repeatedly ascend trees as part of their host selection (Kim et al. 2011c). Young nymphs can be captured on less stickier bands, however stickier and wider bands can be used to trap older nymphs and adults (Dara 2018). The insects can also be removed by hand due to their large size (Kang et al. 2011). In South Korea, Kim et al. (2011c) determined that the best location to set traps for adults was at the base of the preferred host species (including *A. altissima*, *B. platyphylla, E. daniellii*, and *P. amurense*) from August to October.

Figure 18. Tree banding for spotted lanternfly, *Lycorma delicatula* (Photo source Pennsylvania Department of Agriculture).

The use of attractants to improve monitoring is an active area of research. Extracts of *A. altissima* have been investigated as potential attractants for SLF, with *A. altissima* chloroform fractions identified as potential candidates (Lee and Park 2013). Moon et al. (2011) reported that both nymph and adult SLF were attracted to spearmint oil at low doses, and the oil could potentially be used in a lure and kill strategy.

2.2 Management options

2.2.1 Chemical

SLF is susceptible to broad-spectrum pyrethroids, organophosphate and neonicotinoid insecticides (Park et al. 2009; Shin et al. 2010; Hong et al. 2013). The following active ingredients are used in China and South Korea against nymphs and adults: deltamethrin, fenitrothion, imidacloprid, clothianidin (Park et al. 2009), and etofenprox + diazinon, chlorpyrifos, etofenprox, dinotefuran (Hong et al. 2013) (Table 6). Park et al (2009) reported that imidacloprid (4% SL) and clothianidin (8% SC) resulted in 100% insecticidal activity 24 h after treatment. Thiacloprid (10% SC) revealed the poorest insecticidal activity among the insecticides evaluated. In laboratory experiments against 1st and 2nd instar nymphs, the following were also effective: methidathion, phenthoate, bensultap, furathiocarb, bifenthrin, esfenvalerate, acetamiprid, thiamethoxam, chlorfenapyr, spinosad (Shin et al. 2010) (Table 6). Shin et al. (2010) also investigated insecticidal treatment for use against eggs, and found only chlorpyrifos provided mortality.

In China, active ingredients reported for use against SLF in kiwifruit include organophosphates, Trichlorfon (Dipterex) and Dichlorvos (DVVP), and botanical insecticides, Matrine, Nicouline and Azadirachtin (Zhang et al. 1994; Mi et al. 2007). Applications of organophosphates, DDVP and Omethoate, and the pyrethroid, Cyhalothrin, have been reported during the flowering period (Hong and Li 1994; Feng 2000).

In Pennsylvania, systemic insecticides, dinotefuran and imidacloprid, and contact insecticides, bifenthrin and carbaryl, are regarded as the most efficacious against SLF (Dara 2018). PennState Extension recommend the use of systemic insecticides in early summer before adults emerge and, providing the correct application method is used and flowering is avoided to protect pollinators, these remain efficacious into late summer (Leach et al. 2018). A combination of contact and systemic insecticides should be used to provide effective protection. Direct contact sprays are recommended for application to surfaces where SLF feed and walk (Leach et al. 2018).

Botanical insecticides have been evaluated against SLF in Korea. Pyrethrum, *Sophora* and neem extracts killed ≥95% of adults within 48 h, but were less effective against nymphs in some tests (Choi et al. 2012). Biologically-based insecticides, Entrust™ (spinosad) and Venerate™ XC (*Burkholderia spp.* strain), were evaluated and resulted in moderate nymph mortality after application but no control after seven days (Biddinger and Leach 2019). Studies have been conducted on the repellency of natural oils, with lavender oil showing some repellency effect against both adult and nymph SLF (Yoon et al. 2011).

Table 6. Insecticides tested against life stages of spotted lanternfly (SLF), *Lycorma delicatula.* Products marked with an * were highly effective against SLF in laboratory and/or field studies.

Active ingredients	Life stage affected	References
Organophosphates		
Chlorpyrifos	Eggs, 1st and 2nd instars, adult	Hong et al. 2013; Shin et al. 2010
Diazinon	1st, 2nd and 3rd instars	Hong et al. 2013
Fenitrothion	1st and 2nd instars	Park et al. 2009
Methidathion	1st and 2nd instars	Shin et al. 2010
Phenthoate	1st and 2nd instars	Shin et al. 2010
Malathion*		Leach et al. 2018
Trichlorfon		Zhang et al. 1994
Dichlorvos (DVVP)	1st and 2nd instars	Hong and Li 1994; Feng 2000
Omethoate	1st and 2nd instars	Hong and Li 1994
Phosmet		Biddinger and Leach 2019
Carbamates		
Bensultap	1st and 2nd instars	Shin et al. 2010
Furathiocarb	1st and 2nd instars	Shin et al. 2010
Carbaryl*		Dara 2018; Leach et al. 2018; Biddinger and Leach 2019
Pyrethroids		
Bifenthrin*	1st and 2nd instars	Shin et al. 2010; Dara 2018; Leach et al. 2018
Deltamethrin	1st, 2nd and 3rd instars	Park et al. 2009
Esfenvalerate	1st and 2nd instars	Shin et al. 2010
Etofenprox	1st and 2nd instars, adult	Hong et al. 2013
Cyhalothrin		Feng 2000
Zeta-cypermethrin*		Leach et al. 2018
Fluvalinate*		Leach et al. 2018
Neonicotinoids		
Acetamiprid	1st and 2nd instars	Shin et al. 2010; Biddinger and Leach 2019
Clothianidin	1st and 2nd instars	Park et al. 2009
Dinotefuran*	1st and 2nd instars, adult	Hong et al. 2013; Dara 2018; Leach et al. 2018
Imidacloprid*	1st and 2nd instars	Park et al. 2009; Dara 2018
Thiamethoxam*	1st and 2nd instars	Shin et al. 2010; Biddinger and Leach 2019
Thiacloprid		Park et al. 2009

Active ingredients	Life stage affected	References
Other including botanicals, bioinsecticides		
Chlorfenapyr	1st and 2nd instars	Shin et al. 2010
Spinosad Venerate XC	1st and 2nd instars	Shin et al. 2010; Leach et al. 2018
Sophora extract		Choi et al. 2012
Matrine		Mi et al. 2007
Nicouline		Mi et al. 2007
Azadirachtin		Mi et al. 2007
Neem (azadirachtin and neem oil)		Choi et al. 2012; Leach et al. 2018
Insecticidal soaps		Leach et al. 2018
Natural pyrethrins		Leach et al. 2018

Although many insecticides appear to be effective against SLF, it is difficult to deliver insecticide to the pest throughout its entire life cycle. Egg masses are protected by a waxy deposit and are sometimes laid in hard to reach locations, whilst targeting late instar nymphs and adults can be difficult as they become more mobile to actively seek out *A. altissima*. It is at this point that host tree reduction is performed in conjunction with insecticide application (Leach et al. 2018). Another challenge is preventing reinfestation of an area after the use of insecticides. In Korea, SLF was observed to rapidly repopulate pesticide-sprayed vineyards from nearby forested areas which contain suitable host species (Park et al. 2009).

Field trials are being conducted by PennState Extension to evaluate a wider range of insecticides, and to identify those most effective against SLF while posing the least risk to humans, beneficial insects, including pollinators and the environment (Leach et al. 2018). Active research is being conducted to develop programmes for fruit growers, including testing insecticides for use in vineyards, where in addition to the active ingredients mentioned above thiamethoxam has also shown excellent activity against SLF (Biddinger and Leach 2019).

2.2.2 Cultural

A number of cultural methods are essential in the successful management of SLF.

- A **winter clean-up** through pruning is performed to remove egg masses. Green waste sanitation can be achieved through burning and/or burial of contaminated material (Zhang 2013). Mid-winter wood chipping was deemed as an effective method for destroying egg masses of SLF (Cooperband et al. 2018).
- The **removal of preferred host plants**, in particular, *A. altissima*, is used as a method to reduce SLF populations (Leach et al. 2018). Reducing an area to 15%, at most, planted with *A. altissima* is considered as a primary strategy for preventing the spread of SLF; some trees, preferably males, should be retained for use as trap trees (Dara 2018). After removal, herbicide application is required as small pieces of remaining root can generate new shoots (TWG 2017). Herbicides recommended for this purpose tend to contain one of the following active ingredients: triclopyr, dicamba, imazapyr or glyphoshate.

- The purpose of **trap trees** is to attract SLF to the tree(s) with a subsequent insecticide applied, thereby reducing the population before it can spread (Swackhamer et al. 2018). The preferred trap tree is *A. altissima* (TWG 2017). Pennsylvania Department of Agriculture has elected to use a bark spray application of Dinotefuran with a targeted application method. The number of trap trees required per site has not yet been determined and the application of insecticide to the trap trees should be repeated each year until no further SLF are detected.
- **Egg mass scraping** has been used as an effective method for reducing SLF numbers. SLF eggs are laid on many surfaces including trees, rocks, and any other hard surfaces (Barringer 2014), and they can be scraped off a substrate by using a scraper card, putty knife, or similar tool (Seifrit 2019; Zhang 2013). It is unknown if eggs scraped onto the ground can survive so they should be scraped into a bag containing rubbing alcohol or hand sanitiser (Seifrit 2019). This is the most effective way to kill the eggs, but they can also be smashed or burned (Wu 2012). High pressure water jets have been used to destroy egg masses on trees (Chen 1996; Zheng 2015).

Preventing movement of all SLF life stages is achieved by inspecting potential sources such as woody plant debris, green waste, plants, or other objects, with any contaminated material found destroyed or disinfested (Dara 2018). The management of SLF in North America has a primary focus on early detection to prevent the spread of SLF to new locations. An alternative strategy that has yet to be investigated is netting the crop.

2.2.3 Biological

Natural enemies have been identified in China, South Korea and in North America (Section 1.8), and their use as biocontrol agents is under investigation. In China natural enemies are not yet used in human assisted biocontrol (e.g. *D. browni* (Yan et al. 2008); *D. lycormae* (Dong 1983; Yang 1994); *A. orientalis*, (Yang et al. 2015b; Kim et al. 2011b; Choi et al. 2014). However, it has been reported that some growers protect natural enemies by placing removed egg masses into a soft material to give access to parasitic wasps (Wu 2012). In Korea, in has been reported that preserving natural enemies could drastically reduce the risk of SLF reaching pest status (Park et al. 2009).

Entomopathogenic fungi *Beauveria bassiana*, *Isaria fumosorosea*, and *Metarhizium brunneum* may play a role alone or in combination with chemicals for controlling SLF. A Cornell extension specialist, Han Walter-Peterson, believes growers should consider using *Beauveria*-based biopesticides which have good activity against planthoppers (Growing Produce 2018).

2.2.4 Postharvest

Postharvest information available for SLF is limited to wood products in North America. The postharvest treatment options for wood products in Pennsylvania reported that heat treatment of 56°C for 30 mins will kill SLF egg masses on logs, and cold treatment would require a temperature of at least -25°C (EPPO 2016). Other methods considered included ionising radiation, kiln drying, chemical pressure impregnation and fumigation (EPPO 2016).

Table 7. Current and potential methods for pre- and postharvest management of spotted lanternfly, *Lycorma delicatula.* Note: Crop protection programme is abbreviated to CPP.

	Target life stage	Method	Expected outcomes(s)	Likely impact on SLF populations	Used elsewhere	Key limitation(s)	Ease of on orchard implementation	Technical difficulty of research	Relative development costs	Developmental time
Monitoring	All	Surveying	Detecting SLF and host plants	low	China, Korea, Pennsylvania	Survey areas may not be representative	easy	easy	low	<3yrs
	Nymph Adult	Optimising tree banding	Reduction in SLF abundance	medium	China, Korea, Pennsylvania	Not 100% effective at trapping adults	easy	easy	low	<3yrs
	Nymph Adult	Attractants	Improved SLF trapping. Use in attract and kill approach	medium	No. Experimental only	Ongoing replacement of attractant	easy	moderate	medium	4-6yrs
	Nymph Adult	Self-monitored traps	Improved monitoring; less labour intensive	medium	No	Specialist equipment maybe required	easy once research is complete	moderate	medium	4-6yrs
Chemical	Nymph Adult	Foliar sprays (contact)	Knock-down activity	low-medium	China, Korea, Pennsylvania	Short-lived activity. SLF move when disturbed; limited coverage. Limited to 4 pyrethrum insecticides in CPP	easy	easy	low	<3yrs
	Nymph Adult	Trunk sprays (systemic)	Persistent activity	medium	China, Korea, Pennsylvania	Limited to 1 systemic insecticide (Bifenthrin) in CPP	easy	easy	low	<3yrs
	Nymph Adult	Soil drench (systemic)	Persistent activity	medium	Korea, Pennsylvania	Toxicity. No insecticides available. Not compatible with CPP	moderate	moderate	medium	4-6yrs
	NA	Sooty mould preventative	Prevention of sooty mould	low	No	Product efficacy. Repeat applications	easy	low-medium	low-medium	4-6yrs
	Nymph Adult	New insecticides	New products available for use against SLF; inclusion in CPP	medium	Pennsylvania	Limited efficacy against all life stages. CPP compatibility, such as phytotoxicity, residues	easy	moderate	medium (if already present in NZ)	4-6yrs

	Target life stage	Method	Expected outcomes(s)	Likely impact on SLF populations	Used elsewhere	Key limitation(s)	Ease of on orchard implementation	Technical difficulty of research	Relative develop-ment costs	Develop-mental time
Cultural	Egg	Winter clean up	Removal of egg masses	medium	China, Korea, Pennsylvania	Egg masses occur on organic and insert materials	easy	easy	low	<3yrs
	Egg	Egg mass removal	Reduction in egg abundance	medium	China, Korea, Pennsylvania	Egg masses are sometimes hidden	easy	easy	low	<3yrs
	All	Primary host plant removal combined with herbicide application	Reduced number of host plants	medium	China, Korea, Pennsylvania	Unknown host range in New Zealand. Unknown impact of orchard gullies	easy	easy	low	<3yrs
	All	Trap trees	Reduction in SLF abundance	medium	China, Korea, Pennsylvania	Trap trees not available in all orchards	easy	easy	low	<3yrs
	Nymph Adult	Vibration Semiochemicals	Trap and kill approach	medium	No. Research only.	Specialist equipment maybe required	unknown	Moderate-high	medium-high	4-6yrs
Biological	Nymph Adult	Entomopathogens	Medium-term population suppression	medium	Research in Pennsylvania	Offshore products may not be suited for use in NZ and on kiwifruit	easy	moderate	medium-high	4-6yrs
	All	Classical biocontrol - introduction of new parasitoids	Ongoing population suppression	medium	Natural enemies identified. Research in Korea and Pennsylvania	No natural enemies identified in NZ. Identification and rearing of suitable parasitoid. Regulatory approvals	Easy, once research is complete	difficult	high	>7yrs
Post-harvest	NA	Sooty mould removal	Removal of sooty mould from fruit	low	No	Possible fruit damage. Technology availability	Moderate. Easy once technology in place	moderate	medium	4-6yrs
	Egg	Egg mass removal	Removal of eggs from fruit	low	No	Possible fruit damage. Technology availability	Moderate. Easy once technology in place	moderate	medium	4-6yrs
	Egg	Irradiation and/or fumigation treatments	Mortality of egg masses on fruit	low	Pennsylvania	Consumer acceptability. Possible fruit damage	Moderate	difficult	high	>7yrs

3 PEST MANAGEMENT IN KIWIFRUIT

SLF will require a high degree of control to meet the requirements of Zespri's kiwifruit export markets. As a result of cicada and passionvine hopper (PVH) feeding, sooty mould currently costs the industry an estimated $21 million per annum for control and postharvest activities alone (Elaine Gould, pers. comm.); this dollar value does not include thinning costs to remove sooty mould affected fruit or cultural practices that may be undertaken.

Damage caused by SLF to kiwifruit is likely to exceed that caused by PVH and cicadas. With estimated production losses as high as 80–90% (NZKGI 2018) and/or significant market access issues resulting from eggs present on fruit. SLF has the potential to stifle the kiwifruit supply chain and severely impact the industry's ability to export. As is the case with many kiwifruit insect pests, no 'magic bullet' is available to control SLF, and preventing such losses will require a combination of permitted insecticides, cultural methods, biological control, and new technologies such as lure and kill. Monitoring will play a crucial role to in determining population abundance and spread.

3.1.1 Chemical control

Of the active ingredients identified as efficacious against SLF, most are not permitted within the Zespri® Crop Protection Programme (CPP) (Section 2.2.1), primarily because of EU reductions in maximum residue limits (MRLs). The use of unpermitted active ingredients would impede the industry's access to export markets and social licence to operate, as well as disrupt the current kiwifruit IPM system. Many active ingredients included in Section 2.2.1 have been removed from the industries CPP in the last 10–15 years due to reductions in MRLs, for example, diazinon.

Of the insecticides tested offshore, bifenthrin, thiacloprid, pyrethrum and spinosad could be applied against SLF as these are currently permitted within the CPP at certain periods in the cropping cycle (Table 8). However, when tested offshore, only bifenthrin resulted in good activity against SLF. Currently many kiwifruit growers apply bifenthrin plus the super-penetrant Engulf® against passsionvine hopper (PVH) and cicada eggs in winter, and it is possible that this combination would have activity against SLF eggs laid on kiwifruit vines. An application of bifenthrin in late winter or early spring when the nymphs start to emerge could also contribute to population reductions.

The efficacy of Movento® 100SC or mineral oil has not been evaluated against SLF. The current timing of Movento 100SC or mineral oil applications in kiwifruit would coincide with SLF egg hatch and the presence of 1st and 2nd instar nymphs. Both products are most efficacious against immature insect life stages, and it is possible that a spring application of Movento 100SC (plus penetrant plus spreader) and/or mineral oil would impact against early nymphs. Studies to evaluate the efficacy of these current winter/spring treatments against appropriate SLF life stages are warranted.

Few insecticides are currently permitted on kiwifruit vines between fruit-set and harvest, and the opportunity for further chemical control of SLF on kiwifruit vines would likely be limited. Moderate mortality of SLF nymphs has been reported from an application of Spinosad (Table 6), and when applied post-fruit set against leafrollers, could result in mortality of late 1st or 2nd instar nymphs. Later in the season (summer/autumn) many growers use pyrethrum against PVH and greenhouse thrips on kiwifruit vines, and this treatment could contribute to a reduction in SLF adults. However, although efficacy has been reported (Shin et al. 2010; Leach et al. 2018), further invasion of the crop by SLF adults could mean any effect is likely to be short-lived.

Table 8. Insecticides listed in the Zespri® crop protection programme that have, or may have, activity against spotted lanternfly, *Lycorma delicatula.* The SLF life stage present when each insecticide is permitted for use is also listed, as are the key knowledge gaps and limitations.

Crop period	Active ingredients/ insecticides permitted	SLF life stage(s) present	Knowledge gaps and limitations
Dormancy	Bifenthrin (plus Engulf®)	Eggs 1st and 2nd instar nymphs	Unknown efficacy against eggs Possible phase-out
	Mineral oil	Eggs 1st and 2nd instar nymphs	Unknown efficacy Possible phase-out
Budphase	Thiacloprid	1st and 2nd instar nymphs	Limited efficacy Possible phase-out
	Spirotetramat	1st and 2nd instar nymphs	Unknown efficacy
	Mineral oil	1st and 2nd instar nymphs	Unknown efficacy Possible phase-out
Fruit set to monitoring	Spinosad	1st and 2nd instar nymphs	Moderate efficacy after application, no efficacy after 7 days
	Mineral oil	Nymphs Adults	Unknown efficacy Possible phase-out
	Pyrethrum	Adults	Specific products not tested against SLF, SLF flies away after spraying then returns

3.1.2 Cultural control

A number of cultural control techniques implemented in China, Korea and Pennsylvania to help manage SLF could be readily adopted in kiwifruit orchards in New Zealand if required.

The removal of *A. altissima* is common practice in management programmes against SLF, and efforts to expedite the removal of this primary SLF host plant could potentially slow the spread and increase of SLF populations should the pest establish in New Zealand. This tree is classified as a noxious weed in New Zealand, but eradication does not appear to be a current priority. Other primary and secondary host plants, especially those favoured by the early instar polyphagous nymphs, are likely to be abundant within kiwifruit orchards or neighbouring gullies, parks and gardens. Identification of these host plants and removal (or treatment where removal is not feasible), will likely help reduce the increase and spread of SLF into kiwifruit blocks.

Egg mass removal and destruction from infested kiwifruit vines and the canopy frame is practised in China (Wu 2012; Zhang 2013). This practice would fit with current orchard activities in winter, that is, some egg masses would be removed during pruning, with destruction via double mulching of the pruned plant material. Using a specially designed ‘scraper’ to remove egg masses from the vine trunk and leader could potentially be completed alongside the pruning, either by the pruners or by dedicated personnel.

SLF have been used in Chinese medicine since the 12th century, primarily for relief from swelling (Choi et al. 2002). In a recent study, aqueous fractions of SLF have been shown to reduce inflammatory indicators (Baek et al. 2018). Consideration could be given to the use of unwanted SLF biomass for such purposes.

Banding crop plants and trap trees to reduce the abundance of SLF is employed in Korea and Pennsylvania to reduce the abundance of SLF (Choi et al. 2012; Dara 2018). New Zealand kiwifruit growers have had considerable previous experience with banding as a control tool against Fuller’s rose weevil (McKenna et al. 2002). The re-introduction of vine banding is a potential management option, pending efficacy testing in the kiwifruit landscape. Banding trap trees may help remove a portion of the SLF population, but this would be need to be augmented with appropriately timed sprays.

A number of growers are using nets to cover their kiwifruit blocks; some blocks have been netted on all sides, while others are netted on the top only. These nets may have the potential to exclude SLF from the crop, however, there are a number of limitations associated with exclusion nets including negative impacts on dry matter, pollination and increasing populations of other pests. These limitations are currently being investigated in a separate review (McKenna in prep).

Identification of attractants based on pheromones, plant extracts or vibration would allow for the development of lure and kill technology. To this end, collaborations between New Zealand and US researchers should be maintained and strengthened.

3.1.3 Biocontrol

At present no known biological control agents of SLF have been identified as present in New Zealand, and a classical biocontrol programme would be required for biocontrol to have a role in the long-term management of SLF populations. The use of biopesticides and entomopathogens as control agents has received little focus offshore and also warrants investigation.

3.1.4 Summary

Table 9 summarises methods potential methods that could enable management of SLF in kiwifruit. Some methods would be relatively easy to adopt in a short period of time (less than three years), including surveying, tree banding, the use of insecticides currently permitted in the CPP, winter clean-up, egg mass removal, host plant removal and the use of trap trees. Other methods will take longer to implement because of current knowledge gaps and the lack of available technologies. The most significant gaps include the absence of efficacious and safe insecticides for use against SLF, a lack of knowledge on the host plant range of SLF in New Zealand and biological knowledge that could be used to enhance cultural methods and used to develop lure and kill technologies, and a lack of knowledge of the use of biocontrol agents in New Zealand. It is likely that successful management of SLF will only be achieved when these are knowledge gaps have been addressed.

Table 9. A potential management plan for spotted lanternfly, *Lycorma delicatula*, in kiwifruit (based on methods currently available). Techniques marked with an asterisk (*) would be not be suitable for use in organic orchards.

Period	Method	Active Ingredient	Product name (available in Zealand)	Allowed in CPP	Adverse impact risk	Comments
Dormancy	Winter pruning followed by double mulching	NA	NA	Yes	None	
	Egg mass scraping and destruction	NA	NA	Yes	None	
	*Insecticide applied to vines	Bifenthrin	Talstar®100EC plus Engulf® Venom®	Yes	High	Targeted at eggs on vines. May require specialised nozzles
	Primary host plant removal followed up with *herbicide application	Herbicide		Yes	Low	Glyphosate is efficacious against Tree of Heaven
Bud Phase	Vine banding	NA	NA	Yes	None	
Flowering	Vine banding	NA	NA	Yes	None	
Fruit set to monitoring	Host tree banding	NA	NA	Yes	None	
	Trap tree spraying	Pyrethrum Bifenthrin	Pyganic®, ZETaPY, Pylon®, Talstar 100EC plus Engulf	Yes	Moderate	Late afternoon application. Apply to trap trees only in and around orchard
	Contact insecticide to vines	Spinosad	Success™ Naturalyte™, Entrust™ Naturalyte™	Yes	Low	Restrictions on maximum number and timing of sprays
	Contact insecticide to vines	Pyrethrum	Pyganic, ZETaPY, Pylon	Yes	Moderate	Late afternoon application
Monitoring	Egg mass removal and destruction	NA	NA	Yes	None	
	Tree banding	NA	NA	Yes	None	
	Trap tree spraying	Pyrethrum Bifenthrin	Pyganic, ZETaPY, Pylon, Talstar 100EC plus Engulf	Yes	Moderate	Late afternoon application. Not applied to vine only trap trees in and around orchard
	Contact insecticide to vines	Pyrethrum	Pyganic, ZETaPY, Pylon	Yes	Moderate	Late afternoon application
	Sooty mould prevention	*Bacillus amyloliquefaciens*	Triple X	Yes	Low	Use as preventative, spray at 2-3 weekly intervals. Up to 9 applications permitted
Postharvest	Egg mass removal and destruction	NA	NA	Yes	None	
	*Insecticide to vines	Bifenthrin	Talstar 100EC plus Engulf	Yes	High	1 spray per period Targeted at eggs on canes

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APPENDIX 1. HOST PLANT LIST FOR SPOTTED LANTERNFLY, *LYCORMA DELICATULA* (WHITE 1845) (EPPO 2016 USED AS BASIS FOR APPENDIX 1)

Family	Host species	Common name	E	N or A	Feeding observed	References
Actinidiaceae	*Actinidia chinensis*	China Gooseberry		✓	✓	Korea (nymph) (Park et al. 2009); China (feeding, adults and nymphs; Du et al. 2010; Pei and Wang 2001; Zhang et al. 1994; Zhang 2013; Dai 2012; Wu 2012; Zhao et al. 2001; Cai and Wu 2013; Feng 2003; Hong and Li 1994;Li 2006; Mi et al. 2007; Feng 2000; Yuan et al. 1997; Du et al. 2011).
Anacardiaceae	*Rhus* (*Toxicodendron*) *verniciflua*	Chinese Lacquer Tree		✓		Korea (nymph) (Park et al. 2009)
Anacardiaceae	*Rhus javanica*	Macassar Kernels		✓		Korea (nymph) (Park et al. 2009)
Anacardiaceae	*Rhus typhina*	Staghorn Sumac				China (Wang et al. 2015)
Apiaceae	*Angelica dahurica*	Chinese Angelica		✓		Herbaceous (probably nymphs only). Korea (nymph) (Park et al. 2009)
Apocynaceae	*Metaplexis japonica*	Rough Potato		✓		Korea (nymph) (Park et al. 2009)
Araliaceae	*Aralia cordata*	Japanese Spikenard		✓		Herbaceous (probably nymphs only). Korea (nymph) (Park et al. 2009)
Araliaceae	*Aralia elata*	Japanese Angelica		✓		Herbaceous (probably nymphs only). Korea (nymph) (Park et al. 2009)
Asteraceae	*Arctium lappa*	Greater Burdock		✓		Herbaceous (probably nymphs only). Korea (nymph) (Park et al. 2009)
Asteraceae	*Callistephus chinensis*	China Aster		✓		Herbaceous (probably nymphs only). China (CropIPM 2009)
Betulaceae	*Alnus hirsuta*	Manchurian Alder		✓		Korea (nymph) (Park et al. 2009).
Betulaceae	*Betula lenta*	Cherry Birch		✓		USA (captures on sticky bands) (EPPO 2016)
Betulaceae	*Betula papyrifera*	Paper Birch		✓		USA (captures on sticky bands) (EPPO 2016)
Betulaceae	*Betula platyphylla*	Manchurian Birch	✓	✓	✓	Korea (adult, nymph) (Park et al. 2009); confirmed feeding, egg-laying (PennState Extension 2015)
Betulaceae	*Betula platyphylla var. japonica*	Japanese White Birch	✓			Korea (egg laying) (Kim et al. 2011c)
Bignoniaceae	*Catalpa bungei*	Manchurian Catalpa				China (Chou 1946; Chou et al.1985)
Buxaceae	*Buxus microphylla*	Asian Boxwood				China (Chou 1946; Chou et al. 1985)
Cannabaceae	*Cannabis sativa*	Common Hemp		✓		Herbaceous (probably nymphs only). China (Chou 1946; Chou et al. 1985)
Cannabaceae	*Humulus lupulus*	Common Hop				Herbaceous. Popular articles only.
Celastraceae	*Celastrus orbiculatus*	Chinese Bittersweet		✓		USA (captures on sticky bands) (EPPO 2016)
Cornaceae	*Cornus*			✓		USA (resting/aggregating) (Barringer et al. 2015)
Cornaceae	*Cornus controversa*	Giant Dogwood		✓	✓	University of Delaware 2015 (in a general list of hosts). Confirmed feeding (PennState Extension 2015)

Family	Host species	Common name	E	N or A	Feeding observed	References
Cornaceae	*Cornus kousa*	Chinese Dogwood		✓	✓	University of Delaware 2015 (in a general list of hosts); confirmed feeding (PennState Extension 2015)
Cornaceae	*Cornus officinalis*	Japanese Cornel		✓	✓	University of Delaware 2015 (in a general list of hosts); confirmed feeding (PennState Extension 2015)
Cornaceae	*Nyssa sylvatica*	Black Gum		✓		USA (captures on sticky bands) (EPPO 2016)
Cupressaceae	*Juniperus*(*Sabina*) *chinensis*	Hollywood Juniper		✓	✓	China (Li et al. 2013)
Cupressaceae	*Platycladus orientalis*	Dwarf Golden Cedar		✓	✓	China (Li et al. 2013)
Ebenaceae	*Diospyros kaki*	Persimmon	✓			China (egg-laying; Zu 1992)
Elaeagnaceae	*Elaeagnus umbellata*	Japanese Silverberry		✓	✓	University of Delaware 2015 (in a general list of hosts). confirmed feeding (PennState Extension 2015)
Euphorbiaceae	*Mallotus japonicus*			✓	✓	Japan [not considered as hosts but 'adults depend upon'] (adult feeding; Tomisawa et al. 2013)
Fabaceae	*Acacia*					Southern China (Li et al. 1997)
Fabaceae	*Albizia julibrissin*	Silk Tree				China (Chou 1946, Chou et al. 1985)
Fabaceae	*Colutea arborescens*	Bladder Senna				China (Chou 1946)
Fabaceae	*Glycine max*	Soybean		✓		Herbaceous (probably nymphs only) China (Wang et al. 2000; Chou et al. 1985)
Fabaceae	*Maackia amurensis*	Amur Maackia		✓		Korea (nymph) (Park et al. 2009)
Fabaceae	*Robinia pseudoacacia*	Black Locust	✓	✓	✓	China (Chou 1946, Chou et al. 1985) Wang et al. 2000; Japan (egg laying) (Tomisawa et al. 2013). Confirmed feeding (PennState Extension 2015; Yang et al. 2014 [EPPO 2016]).
Fabaceae	*Sophora japonica*	Japanese Pagoda Tree	✓			China (eggs, low hatching rate; Chou 1946; CropIPM.com 2009)
Fagaceae	*Castanea crenata*	Japanese Chestnut	✓			University of Delaware 2015 (in a general list of hosts). Egg-laying (PennState Extension 2015)
Fagaceae	*Fagus grandifolia*	American Beech	✓			USA (egg-laying) (Barringer et al. 2015)
Fagaceae	*Quercus*					China (Chou 1946, Chou et al. 1985)
Fagaceae	*Quercus acutissima*	Sawtooth Oak	✓			Japan (egg laying) (Tomisawa et al. 2013)
Fagaceae	*Quercus aliena*	Oriental White Oak		✓		Korea (nymph) (Park et al. 2009)
Fagaceae	*Quercus montana* (syn. *Q. prinus*)	Chestnut Oak	✓	✓		USA (egg-laying) (Barringer et al. 2015) USA (captures on sticky bands) (EPPO 2016)
Fagaceae	*Quercus rubra*	American Red Oak		✓		USA (captures on sticky bands) (EPPO 2016)
Hydrangeaceae	*Philadelphus schrenckii*			✓		Korea (nymph) (Park et al. 2009)
Juglandaceae	*Carya glabra*	Pignut Hickory		✓		USA (captures on sticky bands) (EPPO 2016)
Juglandaceae	*Carya ovata*	Shagbark Hickory		✓		USA (captures on sticky bands) (EPPO 2016)
Juglandaceae	*Juglans*					China (CropIPM.com 2009)
Juglandaceae	*Juglans hindsii*	Californian Black Walnut		✓	✓	China (Zhang 2001 – adult and nymph feeding)

Family	Host species	Common name	E	N or A	Feeding observed	References
Juglandaceae	*Juglans major*	Arizona Walnut		✓	✓	China (Zhang 2001 – adult and nymph feeding)
Juglandaceae	*Juglans mandshurica*	Manchurian Walnut		✓		Korea (nymph, adult) (Park et al. 2009)
Juglandaceae	*Juglans microcarpa*	Texas Walnut		✓	✓	China (Zhang 2001 – adult and nymph feeding)
Juglandaceae	*Juglans nigra*	Black Walnut		✓	✓	China (Zhang 2001 – adult and nymph feeding); Korea (nymph) (Park et al. 2009), USA (captures on sticky bands) (EPPO 2016)
Juglandaceae	*Juglans sinensis* (syn. of *Juglans regia* var. *orientis)*	Chinese Walnut		✓		Korea (nymph) (Park et al. 2009)
Juglandaceae	*Platycarya strobilacea*					China (Chou et al. 1985)
Juglandaceae	*Pterocarya stenoptera*	Chinese Wingnut		✓		Korea (nymph) (Park et al. 2009), China (Chou 1946)
Lauraceae	*Sassafras albidum*	Common Sassafras		✓		USA (captures on sticky bands) (EPPO 2016)
Lythraceae	*Punica granatum*	Pomegranate	✓	✓	✓	China (Hou 2013 as pomegranate, major damage = adults)
Magnoliaceae	*Liriodendron tulipifera*	Tuliptree	✓	✓		USA (egg-laying) (Barringer et al. 2015), USA (captures on sticky bands) (EPPO 2016)
Magnoliaceae	*Magnolia kobus*	Kobus Magnolia		✓		Korea (nymph) (Park et al. 2009)
Magnoliaceae	*Magnolia obovata*	Japanese Big-Leaved Magnolia		✓		Korea (nymph) (Park et al. 2009)
Malvaceae	*Alcea* (*Althaea*) *rosea*	Garden Hollyhock		✓		Herbaceous. China (Lieu 1934 – habitat, nymphs)
Malvaceae	*Firmiana simplex*	Chinese Parasol Tree		✓		Korea (nymph) (Park et al. 2009); China (Chou 1946; Chou et al. 1985)
Malvaceae	*Hibiscus*					CropIPM.com 2009
Meliaceae	*Cedrela fissilis*	Argentine Cedar		✓		Korea (adult, nymph) (Park et al. 2009)
Meliaceae	*Melia azeradach*			✓	✓	China (Chou 1946; Chou et al. 1985; [EPPO 2016]); Japan (nymphs, adults; Tomisawa et al. 2013)
Meliaceae	*Toona* (*Cedrela*) *sinensis*	Chinese Mahogany	✓	✓	✓	Korea (adult, nymph) (Park et al. 2009); China (Chou et al. 1985; Li et al. 1997; Chou 1946). Confirmed feeding, egg-laying (PennState Extension 2015)
Moraceae	*Broussonetia papyrifera*	Paper Mulberry				China (CropIPM.com 2009)
Moraceae	*Ficus carica*	Common Fig				China (Cai and Wu 2013)
Moraceae	*Morus alba*	White Mulberry		✓		Korea (nymph) (Park et al. 2009)
Moraceae	*Morus bombycis*	Japanese Mulberry		✓		Korea (nymph) (Park et al. 2009)
Oleaceae	*Fraxinus*		✓			Korea Rep. (eggs, EPPO 2016)
Oleaceae	*Fraxinus americana*	White Ash		✓		USA (captures on sticky bands) (EPPO 2016)
Oleaceae	*Ligustrum lucidum*	Chinese Privet				China (Chou 1946; Chou et al.1985)
Oleaceae	*Osmanthus*					China (CropIPM.com 2009)
Oleaceae	*Syringa vulgaris*	Common Lilac	✓			Korea (egg laying) (Kim et al. 2011c)
Onagraceae	*Epilobium angustifolium*	Fireweed		✓		Herbaceous (probably nymphs only). China (CropIPM 2009)
Paulowniaceae	*Paulownia kawakamii*					China (Xiao 1992)

Family	Host species	Common name	E	N or A	Feeding observed	References
Paulowniaceae	*Paulownia shensiensis* (= *P. tomentosa* var. *tsinlingensis*)					China (Chou 1946; Chou et al. 1985)
Platanaceae	*Platanus occidentalis*	American Sycamore	✓	✓		USA (egg-laying) (Barringer et al. 2015), (adult feeding and egg-laying; USDA 2014), USA (captures on sticky bands) (EPPO 2016)
Platanaceae	*Platanus orientalis*	Oriental Plane		✓		Korea (adults) (Han et al. 2008); China (Chou 1946; Chou et al. 1985)
Poaceae	*Phyllostachys heterocycla*	Tortoise-Shell Bamboo				China (Zhao 2006)
Rosaceae	*Amelanchier canadensis*	Juneberry		✓		USA (captures on sticky bands) (EPPO 2016)
Rosaceae	*Malus*			✓	✓	China (adults, Han et al. 2008 citing others; Biosecurity Australia 2009; Zheng et al. 2009; Wang 2008)
Rosaceae	*Malus pumila*	Paradise Apple	✓	✓	✓	Korea Rep. (eggs, EPPO 2016) China (Zheng et al. 2009 – nymph and adult feeding); PennState Extension 2015 (in a list of hosts, no details on life stages)
Rosaceae	*Malus spectabilis*	Chinese Flowering Crab Apple				China (Chou 1946; Chou et al. 1985)
Rosaceae	*Prunus armeniaca*	Apricot	✓	✓	✓	China (Chou 1946; Zhai et al. 2014 as apricots, major damage; Chou et al. 1985 also eggs)
Rosaceae	*Prunus cerasus (Cerasus)*	Sour Cherry				China (Chou et al. 1985)
Rosaceae	*Prunus mume*	Japanese Apricot		✓	✓	China (Han et al. 2008 citing others; adults). Confirmed feeding (PennState Extension 2015)
Rosaceae	*Prunus persica*	Peach		✓	✓	China (Chou 1946 Han et al. 2008 citing others; adults; Chou et al. 1985). Confirmed feeding (PennState Extension 2015)
Rosaceae	*Prunus salicina*	Japanese Plum		✓	✓	China (Han et al. 2008 citing others, adults; Chou 1946). Confirmed feeding (PennState Extension 2015)
Rosaceae	*Prunus serotina*	Black Cherry	✓	✓		USA (resting/aggregating, egg laying) (Barringer et al. 2015), USA (captures on sticky bands) (EPPO 2016)
Rosaceae	*Prunus serrulata var. spontanea*	Japanese Flowering Cherry	✓			Korea (egg laying) (Kim et al. 2011c)
Rosaceae	*Prunus* x *yedoensis*	Hybrid Cherry	✓			China (Chou 1946, Chou et al. 1985); Korea (egg laying) (Kim et al. 2011c)
Rosaceae	*Pyrus*		✓	✓	✓	China (Yang et al. 2015a)
Rosaceae	*Rosa hybrida*	Rose		✓		Korea (nymph) (Park et al. 2009)
Rosaceae	*Rosa multiflora*	Multiflora Rose		✓		Korea (nymph) (Park et al. 2009)
Rosaceae	*Rosa rugosa*	Rugosa Rose		✓		Korea (nymph) (Park et al. 2009)
Rosaceae	*Rubus crataegifolius*	Hawthorn Raspberry		✓		Korea (nymph) (Park et al. 2009)
Rosaceae	*Sorbaria sorbifolia*	False Spiraea		✓		Korea (nymph) (Park et al. 2009); China (Chou, 1946; Chou et al. 1985)
Rosaceae	*Sorbus commixta*	Japanese Rowan		✓		Korea (nymph) (Park et al. 2009)
Rutaceae	*Evodia(=Tetradium) danielii*	Bee-bee Tree	✓	✓	✓	Korea (adult, nymph) (Park et al. 2009) Korea (egg laying, adult feeding) (Kim et al. 2011c)

Family	Host species	Common name	E	N or A	Feeding observed	References
Rutaceae	*Phellodendron amurense*	Amur Cork Tree	✓	✓	✓	Korea (adult, nymphs) (Park et al. 2009; Kim et al. 2011c); USA (feeding) (Barringer et al. 2015); China (Wang 2005; Chen 1996)
Rutaceae	*Zanthoxylum bungeanum*	Chinese Pepper Tree	✓	✓	✓	China (Gao 1993)
Salicaceae	*Populus alba*	White Poplar	✓			Korea (egg laying) (Kim et al. 2011c)
Salicaceae	*Populus grandidentata*	Big-toothed Aspen		✓		USA (captures on sticky bands) (EPPO 2016)
Salicaceae	*Populus koreana*	Korean Poplar		✓		Korea (adult) (Park et al. 2009)
Salicaceae	*Populus simonii*	Chinese Poplar				China (Chou 1946)
Salicaceae	*Populus tomentiglandulosa*			✓		Korea (adults) (Han et al. 2008)
Salicaceae	*Populus tomentosa*	Chinese White Poplar				China (Wang et al. 2015)
Salicaceae	*Salix*		✓	✓	✓	USA (feeding) (Barringer et al. 2015), (feeding and egg-laying) (USDA 2014), USA (captures on sticky bands) (EPPO 2016)
Salicaceae	*Salix babylonica*	Weeping Willow		✓		China (Lieu 1934)
Salicaceae	*Salix matsudana*	Corkscrew Willow		✓	✓	China (Lieu 1934); USA (feeding) (Barringer et al. 2015). Confirmed feeding (adult) (PennState Extension 2015)
Salicaceae	*Salix udensis*	Sakhalin Willow		✓	✓	USA (feeding) (Barringer et al. 2015). Confirmed feeding (adult) (PennState Extension 2015)
Sapindaceae	*Acer buergerianum*	Trident Maple				China (Chou 1946; Xiao 1992)
Sapindaceae	*Acer mono*	Mono Maple				China (Chou 1946; Xiao 1992)
Sapindaceae	*Acer palmatum*	Japanese Maple	✓	✓	✓	Korea (egg laying) (Kim et al. 2011c), Japan (general search), confirmed feeding and egglaying (PennState Extension 2015), USA (captures on sticky bands) (EPPO 2016)
Sapindaceae	*Acer platanoides*	Norway Maple		✓		USA (captures on sticky bands) (EPPO 2016)
Sapindaceae	*Acer rubrum*	Red Maple	✓	✓		USA (resting/aggregating, egg laying) (Barringer et al. 2015), USA (captures on sticky bands) (EPPO 2016)
Sapindaceae	*Acer saccharum*	Sugar Maple		✓	✓	USA (feeding) (Barringer et al. 2015); Korea (as *Acer saccharinum*) (Kim et al. 2011c), USA (captures on sticky bands) (EPPO 2016)
Simaroubaceae	*Ailanthus altissima*	Tree of Heaven	✓	✓	✓	Korea (adult, nymph: Park et al. 2009, egg laying Kim et al. 2011c); Japan (Tomisawa et al. 2013); USA (Barringer et al. 2015); China (Chou 1946; Ni et al. 2004; Zheng 2015; Li 1578; Lieu 1934; Chou et al. 1985; Wang et al. 2015; Bai 2004; Chen 2011; Pei and Wang 2001; Cai and Wu 2013; Dong 1983; Yuan et al. 1997; Du et al. 2011; Wang et al. 2000; Liu 1939; Li et al. 2013).
Simaroubaceae	*Picrasma quassioides*	Nigaki		✓		Korea (adults, nymphs) (Park et al. 2009)
Solanaceae	*Nicotiana*					China (as tobacco, Yuan et al. 1997)
Styracaceae	*Styrax japonicum*		✓	✓	✓	Korea (nymph, adult) (Park et al. 2009); Japan (egg laying and adult feeding) (Tomisawa et al. 2013); USA (feeding) (Barringer et al. 2015). Confirmed feeding (adult, nymph; PennState Extension 2015)

Family	Host species	Common name	E	N or A	Feeding observed	References
Styracaceae	*Styrax obassia*	Big-Leaf Storax		✓	✓	Korea (nymph) (Park et al. 2009). Confirmed feeding (adult, nymph; PennState Extension 2015)
Tamaricaceae	*Tamarix chinensis*	Chinese Tamarisk				China (Wang et al. 2015)
Theaceae	*Camellia sinensis*	Tea		✓		China (probably nymphs or adults, Mei et al. 2011)
Tilioideae	*Tilia americana*	American Basswood		✓		USA (captures on sticky bands) (EPPO 2016)
Ulmaceae	*Ulmus pumila*	Dwarf Asiatic Elm				China (Chou 1946; Chou et al. 1985)
Ulmaceae	*Ulmus rubra*	Slippery Elm		✓		USA (captures on sticky bands) (EPPO 2016)
Ulmaceae	*Zelkova serrata*	Japanese Zelkova	✓			Korea (egg laying) (Kim et al. 2011c)
Vitaceae	*Parthenocissus quinquefolia*	Virginia Creeper		✓	✓	Korea (adult, nymph) (Park et al. 2009), China (EPPO 2016)
Vitaceae	*Vitis amurensis*	Amur Grape		✓		Korea (adult, nymph) (Park et al. 2009); China (Liu et al. 2015)
Vitaceae	*Vitis sp.*			✓	✓	USA (wild *Vitis,* feeding) (Barringer et al. 2015); China (Wang et al. 2000; CropIPM.com 2009; Qi et al. 2007), USA (captures on sticky bands) (EPPO 2016)
Vitaceae	*Vitis vinifera*	Wine Grape	✓	✓	✓	Korea (eggs, adult, nymph) (Park et al. 2009; EPPO 2016). Confirmed feeding, egg-laying (PennState Extension 2015); China (eggs, nymphs, adults, feeding; Chou 1946; He et al. 2007; Feng 2012; Yang et al. 2015a; Qiu et al. 1991; Feng 2012; Lieu 1934; Chou et al. 1985; Wang et al. 2006; Zhu et al. 1997; Zhang et al. 2002; Wang et al. 2011; Qi et al. 2007; Chen and Wang 2010; Xue and Jiao 2002; Xue 2004; Zhao 2006; Zhang and Cheng 2000; Qiu et al. 1994; Ge 2008; Li et al. 2009).

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