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Pest risk assessment: *Lycorma delicatula* (Spotted lanternfly)

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Pest Risk Assessment: *Lycorma delicatula* (Spotted lanternfly)

Version 1.0

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Approved for general release

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New Zealand is a member of the World Trade Organisation and a signatory to the Agreement on the Application of Sanitary and Phytosanitary Measures ("The Agreement"). Under the Agreement, countries must base their measures on an International Standard or an assessment of the biological risks to plant, animal or human health.

This document provides a scientific analysis of the risks associated with *Lycorma delicatula* on multiple pathways. It assesses the likelihood of entry, exposure, establishment and spread of *Lycorma delicatula* in relation to all potential pathways and assesses the potential impacts of this organisms should it enter and establish in New Zealand. The document has been internally and externally peer reviewed and is now released publicly. Any significant new science information received that may alter the level of assessed risk will be included in a review, and an updated version released.

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Executive summary

Purpose

This document assesses the biosecurity risks associated with *Lycorma delicatula* entering New Zealand via all likely entry pathways. The results of this work will support a review of the effectiveness of risk management on the main entry pathways for *L. delicatula*. The analysis also considers surveillance, monitoring and management options.

Background

Lycorma delicatula is a phloem feeding hemipteran insect in the family Fulgoridae. Native to China, *L. delicatula* is a known hitchhiker species that is invasive in South Korea, and the USA (Pennsylvania), where it continues to spread. Commonly known as the spotted lanternfly (SLF), *L. delicatula* causes significant feeding damage to a wide array of economically important crop species when it is at high abundance. In addition to the physical damage it causes, SLF excretes large quantities of honeydew, which promotes growth of sooty mould where it falls. This sooty mould inhibits photosynthesis and reduces plant growth. Sap from feeding wounds and the honeydew excreted by the bug may also attract large numbers of ants, bees, hornets, and wasps.

Risk Assessment Findings

Lycorma delicatula is not present in New Zealand. This analysis examines the risk of *L. delicatula* entering New Zealand as a hitchhiker on inanimate pathways, such as containers and their contents, and new and used vehicles, machinery and equipment. The analysis also examines the risk of entry of *L. delicatula* adults, nymphs and eggs associated with nursery stock, and cut flowers and foliage, as well as on the passenger and personal effects pathways, the courier pathways, sea vessels and aircraft and forest products.

Likelihoods of entry and exposure are assessed separately for each pathway. The highest likelihood of entry was considered to be on inanimate pathways, forest products and associated with passenger personal effects. The life stage considered to be most likely to enter New Zealand is overwintering egg masses, however, given the hatching times at temperatures typically experienced on-board container ships, and the duration of journeys from countries where SLF is known to be present, the likelihood of entry of viable unhatched eggs is considered low. If viable unhatched eggs were to arrive in New Zealand, the likelihood of exposure to suitable environmental conditions was considered moderate to high on vehicles, moderate on forest products and containers and low to negligible on other pathways.

The likelihood of establishment and spread is considered independently of entry and was considered high based on climate matching, host availability and capacity for eggs to be transported over long distances on the substrates they are laid on.

The economic consequences of *L. delicatula* establishing in New Zealand are considered to be moderate to high with moderate uncertainty. The environmental consequences were considered to be low with high uncertainty and the socio-cultural impacts were considered to be low. Human health impacts are considered negligible.

A summary of the risk assessment outcomes is provided in a table below.

This document also discusses current and developing surveillance options including the use of light and sticky traps, augmented with a variety of attractant lures. The analysis also summarises the available literature on biological, chemical and repellent based management options, and identifies gaps in the current knowledge of SLF biology.

Risk estimates of *Lycorma delicatula* on all pathways						
Risk assessment stage	**Pathway**	**Considered to be:**				
		Negligible	**Very Low**	**Low**	**Moderate**	**High**
Likelihood of entry	Inanimates			■		
	Air containers		■			
	Courier	■	■			
	Nursery stock		■	■		
	Cut Flowers and Foliage	■				
	Passenger Personal Effects		■	■		
	Forest Products			■		
	Vessels and Aircraft		■	■		
Likelihood of entry of specific life stages	Egg masses			■		
	Nymphs	■	■			
	Adults	■	■			
Likelihood of exposure	Inanimates				■	■
	Air containers	■	■			
	Courier			■	■	
	Nursery Stock	■				
	Cut Flowers and Foliage		■			
	Passenger Personal Effects		■	■		
	Forest Products				■	
	Vessels and Aircraft	■	■			
Likelihood of establishment	Adults			■	■	
	Egg masses					■
	Nymphs			■	■	
Likelihood of spread	Established populations				■	■
Potential magnitude of consequences	Economic				■	■
	Environmental			■		
	Socio-cultural			■		
	Health	■				

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1 Risk analysis of *Lycorma delicatula* (spotted lanternfly)

1.1 Introduction

Scientific name: *Lycorma delicatula* (White, 1845) (Hemiptera: Fulgoridae)
Other relevant scientific names:
Common name: Spotted lanternfly
Spot clothing wax cicada (Korea)

Lycorma delicatula (spotted lanternfly) is native to China (Liu 1939 cited in Kim *et al.* 2013). It has also been reported to be present in Taiwan (Kim *et al.*2013) and Vietnam (Pham *et al*. 2011) and is often reported to be native to these countries (e.g. Jung *et al.*2017; Lee *et al.* 2019), however the veracity of this is uncertain (see section 3 below). *Lycorma delicatula* has also been reported to be present and native to India (e.g. Jung *et al.* 2017), but this too may be questionable. *Lycorma delicatula* is reported to be invasive in South Korea, Japan and the USA (Jung *et al.* 2017, Crowe, 2018).

The spotted lanternfly (SLF) is damaging to a wide variety of economically significant horticultural species such as *Vitis* spp. (grapevine), *Prunus* spp. (almond, apricot, cherry, nectarine, peach and plum), *Malus* spp. (apple) and *Juglans* spp. (walnut), as well as forestry species including *Pinus* spp. (pine), *Quercus* spp. (oak) and *Populus* spp. (poplar).
The Spotted lanternfly is a phloem feeder, using its piercing mouthparts to suck sap from its hosts. It is not known to feed on fruit. As SLF tends to feed in groups, the damage caused by feeding can result in withering or death of branches. In addition, the SLF excretes large quantities of sugary honeydew, which promotes the growth of sooty mould and can attract large numbers of ants and wasps.

The spotted lanternfly overwinters as an egg. Eggs are laid in clusters of 30-50 on smooth vertical surfaces and are protected by a waxy covering. This covering, in combination with the egg chorion and reduced metabolism when overwintering, renders many insecticides ineffective against SLF eggs.

1.2 Purpose

This document assesses the biosecurity risks associated with *Lycorma delicatula* entering New Zealand via all likely entry pathways. The results of this work will support a review of the effectiveness of risk management on the main entry pathways for *L. delicatula*. The analysis also considers surveillance, monitoring and further management options.

1.3 Scope

This document will assess the likelihood of entry, exposure, establishment and spread and impact of the spotted lanternfly (*Lycorma delicatula*) on all possible pathways of entry: containers and their contents, vehicles, machinery and equipment, nursery stock, fresh produce, cut flowers and foliage, forest products and passenger luggage, from countries within the lanternfly’s known distribution.

1.4 Taxonomy

There are four species recognised in the genus *Lycorma* (Hemiptera:Fulgoridae):

- *Lycorma delicatula* (White 1845);
- *L. imperialis* (White, 1846);
- *L. meliae* Kato, 1929;
- *L. olivacea* Kato, 1929

All were first described from Asia (China, Taiwan, Bangladesh and India (FLOW, 2019)).

There are two synonyms of *Lycorma delicatula*:
Aphaena delicatula White, 1845
Lycorma delicatulum (White, 1845)

Three subspecies of *L. delicatula* are recognised (FLOW, 2019):
Lycorma delicatula delicatula
Lycorma delicatula jole Stal, 1863
Lycorma delicatula operosa (Walker, 1858)

These subspecies are referred to as infraspecies by Global Biodiversity Information Facility (GBIF) (2019).

2 Hazard identification

2.1 Description

Lycorma delicatula is a phloem feeding hemipteran insect in the family Fulgoridae. Native to China. *L. delicatula* is a known hitchhiker species and is invasive in South Korea, and the USA, where it continues to spread. Commonly known as the spotted lanternfly (SLF), *L. delicatula* causes significant feeding damage to a wide array of economically important crop species when it is at high abundance. In addition to the physical damage it causes, SLF excretes large quantities of honeydew, which promotes growth of sooty mould where it falls. This sooty mould inhibits photosynthesis and reduces plant growth. Sap from feeding wounds and the honeydew excreted by the bug may also attract large numbers of ants, bees, hornets, and wasps (Dara *et al*. 2015).

2.1.1 New Zealand status

Lycorma delicatula is not known to be present in New Zealand. It is not recorded in: Gordon (2010), NZOR (2019), PPIN (2019), and is not recorded as present in BRAD, (2019). *Lycorma delicatula* is regulated (BORIC, 2019).

2.2 Commodity association

Lycorma delicatula is a phloem feeding insect that typically lays its eggs on smooth vertical surfaces. Based on this, its adult and nymphal stages may be associated with host material, which can be imported as Nursery Stock, Fresh Produce and Cut Flowers and Foliage and these pathways will be assessed below. Eggs may be associated with either host material

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imported as Nursery Stock or Cut Flowers and Foliage, with Forest Products such as Sawn Timber, Poles Piles Rounds and Sleepers, or with inanimate commodities, such as containers and containerised goods, wood packaging and pallets, Vehicles, Machinery and Equipment and with Personal Effects.

Adults and nymphs of *Lycorma delicatula* are disturbed by handling. Adults will fly or hop and nymphs will hop or drop away from the source of disturbance. Early instar nymphs will drop off host plants when they encounter an obstacle or are disturbed (Kim *et al.* 2011). Despite their comparatively wide host range, it is unlikely that adults or nymphs would remain associated with Fresh Produce, Cut Flowers and Foliage or Nursery Stock (whole plants) as these items are frequently handled, moved or washed, which would be sufficient stimulus to prompt spotted lanternfly to abandon the substrate.

Hong *et al.* (2012) identified eggs associated with planting materials [Nursery Stock] and wood packaging from China as the likely pathway of entry for *L. delicatula* into South Korea.

2.2.1 Plant associations

Lycorma delicatula is known to feed on more than 70 hosts (Dara *et al.* 2015) including commercially significant species such as *Actinidia chinensis* (kiwifruit), *Juglans* spp. (walnut*)*, *Malus* spp. (apple), *Prunus* spp. (stonefruit), *Rosa* spp. (rose), and *Vitis* spp. (grapevine) (Park *et al.* 2009, Dara *et al.* 2015). Eggs are likely to be laid on hosts with smooth rather than coarse bark (Kim *et al.* 2011), on vertical surfaces and the underside of limbs typically, but not exclusively up to five metres above ground level (Tomisawa *et al.* 2013).

The spotted lanternfly's host range is broadest during its nymphal stages and narrows as adults prepare to lay eggs. Kim *et al.* (2011) identify the key hosts of adult females prior to egg laying as *Ailanthus altissima (tree of heaven)*, *Evodia daniellii* (synonym of *Tetradium daniellii*) (Korean evoidia) and *Phellodendron amarense* (Amur corktree). *Ailanthus altissima* and *Tetradium daniellii* are present in New Zealand (NZOR, 2019). However, *Ailanthus altissima* is on the National Pest Plant Accord and is listed as an unwanted species in the Unwanted Organism Register (UOR). Importation of *A. ailanthus* is prohibited. Similarly there is no Import Health Standard (IHS) for the import of either *Tetradium daniellii* or *Phellodendron amarense* Nursery stock (MPI, 2019).

2.3 Potential for entry, establishment and impact

2.3.1 Entry

Lycorma delicatula is a known hitchhiker species. The spotted lanternfly is believed to have entered Korea as egg masses associated with wood packaging and Nursery Stock, and to have entered the USA as egg masses associated with large stones and slabs used as landscaping materials. In addition to South Korea and the USA, *L. delicatula* is invasive in some parts of Japan. It has successfully established in these countries.

Eggs are laid between August and November (Dara *et al.* 2015) in grey coloured oothecae (Figure 3 (right)) deposited on smooth barked plants and other smooth surfaces found outdoors such as stones, posts and outdoor equipment (potentially including vehicles, machinery and other inanimate objects).

Dependent on temperature, it is possible for newly laid eggs to survive long distance travel without hatching. Hatching times from 10 days at 25°C (Song *et al.* 2010) to 56 days at 15°C (Choi *et al.* 2012) have been reported. An incubation time of 56 days as reported in Choi *et al.* (2012) would be sufficient for newly laid eggs to make the journey to New Zealand and arrive unhatched from most locations. However, the hold temperature of a vessel travelling from the Northern Hemisphere to New Zealand generally ranges between 25° and 40°C, with temperature peaking as the vessel moves through the tropics where the ambient temperature is at its highest. Additional heat may be generated by two major sources, the heating of fuel oil (so that it can be pumped from the storage tanks to the engine room) and by operating integrated refrigerated containers. Hold areas with no fuel tanks below them will likely be at the lower end of the temperature range. Those housing active integrated refrigerated containers or situated above fuel tanks are likely to be at the higher end of the temperature range (Bruce Hunter – Maersk NZ Port Captain Pers. Com.). These temperatures in combination with typical shipping times from locations where SLF is established indicate that eggs are likely to hatch in transit.

2.3.2 Establishment

Climate matching (Phillips *et al*. 2018) with *L. delicatula*'s known native and invaded distribution indicates a 70-80 % similarity with New Zealand's climate (Figure 1.). The likelihood that climate would be limiting to the establishment of the spotted lanternfly in New Zealand is considered very low.

Given the broad host range of *L. delicatula* (Appendix Table 1) and the presence of many of these hosts in New Zealand, including species indicated to be associated with egg laying (Kim *et al.* 2011, Liu et al 2019), the likelihood that lack of hosts would be limiting to the establishment of *L. delicatula* is considered very low.

Lycorma delicatula was evaluated as part of MPI's Organism Ranking System expert evaluation of 2016, which concluded that there was a high probability of spread to full extent. This evaluation was based on the lanternfly's broad host range, the climatic suitability of New Zealand, that females produce large numbers of eggs and that there is an absence of any effective surveillance tools for *L. delicatula*. It was suggested that this lack of surveillance may mean that a population of *L. delicatula* could become well established before it was first detected (Halloy 2016).

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Figure 1. The reported distribution of *Lycorma delicatula* (CABI, 2019) overlaid on New Zealand climate match map (Philips *et al.* 2018) where grey = <70% similarity to New Zealand climate, yellow =70% similarity, orange 80% pink 90% and mauve 100%

2.3.3 Impact

Spotted lanternfly pierce their hosts' stems to feed from phloem tissue. The lanternfly excretes large quantities of honeydew, which promotes growth of sooty mould that covers photosynthetic surfaces on the host plant and can inhibit growth.

Lycorma delicatula sequesters toxins from the plants it feeds on to act as a deterrent to predators (Kang *et al.* 2011; Kang *et al.* 2017). In the absence of natural enemies to regulate population growth, the insect could infest hosts in large numbers, causing disease in the plant and in some cases death (Anonymous, 2017).

Lycorma delicatula has the potential to have a negative impact on the grape and fruit tree industries (Barringer *et al.* 2015) and feeding damage has been reported on *Actinidia chinensis*, *Juglans* spp., *Malus* spp., *Prunus* spp., *Rosa* spp., and *Vitis* spp. (Dara *et al.* 2015)

Damage to grape vines has been reported in South Korea (Kim *et al.* 2011) and the lanternfly has been observed feeding on wild *Vitis* spp. in Pennsylvania (Barringer *et al.* 2015). In South Korea, significant reduction in vine growth and yield has been reported as a result of spotted lanternfly infestation and some growers have been forced to sell their grapes for juice rather than as whole fruit because of reduced quality (Song, 2010).

The potential impacts of *L. delicatula* were evaluated as part of the MPI Organism Ranking System expert evaluation of 2016, which concluded that 'The overall economic impact [of Spotted lanternfly in New Zealand] would be high' (Halloy. 2018).

Hazard identification conclusion

Given that *Lycorma delicatula*

- Is a known hitchhiker species that has successfully established in countries outside its native range;
- Continues to spread through the USA;
- Is not recorded from NZ;
- Can potentially establish in New Zealand;
- Can potentially cause unwanted impacts including damage to multiple fruit crop species leading to significant financial losses; and
- Produces large quantities of honeydew, which promotes sooty mould, inhibits plant growth and facilitates increase in wasp and ant abundance

Lycorma delicatula is considered a hazard in this risk analysis.

3 General geographic distribution

Lycorma delicatula's reported distribution range extends from approximately 11.5° to 40° latitude (Figure 2). However, some of this reported range is based on single reports or museum specimens and should be viewed as unconfirmed. This uncertainty of distribution is discussed below. New Zealand falls, at least partly, within the Southern Hemisphere equivalent of this reported range lying between -35° and -46° latitude.

Asia

Lycorma delicatula is native to China (Liu 1939 cited in Kim *et al.* 2013). Until the 1930s, the spotted lanternfly was known mainly from the Northern Provinces of Shanxi, Shandong and Hebei. Today, its distribution in China is reported to have expanded to include Anhui, Beijing, Guangdong, Henan, Hubei Jiangsu, Shaanxi, Sichuan, Yunnan and Zhejiang (Li *et al*. 1997, Kim *et al*. 2013).

Lycorma delicatula's native range has been reported to extend to Taiwan, (Li *et al.* 1997) and as far South as Vietnam (Pham, 2011). However, the provenance of these reports is uncertain. Reports of *L. delicatula* in Taiwan appear to be based on the results of a survey of forestry pests in Southern China conducted by Li *et al.* (1997). *Lycorma delicatula* was detected on *Acacia* spp. and *Toona sinensis* and was rated as "important locally [rather than being widespread] or only in some years". Li *et al.* (1997) note a "general perception that the majority of important arthropod pests and weeds in China are native", but include no specific mention of whether *L. delicatula* is native or introduced in Taiwan. There do not appear to be any subsequent records of *L. delicatula* in Taiwan (searches include Google Scholar (2019), GBIF (2019) and iNaturalist (2019)). Given that there appears to be only one primary reference to *L. delicatula* in Taiwan, that this reference is more than twenty years old and that there do not appear to be any subsequent records of *L. delicatula* in Taiwan, the presence of *L. delicatula* in Taiwan is considered uncertain.

The record of *L. delicatula* in Vietnam appears to be based on a single museum specimen. A Google translation from the Vietnamese of the entry for *L. delicatula* in Pham *et al.* (2011) reads "Allocation: Viet Nam (A specific location where specimens are collected from the Museum of History in Luan Don)". Luan Don, may refer to Don Luan (Đồng Xoài), which is situated in Southern Vietnam about 100km northeast of Ho Chi Minh City. The same reference also includes "Central India and Quoc Lao Cambodia." in *L. delicatula*'s range, but does not provide any supporting information. As the reported presence of *L. delicatula* in Vietnam appears to be based on a single museum specimen and there do not appear to be any

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subsequent reports of *L. delicatula* in Vietnam (searches included Google Scholar, GBIF and I Naturalist) the presence of *L. delicatula* in Vietnam is considered uncertain.

Lycorma delicatula has also been recorded to be native to India (e.g. Jung *et al.* 2017). This appears to be based on a record by Distant, (1906) from Assam, Sibsagar (possibly a misspelling of Sivasagar) region of Northeast India, which they describe as "a doubtful locality of Atkinson, though there is every probability it occurs in the confines of British India". However, there do not appear to be any subsequent records (searches include Google Scholar (2019), GBIF (2019) and iNaturalist (2019).The presence of *L. delicatula* in India is therefore considered unconfirmed.

Similarly, Rahman *et al.* (2016) include *L. delicatula* in a preliminary checklist of Auchenorryncha (Hemiptera) from Bangladesh based primarily from literature records. However, the specific text that the inclusion of *L. delicatula* in the checklist is based on is not given. No other records of *L. delicatula* in Bangladesh could be found (searches include Google Scholar 2019, GBIF 2019 and iNaturalist 2019). For these reasons the presence of *L. delicatula* in Bangladesh is considered uncertain.

The SLF is reported to be invasive in South Korea (Lee *et al.* 2009), where it has significant economic impacts on vineyards. *Lycorma delicatula* has been sporadically found in Japan since the 1930s (Barringer *et al.* 2015), and has been an outbreak species in the Hakusan, Ishikawa prefecture (Kim *et al.* 2013). Molecular analyses of *L. delicatula* specimens collected from South Korea and Japan found them to be genetically identical to those from Beijing, Tianjin, Qingdao, and Shanghai, China (Kim *et al.* 2013).

Table 1. Reported distribution of *Lycorma delicatula* with indicative invasiveness.

Country	Notes	References
Bangladesh	Uncertain: *L. delicatula* is included in a checklist of Auchenorrhyncha from Bangladesh based on literature records, However, the specific record placing *L. delicatula* in Bangladesh is not cited.	Rahman *et al.* 2016
China	Native Range: Northern China: - Shanxi, Shandong and Hebei provinces. Expanded Range: Anhui, Beijing, Guangdong, Henan, Hubei, Jiangsu, Qingdao, Shaanxi, Shanghai, Sichuan, Tianjin Yunnan and Zhejiang	Kim *et al.* 2013; Jung *et al.* 2017
India	Assam. Status uncertain. Based on an entry by Distant (1906) "a doubtful locality of Atkinson, though there is every probability it occurs in the confines of British India"	Distant, 1906
Japan	Invasive: Ishikawa prefecture, Fukui Prefecture,	Kim *et al.* 2013; Umemera *et al.* 2013
South Korea	Invasive: Seoul, Goyang, Incheon, Cheonan, Cheongju, and Jeongeup, Gyeonggi-do (state) Paju, Gapyeong, Gwangmyeong, Sungnam, Gunpo, Anseong, Chungnam (state) Gongju, Yeongi, Asan, Chung-buk (state) Chungwon, Jincheon, Boeun, Gangwon (state)	Song, 2010

Country	Notes	References
	Chuncheon, Won-ju, Gyeong-buk (state) Yeongchun.	
Taiwan	Uncertain: Reported as present in Li *et al.* 1997 and as Native range in Lee *et al.*(2013) but the source citations (Xiao, 1992; Hua, 2000) were not available.	Li *et al.* 1997; Lee *et al.* 2013
United States of America	Invasive: Delaware, Maryland, New Jersey, Pennsylvania, Virginia,	Barringer *et al.* 2015 EPPO, 2018 Cornell CALS, 2019
Vietnam	Status uncertain: Vietnam is frequently cited as part of *L. delicatula*'s native range However, all citations seem to be based on a single record from 2011. A Google translation of this record from the Vietnamese reads "Allocation: Viet Nam (A specific location where specimens are collected from the Museum of History in Luan Don). World: Central India, Quoc Lao Cambodia". It appears the presence of *L. delicatula* in Vietnam is based on a single museum specimen. For this reason, its presence in Vietnam is considered uncertain.	Pham, 2011

Europe:

Not known to be present in Europe.

***North America*:**

In the USA, *Lycorma delicatula* was first recorded in Pennsylvania (Barringer *et al.* 2015). In 2014, an "unusual pest in large numbers on *Ailanthus altissima*" was reported in Pennsylvania, USA. It was subsequently identified as *L. delicatula* - the first report on that continent (Barringer *et al.* 2015). Based on the presence of overwintering egg masses, an established population was declared. The spotted lanternfly is believed to have entered the USA on imported landscaping stones and attempts to eradicate it have been unsuccessful to date. It has subsequently spread through several counties in Pennsylvania (Berks, Bucks, Carbon, Chester, Dauphin, Delaware, Lancaster, Lehigh, Lebanon, Monroe, Montgomery, Northampton, Philadelphia and Schuylkill). The SLF has also established in the States of Delaware (Newcastle County), Maryland (Cecil County), New Jersey (Burlington, Camden, Gloucester, Hunterdon, Mercer, Salem, Somerset and Warren Counties) and Virginia (Frederick County Adult specimens of SLF have also been collected in multiple counties of New York State as well as Connecticut, and Massachusetts, but no egg masses or nymphs have been detected to date (Cornell CALS, 2019).

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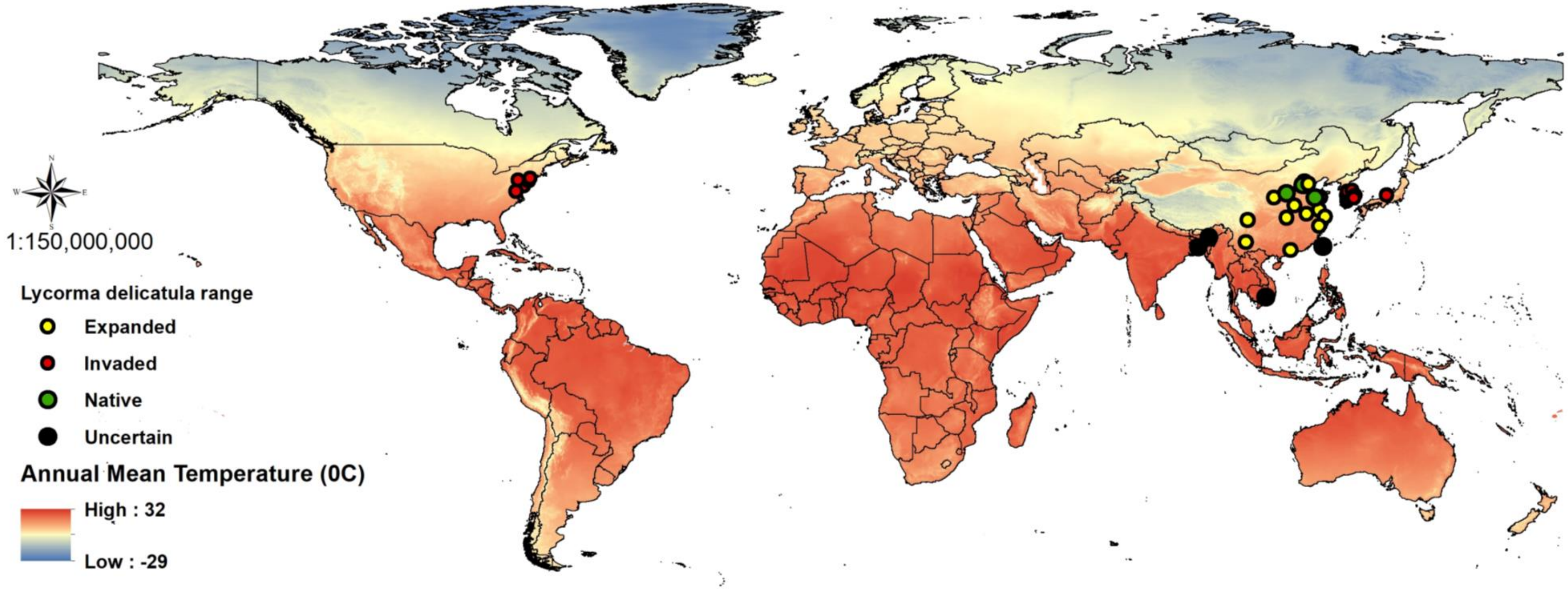

Figure 2. The reported global distribution of *Lycorma delicatula* at July, 2019. Native range is marked in green and is confined to the original distribution described by Liu (1939) (cited in Kim *et al.* 2013). Subsequent records in China are marked in yellow as expanded distribution. The invaded range is marked in red. Where the presence of *L. delicatula* is uncertain or it is unclear whether it is native or invasive in that area is marked in black (Map credit: Hossein Narouei-Khadan)

4 Biology

The spotted lanternfly (*Lycorma delicatula*) is a univoltine phloem feeding insect in the family Fulgoridae. *Lycorma delicatula* is hemimetabolous, completing four nymphal instars before reaching maturity. Eggs are laid in clusters protected by a waxy ootheca. The spotted lanternfly over-winters in the egg. A full description of each life-stage and their known environmental requirements is presented below.

4.1 General description of life stages

4.1.1 Eggs

Lycorma delicatula eggs are approximately 2.6 mm in length and 1.4 mm in width, greyish and ovoid in shape with a distinctive "stem-like" structure at the anterior end that runs back across the dorsal surface of the egg (Figure 3 (left)) (Park 2009). They are deposited in parallel lines of 5-7 eggs in clusters of 30-50, protected by a waxy grey ootheca (Figure 3 (right)) (Kim *et al.* 2011). In South Korea, oviposition occurs in autumn and has been reported to begin in late-September and early October (Shim and Lee 2015) and may continue until November (Kim *et al.*2011). In the USA oviposition begins in September and continues through December (Penn State Extension, 2019). Hosts with smooth bark are preferred over those with rough bark (Kim *et al.* 2011), though oviposition on rough barked species has been reported, in particular on the inner surface of bark fissures (EPPO, 2016). Eggs may also be deposited on smooth inanimate objects such as fence posts, stones and outdoor equipment (Dara *et al.* 2015). Tomisawa *et al.* (2013) observed that egg masses were typically deposited on the underside of limbs up to 5 metres above the ground, though some egg masses were deposited as high as 10.5 metres. As many as 197 oothecae have been observed in a single host tree (Dara *et al.* 2015) and Liu (2019) observed higher egg mass densities on inanimate substrates (fenceposts), than on the most frequently used plant host substrates.

Lycorma delicatula overwinters in its egg form and first nymphs have been reported to emerge in April in the USA (Penn State Extension, 2019) and May in Korea (Kim *et al.* 2011). Development is suspended by diapause in the early stages of embryonic development after the head, thorax and abdomen have become differentiated and appendages are present as lobes. The diapausing embryo is situated on the top of the yolk within the egg (Shim and Lee, 2015). In a field monitoring experiment conducted in Korea, hatching was typically observed to occur between 5:00am and 8:00am (Kim *et al.* 2011). However, it is unknown whether this is always the case in all *L. delicatula* populations, or whether there were particular abiotic conditions, such as rainfall, temperature or cloud cover, that prompted hatching during at this time during the observation period.

Effects of temperature on hatching rates

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There are conflicting estimates of the lower developmental threshold for egg development. Based on laboratory incubation experiments, this threshold has been estimated to be: 8.14°C (Choi *et al.* 2012), 11.13°C (Park, 2009) and 12.75°C (Song, 2010). It is unclear whether this variation is the result of regional/population differences, physiological pre-conditioning or inconsistencies in the methods of the incubation experiments.

Hatching time and hatching rates at varying incubation temperatures are presented in Song (2010), Choi *et al.* (2012) and Park (2015) and are reproduced in Table 2. There is a notable discrepancy between the hatching rates and reported optimal temperatures among these studies, with optimum developmental temperatures (based on % hatched) of 25°C, 15°C and 23°C reported respectively and development taking from 10 to 72.6 days to complete dependent on temperature. Lee *et al.* (2011) demonstrated that there is considerable variation in egg mortality dependent on location, based on comparison of three areas of South Korea; Chuncheon, Cheongju and Wanju where significantly different egg mortality (93.3; 37.9 and 17.0 % respectively) were observed.

Some variation may also be attributable to when the eggs used in the experiments were collected. Shim and Lee, (2015) observed that the hatching rates of eggs collected from the field in late autumn (November) and incubated under controlled conditions was significantly lower than those collected in March and subjected to the same conditions. Song *et al.* (2010), collected the eggs used in their experiment in December and subjected them to between 5 and 20 days cold treatment prior to incubating them at temperatures between 15°C and 30°C. Choi *et al.* (2012) collected eggs in mid-February and incubated them at temperatures between 20°C and 30°C.

Table 2. Hatching time (days) and % hatching rates of *L. delicatula* eggs reared in laboratories at various temperatures as presented in Song, (2010), Choi *et al.* (2012) and Park (2015).

Temp° C		10	12	15	18	19	20	21	23	24	25	27	30	31	33	35
Song 2010	Time (days)	-	-	26+	-	-	16+	-	-	-	10 - 17	-	10	-	-	-
	Hatch rate (%)			14			16				27		<27			
Choi *et al.*2012	Time (days)	-	-	55.9	-	-	26.8	-	-	-	21.6	-	-	-	-	-
	Hatch rate (%)			61.9			57.8				30.4		0			
Park 2015	Time (days)	-	0	72.6* (71.9; 75.0)	45.0	40.7	-	31.3	23.4	21.0	-	18.4* (18.3; 18.6)	-	15.3	-	-
	Hatch rate (%)		0	70.6* (54.9; 80.1)	50.7	67.1		53.3	78.6	55.5		70.1* (76.2; 67.1)		25.9	0	0

Note: Song, (2010) presents the first day of hatching rather than the average hatching time. Values from Park (2015) marked with an * are the average of two years. The individual values for each year are presented in parentheses.

It is worthy of note, that the USDA Spatial Analytic Framework for Advanced Information Systems (SAFARIS) PestCAST (Takeucji et al. 2019), which used to forecast development and emergence of *L. delicatula* stages using near real time weather data, uses 8.14°C as the lower developmental threshold for all life stages and 30°C as the upper developmental threshold. Using these parameters completion of peak egg development is estimated to be 355.4 degree days. Using these parameters egg development would be completed in 51.5 days at 15°C, 21 days at 25°C and 16 days at 30°C.

Effects of daylength on hatching rates

Song, (2010) concluded that daylength does not have an effect on hatching rates of *L. delicatula* eggs. No statistically significant difference was found in hatching rates of eggs incubated at 25°C under 16 hours light/8 hours dark; 12 hours light /12 hours dark and 8 hours light/16 hours dark conditions. No information was found indicating whether movement from short day to long day conditions would have any effect on hatching rates, or whether confinement in the dark for prolonged periods would affect hatching rates.

Requirement for exposure to cold during diapause

There is some evidence to suggest that *L. delicatula* eggs require a chilling period to complete development and it has been suggested that the duration of this period may be five months (Shim and Lee 2015). However, this remains inconclusive.

Shim and Lee, (2015) incubated overwintering *L. delicatula* eggs collected between November and March at 25°C and found that hatching rates increased significantly with time in diapause. Hatching rates ranged from 14.2% in November to 88.8% in March, and it was suggested that prolonged exposure to cold temperatures (i.e. cold reactivation) facilitates diapause termination in *L. delicatula* and that the length of exposure necessary for successful hatching is five months. However, Shim and Lee, (2015) did not report or estimate the requisite temperature for chilling.

Park (2009) found that a period of 15 days at 5°C after mid-winter was necessary for successful diapause termination, but found these conditions were not sufficient in early diapause and suggested that exposure for a longer period and/or at a lower temperature may be necessary in the early phases of diapause. This is somewhat supported by the findings of Song (2010), which show an increase from a 4% hatching rate in eggs collected in December and chilled at 5°C for 15 days to hatching rates of 24% in eggs collected at the same time and chilled at the same temperature for 20 days. However, it should also be noted that Song, (2010) reported a higher (27%) hatching rate in eggs collected in December and incubated at 25°C without any chilling period.

Song (2010) concluded that *L. delicatula* eggs did not require prolonged exposure to cold during diapause in order to complete development. This is based on a series of cold treatment experiments where *L. delicatula* eggs collected in December were refrigerated at various temperatures at or below 5°C for up to 20 days before being incubated at temperatures between 15°C and 30°C. Hatching rates were reported to be higher without cold treatment than in those eggs subject to cold treatment. However, the lower temperature tolerance of *L. delicatula* eggs may decrease with time. Hatching rates were also reported to fall significantly when incubated at 30°C (Song 2010).

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Effects of winter temperatures on egg mortality

Under experimental conditions 100% egg mortality was observed when eggs held at -10°C for 5-10 days were incubated at 25° C (Song, 2010). Similarly Lee *et al.* (2014) identified -11°C as the lower lethal threshold temperatures for *L. delicatula* eggs. Based on the average daily temperature between the beginning of December and the end of February, Lee *et al.* (2011) estimated that 100% egg mortality occurred at −3.44 °C. However, the lower lethal threshold temperature was calculated to be −12.72 °C based on the mean lowest daily temperatures in January alone (Lee *et al.* 2011), which may indicate that *L. delicatula*'s tolerance to cold increases over time. Park (2015) suggest that temperatures in January are a strong predictor of hatching ability of *L. delicatula* eggs in spring. Significant variation was observed in tolerances to cold between regions (Lee *et al.* 2011), suggesting that there may be variation in cold tolerance among populations.

Figure 3. Left: rows of *L. delicatula* eggs deposited on the trunk of a tree partially covered by a waxy ootheca (egg case). Note the distinctive "stem-like" structure visible on the dorsal surface of uncovered eggs. Right: waxy ootheca of *L. delicatula* on the bark of tree of heaven (image Pennsylvania State Agriculture Department). Female spotted lanternflies lay their eggs in rows and cover them with secretions, but sometimes they miss some of the jellybean-like eggs, leaving them exposed. (EMELIE SWACKHAMER / CONTRIBUTED PHOTO) https://www.mcall.com/news/local/mc-nws-spotted-lanternfly-egg-mass-20180925-story.html

4.1.2 Nymphs

Nymphs of *L. delicatula* first appear in May (Northern hemisphere spring). On hatching, first instar *L. delicatula* nymphs tend to climb upwards on the host tree (Kim *et al.* 2011). However, the architecture of their tarsi means that they are easily dislodged and fall to the ground. From the ground they will climb and feed on whatever plant they encounter. The first instar is highly polyphagous (Kim *et al.* 2011), but the host range narrows with each successive nymphal stage. Nymphs often aggregate in large numbers on the branches of host trees (Jang *et al.* 2013).

Lycorma delicatula undergoes four nymphal stages (Figure 4.). The first three nymph stages are black with white spots. The fourth is predominantly red, retaining the white spots of earlier stages and also a black longitudinal pattern. The average size of each instar is: 1st instar 3.6–4.4 mm; 2nd instar 5.1–6.4mm; 3rd instar 6.9–9.4 mm and 4th instar 10.9–14.8 mm (Dara *et al.* 2015).

Figure 4. The four nymphal stages of *Lycorma delicatula* arranged from 1st to 4th from left to right. (Image from Dara *et al.* 2015)

Park *et al.* (2009) monitored development of nymphs raised on *Parthenocissus quinquefolia* (Virginia creeper) in South Korea under controlled conditions. Development from emergence of the first instar to moulting into an adult took an average of 82.7 days, however the temperature at which this development occurred was not reported. Mean development times observed for each instar were:

- First instar – 18.8 days
- Second instar – 20.9 days
- Third instar – 20.8 days
- Fourth instar – 22.2 days

Park (2015) estimated the lower developmental threshold temperature for nymphs to be the same as the temperature demonstrated for eggs, i.e. 11.13°C. This estimate of nymphal development thresholds was validated by comparing modelled and infield values. However, there has been no experimental confirmation of this threshold to date.

4.1.3 Adults

Adult *L. delicatula* are 21–27mm in length measured from the head to the end of the folded wing; males are smaller (21–22 mm) than females (24–27 mm) (Dara *et al.* 2015). When closed, the forewing has a distinctive spotted pattern at its anterior end with a linear pattern at its tip, the hind wing is partially red with black spots nearest the insect's body and black and white patternation toward the tip. The abdomen is yellow, incompletely divided by black bands (Figure 5.). Adults are found in summer from July onwards in the lanternfly's native and invaded range (Kim *et al.* 2011; Dara *et al.* 2015) and live up to four months, continuing to feed until October (Liu 2019).

Adult spotted lanternfly may employ one of three physical predator escape strategies (Kang *et al.* 2017). When a predator is near, but there is no tactile contact, SLF rely on the camouflage afforded by their spotted wings. If they are touched, for example by an

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exploratory peck from a bird, they will hop rapidly away from the source of disturbance. If this fails to deter the predator and they are grabbed, they will initiate a deimatic display by revealing their red and black hind wings and yellow and black abdomen to startle their potential predator. Tomisawa *et al.* (2013) observed that flight in response to disturbance is typically not greater than 2 metres and that the adult lanternfly will try to return to the same tree it was disturbed from. Where adults are associated with goods for export, the levels of stimulus necessary for the bug to hop or fly away may affect their likelihood of remaining associated with an object or commodity as it is loaded into a container.

Lycorma delicatula is not a strong flyer, typically travelling no more than 40 metres in a single flight (Myrick and Baker, 2019). The lanternfly tends to fly into the wind and launches itself from higher in a tree for dispersal. It is not clear how many successive flight bouts the adult undertakes or the interval between each flight bout.

Oviposition preferences

Oviposition typically occurs in the early evening and continues until nightfall (Tomisawa *et al.* 2013). *Lycorma delicatula* is known to deposit its eggs on several different host species, which represent a subset of its total host range (Appendix Table 1.). Host preference has been suggested to be driven by the need for a smooth surface (Kim *et al.* 2011) and by colour – particularly favouring red-brown greys (EPPO, 2016).

Egg masses may be deposited on any branch with a diameter greater than 1 cm (EPPO, 2016), and *L. delicatula* has been reported to lay eggs on inanimate objects such as stones, houses, fence posts, lawn furniture and metal sheeting.

A study of oviposition substrate selection in the USA recorded egg masses deposited on 22 plant species from 14 families and two inanimate substrates. Generally, tree-of-heaven (*Ailanthus altissima*), black cherry (*Prunus serotina*), black birch (*Betula lenta*), and sweet cherry (*Prunus avium*) were the most commonly used substrates accounting for 23.98, 19.76, 14.93 and 9.81% of the egg masses detected, though the dominant substrate varied from survey site to survey site (Liu, 2019). Inanimate substrates (metal fence posts and stone) accounted for 4.68% and 2.26% of the total egg masses observed respectively, but the density of egg masses on fence posts (number of egg masses/ M^2) was significantly greater than on the most commonly used plant hosts (Liu 2019).

Comparison of the most commonly used oviposition substrates in the USA with those in Korea and Japan revealed only limited overlap, with tree of heaven and black locust () being the only species common to Asia and the USA, though the genera *Betula*, *Prunus* and *Quercus* were common substrates to both regions(Liu 2019).

Prior to egg laying, *L. delicatula* adults have been demonstrated to show a preference for plant species such as *Ailanthus altissima*, and *Tetradium* (*Evodia*) *daniellii* which contain toxic alkaloids (Kim *et al.* 2011). The spotted lanternfly accumulates these toxins to deter predators. However, as twenty four oviposition hosts have been identified in Asia and a further twenty in the USA (appendix 1) in addition to observations of oviposition on inanimate substrates, these preferred oviposition hosts, are not a requirement to complete its life cycle (Liu 2019).

Figure 5. Adult Spotted lanternfly at rest (left image: Lawrence Barringer, Pennsylvania Department of Agriculture, Bugwood.org.) and with wings extended (right image from Dara *et al.* 2015).

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5 Risk assessment

This assessment estimates the likelihood of spotted lanternfly entering, finding suitable habitat and establishing in New Zealand and the likely economic, environmental and social impacts if this were to occur. For the purposes of this assessment, likelihood is divided into five categories: **Negligible**, **Very Low**, **Low**, **Moderate** and **High**. These categories are defined as follows:

- **Negligible**- Not worth considering; insignificant
- **Very Low** - Close to insignificant
- **Low** – Less than average, coming below the normal level
- **Moderate** – Around the normal or average level
- **High** – Extending above the normal or average level

5.1 Entry assessment

5.1.1 Interceptions

To date, there have been no interceptions of *Lycorma delicatula* on any pathway at the New Zealand border (LIMS, 2019). The EPPO (2016) pest risk analysis includes details of two interceptions of *L. delicatula*: one of egg masses on landscaping stones in Pennsylvania and the other of a single dead adult associated with a consignment of steel. A large number of adult spotted lanternfly were intercepted on-board a cargo ship arriving in Brooklyn USA in September, 2019 (Glasser-Baker, 2019). Given the time of year, and that the SLF intercepted in Brooklyn were adults, it seems likely that these SLF originated from elsewhere in the USA rather than being transported from overseas.

5.1.2 Pathway Assessment

Based on the biology of *L. delicatula*, particularly its feeding and oviposition habits, the following pathways are assessed below: sea containers and containerised goods, air containers and their contents, courier packages, nursery stock, cut flowers and foliage, personal effects and luggage, vehicles, machinery and equipment, forest products (wood packaging, sawn timber, poles piles rounds and sleepers), and vessels and aircraft.

5.1.2.1 Sea containers and containerised goods

In its invaded range spotted lanternfly nymphs emerge in May, and complete their final moult into adults in late July (Park *et al.* 2009; Dara *et al.* 2015). In the USA, spotted lanternfly adults are reported to live for approximately four months, continuing to feed until October (Liu 2019). Oviposition has been reported as late as November in Korea and December in the USA (Kim *et al.* 2011, Penn State Extension, 2019), but it is unclear whether this is the result of adults being longer lived or emerging later there. During this active period, nymphs are feeding and adults will be feeding, seeking mates and females will subsequently search for suitable oviposition sites. Prior to arriving at port, containers and some containerised goods may be stored outdoors near areas where *L. delicatula* is present. Where outdoor storage is near wooded areas, shelter belts, agricultural areas or other areas where suitable host material for *L. delicatula* is present there is potential for contamination. In a US survey, Liu (2019) found that approximately 67% of *L. delicatula* egg masses were deposited on four plant host species and that a further 7% of egg masses were deposited on inanimate substrates. The density of egg masses on inanimate substrates was found to be significantly higher than on the most commonly used plant host substrates (Liu 2019).

Adults and nymphs

Adults and nymphs of *Lycorma delicatula* are mobile and will move away from sources of disturbance. Adults may fly or hop and later instar nymphs will hop away from a source of disturbance. Early instar nymphs will drop off host plants or other substrates when they encounter an obstacle or are disturbed (Kim *et al.* 2011). Given this combination of irritability and mobility, and considering that their behaviour will be centred on feeding, mating and oviposition, the likelihood that nymphs and adults would remain associated with goods that are frequently moved or handled is considered very low.

Should nymphs or adults become associated with a shipping container or inanimate containerised goods there is a very low to negligible likelihood that they would encounter suitable food hosts. Under experimental conditions, Lee *et al.* (2009) demonstrated that when spotted lanternfly nymphs held at 25 ± 2 °C, 50 ~ 60% relative humidity and under 16L: 8D photoperiodic conditions were fed only water they survive only four or five days. Under the same conditions adults were found to survive only two or three days. However, adults fed on an aqueous solution of fructose, glucose and sucrose in a ratio comparable to the sap of tree of heaven (*Ailanthus altissima*) under the same temperature, humidity and daylength conditions only survived between 6 and 8 days. The comparatively short survival of adults fed a combination of sugars suggests factors other than carbohydrate availability may influence mortality, but the results suggest that absence of food would be a limiting factor to survival of a voyage. Particularly at higher temperatures such as those reported from containers and vessel holds making the journey from the Northern Hemisphere to New Zealand (Weiskircher, 2008; Nixon *et al.* 2019).

Eggs

Lycorma delicatula eggs are deposited in clusters of 30-50 on host trees with smooth bark (Kim *et al.* 2011). Tree of heaven (*Ailanthus altissima*) has been identified as a preferred host tree for egg laying, but eggs may also be deposited on other species and on smooth inanimate objects such as fence posts, stones or outdoor equipment (Dara *et al.* 2015, Liu 2019). In South Korea, eggs are typically deposited in autumn (between late September and early October) (Shim and Lee, 2015) but have been reported to be deposited as early as August and as late as November (Kim *et al.* 2011).

Temperatures of 45°C have been reported inside sea containers travelling between Australia and Spain and temperatures greater than 50°C have been recorded in containers exposed directly to the sun (Weiskircher, 2008). However, interior temperatures are variable dependent on both where in the container a measurement is taken and where in the vessel a container is situated. For example, the upper portion of a container interior in direct sunlight can be 15°C warmer than the outside temperature and the bottom row of boxes in a container can be 20°C cooler than the top row (Weiskircher, 2008).

In general the hold temperature of a vessel travelling from the Northern Hemisphere to New Zealand ranges between 25° and 40°C, with temperature peaking as the vessel moves through the tropics where the ambient temperature is at its highest.

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Additional heat is generated by two major sources, the heating of fuel oil (so that it can be pumped from the storage tanks to the engine room) and by operating integrated refrigerated containers. Hold areas with no fuel tanks below them will likely be at the lower end of the temperature range. Those housing active integrated refrigerated containers or situated above fuel tanks are likely to be at the higher end of the temperature range (Bruce Hunter – Maersk NZ Port Captain Pers. Com.).

Hatching rates of *L. delicatula* eggs have been demonstrated to decrease from ~62% to 30% with an increase in temperature from 15°C to 25°C and between zero (Choi et al. 2012) and <27% (Song 2010) hatching rates have been reported at 30°C. It is highly likely that *L. delicatula* eggs exposed to prolonged periods at 30°C in transit will be non-viable. Eggs exposed to temperatures between 15°C and 25°C are likely to remain viable and, based on experimental results, it is possible that development may be completed in transit at temperatures around 25°C in 10 (Song *et al.* 2010) to 22 days (Choi *et al.* 2012). However, based on the same experimental results hatching rates could be expected to be lower than 32%. Emerging nymphs are not expected to live longer than five days in the absence of suitable food (Lee et al. 2009).

Hatching rates of eggs collected from the field and incubated at 25°C have been observed to increase the later in the season the eggs are collected. Shim and Lee (2015) reported hatching rates ranging from 14.2% in November to 88.8% in March. These observations are analogous to the length of cold diapause experienced by eggs prior to containers being loaded on to a vessel where they are exposed to elevated temperatures. Based on the results of Shim and Lee (2015), it may be expected that viability of eggs will be greater if they are exported from the donor country in March than if they are exported in November.

Given that *Lycorma delicatula*:

- adults and nymphs are mobile and easily disturbed
- adults and nymphs are phloem feeders and are unlikely to encounter suitable food on or in a container
- nymphs are not expected to live more than five days without food
- adults are not expected to live more than three days without food
- overwinters as eggs in a state of developmental diapause
- eggs may be deposited on any smooth vertical surface
- eggs are covered by a protective greyish brown waxy layer
- eggs take ~56 days to hatch at 15°C, between 10 and 22 days at 25°C and hatching rates are very low to negligible at>30°C
- egg hatching rates increase with time in diapause
- eggs are likely to encounter temperatures on vessels that are higher than those encountered while naturally overwintering and may be sufficient to complete incubation
- eggs would be moving from Northern Hemisphere autumn/winter to Southern Hemisphere spring/summer

The likelihood of adult SLF or nymphs entering New Zealand associated with sea containers and their contents is considered **Very Low** to **Negligible**

The likelihood that viable SLF egg masses will enter New Zealand on sea containers or their contents is considered **Low**.

5.1.2.2 Air containers and their contents

All air containers and associated packaging entering New Zealand must be managed for regulated pests (including *Lycorma delicatula*). The acceptable threshold for regulated pests on air containers and associated packaging is zero (MPI 2018). For insects, management options include visual inspection and confirmation of freedom from regulated pests by an accredited person, or prophylactic treatment with either heat (60°C for ten minutes) or methyl bromide (either 40 g/m^3 at 16-21+°C or 48 g/m3 at 10-15°C) for 24 hours. If a regulated pest is detected during visual inspection, treatment is mandatory.

Entry of nymphs and adults

Lycorma delicatula is univoltine. Nymphs typically emerge in spring (approximately May) and adults in summer (approximately July) in both their native and invaded range. Adults remain active until autumn (approximately November). During this time, nymphs are primarily focused on feeding and adults on feeding, finding a mate, and, in the case of mated females, finding a suitable substrate for oviposition. As all active life stages of *L. delicatula* are phloem feeders, the likelihood that *L. delicatula* would remain associated with a substrate such as an air container, packaging materials or inanimate cargo that does not offer sustenance is considered **Very Low**. The possibility that a gravid female could become entrapped in a container cannot be discounted, however given their size and mobility, there is a high likelihood that they would be detected by visual inspection.

Lycorma delicatula nymphs are flightless and, while they are winged, adult spotted lanternfly are poor flyers traveling no more than 40 metres in a single flight. Given that air canisters are likely to be stored either at an airport or at a freight forwarders and that both these locations are likely to be devoid or sparsely populated with suitable host material, the likelihood that air canister would become contaminated is considered **Very Low.**

Adults and nymphs of *Lycorma delicatula* are mobile and will move away from sources of disturbance. Adults may fly or hop and later instar nymphs will hop away from a source of disturbance. Early instar nymphs will drop off host plants or other substrates when they encounter an obstacle or are disturbed (Kim *et al.* 2011). Given this combination of irritability and mobility, and considering that their behaviour will be centred on feeding, mating and oviposition, the likelihood that nymphs and adults would remain associated with items such as an air container, packaging materials or inanimate cargo that are frequently moved or handled is considered **Very Low.**

Entry of eggs

Lycorma delicatula eggs are typically deposited in autumn (between late September and early October) (Shim and Lee, 2015) but have been reported to be deposited as early as August and as late as November (Kim *et al.* 2011). Specific hosts such as *Ailanthus altissima* and *Tetradium daniellii* are preferred oviposition substrates. However, eggs may be deposited on inanimate vertical surfaces, particularly where suitable hosts are sparse or where SLF population densities are sufficiently high to promote competition for suitable oviposition sites (Kim *et al.* 2011; Liu, 2019). The eggs are laid in masses of 30 to 50 protected by a waxy grey ootheca. This ootheca may make egg masses difficult to see. The spotted lanternfly overwinters in its egg and nymphs do not emerge until spring (May). It is possible that egg

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masses could be associated with the interior or exterior of an air canister between August and May. However, given that air canisters are likely to be stored either at an airport or at a freight forwarders and that both these locations are likely to be devoid or sparsely populated with suitable host material, the likelihood that adults, which are poor flyers, would move a significant distance from suitable host material to deposit eggs on air canister is considered **Very Low.**

Aircraft hold temperatures are typically held at or above 7°C, but may be greater than 18°C where live animals are held. However, temperatures up to 32°C have been reported in the aft hold of a Boeing 747-400 combi (Emond 1999). Generally, hold temperatures fall within the range suitable for continued development of overwintering eggs, and this in combination with comparatively short (≤36 hour) flight times indicates that eggs would remain viable on arrival in New Zealand.

Air canisters are likely to arrive in New Zealand within 36 hours of departure from their country of origin. As *L. delicatula* occurs only in the Northern Hemisphere this means that nymphs would be moving from spring to autumn, adults from summer to winter and egg masses from autumn/winter into spring /summer.

Given that:

- *Lycorma delicatula* nymphs are flightless and adults are poor flyers
- Air canisters are stored at the airport of departure or at freight forwarding facilities, where host and preferred oviposition material is limited
- Nymphal behaviour is centred on feeding
- From July to late September adult behaviour is centred on feeding and later, mate finding
- Adults and nymphs move in response to disturbance
- Eggs may be deposited on smooth vertical inanimate surfaces
- Eggs may be present between late September and May

The likelihood that *L. delicatula* adults or nymphs will enter New Zealand associated with air containers is considered **Very Low**

The likelihood that *L. delicatula* eggs will enter New Zealand associated with air containers is considered **Very Low**

5.1.2.3 Courier pathway

Identification of items likely to harbour spotted lanternfly sent via the courier pathway presents a challenge. The contents of a package are primarily identified by the declaration on the customs certificate. There are currently no detector dogs trained to detect spotted lanternfly in New Zealand or elsewhere. To date, there have been no known reports of *L. delicatula* associated with the courier pathway in New Zealand or overseas.

Entry of nymphs and adults

Adults and nymphs of *Lycorma delicatula* are mobile and will move away from sources of disturbance. Adults may fly or hop and later instar nymphs will hop away from a source of disturbance. Early instar nymphs will drop off host plants or other substrates when they encounter an obstacle or are disturbed (Kim *et al.* 2011). Given this combination of irritability and mobility, and considering that their behaviour will be centred on feeding, mating and oviposition, the likelihood that nymphs and adults would remain associated with goods, especially those that have been moved and handled during packaging is considered **Very Low.**

If nymphs or adults became associated with a goods packed and sent to New Zealand by courier there is a negligible likelihood that they would encounter suitable food hosts. In the absence of food, nymphs have been demonstrated to survive only four or five days. Under the same conditions adults were found to survive only two or three days. There is, therefore a low to **Very Low** likelihood that nymphs or adults would arrive at their destination alive.

Entry of eggs

Lycorma delicatula eggs are deposited in clusters of 30-50 on host trees with smooth bark and on smooth inanimate objects such as fence posts, stones or outdoor equipment (Dara *et al.* 2015). The substrate for oviposition is typically greater than 10mm in diameter (EPPO, 2016). Eggs are generally deposited in autumn (between late September and early October) (Shim and Lee, 2015) but have been reported to be deposited as early as August and as late as November (Kim *et al.* 2011). Female *L. delicatula* favour trees including *Ailanthus altissima* (tree of heaven) prior to oviposition, potentially because they accumulate toxic alkaloids from the plant and incorporate these in the ootheca to act as a deterrent to predators.

The likelihood of infestation by *L. delicatula* eggs on items sent by international courier from a country where *L. delicatula* occurs would depend on a number of factors, including whether the item was stored in or outdoors, the size and complexity of the item, and what time of year the item was packed and sent. Broadly, smooth items with a surface that is greater than 10mm in diameter that have been stored outside at some point between September and May in an area where *L. delicatula* is at high abundance would have the highest likelihood of contamination. Given that egg masses are covered by a waxy grey ootheca there is a low likelihood that they would go undetected during manual packing.

Given that

- Items sent by courier will be handled during packing
- *L. delicatula* adults and nymphs are mobile and irritable and will move away from the source of disturbance
- Given that *L. delicatula* is a phloem feeder, the likelihood that there would be a suitable food source in a courier package is negligible.
- Without food *L. delicatula* nymphs have been demonstrated to survive no more than five days and adults no more than three days.
- Items would need to be stored outside for some time between September and November for eggs masses to be deposited on them
- Eggs are covered with a waxy grey ootheca.

The likelihood that *L. delicatula* adults and nymphs would enter on the Courier pathway is considered **Negligible**

The likelihood that *L. delicatula* eggs would enter on the Courier pathway is considered **Very Low**

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5.1.2.4 Nursery Stock

Nursery stock may refer to whole plants, cuttings (dormant or non–dormant), bulbs and tubers and tissue culture (MPI IHS 155.02.06, 2019). Of these, spotted lanternfly adults and nymphs are only likely to be associated with whole plants and eggs may be associated with whole plants, and budwood cuttings >1cm in diameter. Whole plants is a comparatively low volume pathway and there have been no reports of *L. delicatula* interceptions on this pathway between 2005 and 2018 (MPI, 2019).

All spotted lanternfly life stages have the potential to be associated with whole plants within the lanternfly's host and geographic range that are imported as nursery stock. However, adults are highly mobile and are likely to hop or fly away when disturbed. There is a very low likelihood they would remain associated with any plant that is routinely handled under production conditions. Nymphs are also highly mobile and hop or fall away when disturbed. However, the possibility that nymphs that have hatched from egg masses in transit could be present cannot be discounted.

Whole plants must be accompanied by a phytosanitary certificate confirming they have been inspected prior to export and found to be free of any visually detectable regulated pests, and treated for insects and mites as part of Basic entry conditions (MPI, 2019). The approved treatments include fumigation with methyl bromide, or spray/dip treatment with any two of the following active chemicals: carbaryl, tebufenozide, imidacloprid, thiacloprid, acephate, chlorpyrifos, dimethoate, pirimiphos-methyl, deltamethrin, fenvalerate or spinosad.

Of the insecticides listed above, Park *et al.*2009 demonstrated that treatment of *L. delicatula* nymphs (n=90) with deltamethrin (1% emulsion) resulted in 100% mortality, imidacloprid (4% solution) resulted in 85.1 (±1.2) % mortality and treatment with thiacoprid (10% solution) resulted in 75 (±8.24)% mortality within two hours of treatment. It is worth noting however, that the sample size (n=90) was comparatively small compared with the number required to establish 99.9% efficacy at the 95 % confidence level described in Ormsby (2018).

Shin *et al.* (2011) tested 26 insecticides on *L. delicatula* eggs, of which five are among those specified in the Import Health Standard for Nursery Stock: chlorpyrifos, imidacloprid, deltamethrin, tebufenozide and spinosad. Of these only chlorpyrifos resulted in 100% mortality of eggs, though again, sample sizes were comparatively small (n=44 - 97). It is worth noting that where treatment of nymphs with deltamethrin resulted in 100% mortality, treatment of eggs with the same compound at the same rate had no lethal effects.

Table 3. There is limited information available on the effectiveness of insecticides approved for the treatment of nursery stock on various life stages of *Lycorma delicatula*. What is available is summarised below.

Group	Active	Egg	Reference	Nymph	Reference	Adult	Reference
Fumigant	Methyl-bromide	No data		No data			
Organophosphate	Acephate	No data		No data			
	Chlorpyrifos	100% (n=97) 100%* (n=8 lab,	Shin *et al.* (2011) *Leach *et al.* (2019)	No data			

		29 field)					
	Dimethoate	No data		No data			
Carbamate	Carbaryl	No data		100±0 decreasing to 10.0±7 after 14 days	Leach *et al.* (2019) Note: Result for residual effect	88.9±4.1 (after 24hrs), 95.8 ±2.9 (48hrs)	Leach *et al.* (2019)
Neonicotinoids	Imidacloprid	21.2% (n=75)	Shin *et al.* (2011)	85.1(±1.2)% (n=90)	Park *et al.* (2009)	79.4±6.5 (24hrs) Note: Result for imidacloprid + beta-cyfluthrin	Leach *et al.* (2019)
	Thiacloprid	No data		75 (±8.24)% (n=90)	Park *et al.* (2009)		
Pyrethroid	Deltamethrin	0% (n=44)	Shin *et al.* (2011)	100% (n=90)	Park *et al.* (2009)		
Synthetic-pyrethroid	Fenvalerate	No data		No data			
Insect Growth Regulator	Tebufenozide	26.2% (n=81)	Shin *et al.* (2011)	No data			
Other	Pirimiphos-methyl	No data		No data			
	Spinosad	37.4% (n=85)	Shin *et al.* (2011)	57.9±11.5	Leach *et al.* (2019) Note: Result for residual effect		

In addition to the specified insecticide treatments, all nursery stock, unless specified in schedules of special entry conditions must undergo a period of post entry quarantine, typically not less than three months.

Entry of eggs

Lycorma delicatula eggs are typically laid in clusters of between 30 and 50 on vertical planes of smooth barked hosts greater than 1cm in diameter (EPPO 2016). These egg clusters are protected by a waxy covering which may make them harder to see on the host’s stem or trunk. However, egg masses are likely to be obvious on budwood cuttings and should be readily detected by visual inspection. Plant hosts reported to be used by *Lycorma delicatula* for oviposition that may be imported as whole plants are summarised in Table 4.

Insecticide dose rates required for effective control of the egg stages of insects may be significantly higher than those required for effective control of nymphs or adults. For example, the required dose for sulfuryl fluoride needed to effectively control eggs may be 29 times greater than that required for adults (Ormsby, 2018). There is limited information available that is specific to the treatment of spotted lanternfly eggs. However as the embryo is in a state of developmental diapause, which is accompanied by a reduced metabolic and respiration rate, and is protected by the egg chorion, which is in turn protected by a waxy coat, insecticide efficacy is likely to be significantly reduced.

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Table 4. Import specifications for plant hosts of *Lycorma delicatula* that are known to be used for oviposition. Taxa that have been identified as hosts, but for which the life stage(s) that are associated are not reported are included and marked "not reported".

Host Species	**Import Specification for Nursery Stock**	**Imported as Whole Plants**	**Life stages associated**	**Host reference**
Acer negundo	L2, L3 see 155.02.06 under Acer	Yes	Eggs	Liu 2019
Acer palmatum	L2, L3 see 155.02.06 under Acer	Yes	Eggs	Dara *et al.* 2015
Acer platanoides	L2, L3 see 155.02.06 under Acer	Yes	Eggs	Liu 2019
Acer rubrum	L2,L3 see 155.02.06 under Acer	Yes	Eggs	Dara *et al.* 2015
Acer saccharum	L2,L3 see 155.02.06 under Acer	Yes	Eggs	Dara *et al.* 2015, Liu 2019
Ailanthus altissima	Entry prohibited	n/a	eggs/adults/nymphs	Park *et al.* 2009: Dara *et al.* 2015;
Betula alleghaniensis	L2 (Basic)	Yes	Eggs	Liu 2019
Betula lenta	L2 (Basic)	Yes	Eggs	Liu 2019
Betula nigra	L2 (Basic)	Yes	Eggs	Liu 2019
Betula platyphylla	L2 (Basic)	Yes	Eggs	Park *et al.* 2009; Dara *et al.* 2015
Carpinus caroliniana	L2 see 155.02.06 under Carpinus	Yes	Eggs	Liu 2019
Carya ovata	L2 see155.02.06 under Carya	Yes	Eggs	Liu 2019
Castanea crenata	L3 see 155.02.06 under Castanea USA only	Yes	Eggs	Lee et al. 2011 in Liu 2019
Cornus florida	L2 see 155.02.06 under Acacia	Yes	Eggs	Liu 2019
Diospyros kaki	L3 see 155.02.06 under Diospyros	Yes	Eggs	Zu 1992 in Liu 2019
Fagus grandifolia	L2 see 155.02.06 under Fagus	Yes	Eggs	Dara *et al.* 2015
Fraxinus americana	L2 see 155.02.06 under Aesculus	Yes	Eggs	Liu et al 2019
Lindera benzoin	L2 (Basic)	Yes	Eggs	Liu 2019
Liriodendron tulipifera	L2, L3 see 155.02.06 under Carya ovata	Yes	Eggs	Dara *et al.* 2015
Malus spp.	L2,L3 see 155.02.06 under Malus	No	Not reported	Dara *et al.* 2015
Melia azedarach	L2 see 155.02.06 under Araucaria	Yes	Eggs	Chu 1930 in Liu 2019
Ostrya virginiana	L2, L3 see 155.02.06 under Carya ovata	Yes	Eggs	Liu 2019
Pinus strobus	Requires assessment	n/a	Eggs	Liu 2019
Platanus occidentalis	L2 see 155.02.06 under Platanus	Yes	Eggs	Dara *et al.* 2015
Platanus orientalis	L2 see 155.02.06 under Platanus	Yes	Not reported	Dara *et al.* 2015
Populus alba	L3 see 155.02.06 under Populus	Yes	Eggs	Dara *et al.* 2015
Populus tomentiglandulosa	Not Listed	n/a	Not reported	Dara *et al.* 2015
Prunus armeniaca	L2,L3 see 155.02.06 under Prunus	No	Eggs	Chou et al. 1985 in Liu et al 2019
Prunus avium	L2,L3 see 155.02.06 under Prunus	No	Eggs	Liu 2019
Prunus mume	L2,L3 see 155.02.06 under Prunus	No	Not reported	Dara *et al.* 2015
Prunus persica	L2,L3 see 155.02.06 under Prunus	No	Not reported	Dara *et al.* 2015
Prunus salicina	L2,L3 see 155.02.06 under Prunus	No	Not reported	Dara *et al.* 2015
Prunus serotina	Entry prohibited	n/a	Eggs	Dara *et al.* 2015
Prunus serrulata	L2, L3 see 155.02.06 under Prunus	No	Eggs	Dara *et al.* 2015
Prunus xyedoensis	L2, L3 see 155.02.06 under Prunus	No	Eggs	Dara *et al.* 2015

Punica granatum	L2 see 155.02.06 under Epipremnum	Yes	Eggs	Hou 2013 in Liu 2019
Pyrus sp.	Pathway suspended	n/a	Eggs	Yang et al 2015 in Liu 2019
Quercus acutissima	L3 see 155.02.06 under Quercus	Yes	Eggs	Tomisawa et al. 2013 in Liu 2019
Quercus montana	Not Listed	n/a	Eggs	Dara *et al.* 2015
Quercus rubra	L3 see 155.02.06 under Quercus	Yes	Eggs	Liu 2019
Robinia pseudoacacia	L2 (Basic)	Yes	Not reported	Dara *et al.* 2015
Salix matsudana	L3 see 155.02.06 under Salix	Yes	Not reported	Dara *et al.* 2015
Salix spp.	L3 see 155.02.06 under Salix	Yes	eggs/adults/nymphs	Dara *et al.* 2015
Sassafras albidum	See 155.02.06 under Hebe	Yes	Eggs	Liu 2019
Styphnolobium japonicum	Not listed	n/a	Eggs	Zhou 1992 in Liu 2019
Syringa vulgaris	L2 see 155.02.06 under Aesculus	Yes	Eggs	Dara *et al.* 2015
Tetradium daniellii	Requires assessment	n/a	Eggs/Nymphs	Dara *et al.* 2015
Toona sinensis	Requires assessment	n/a	Adult/nymph/ egg	Li *et al.* 1997; Park *et al.*2009; Dara *et al.* 2015
Ulmus spp	L3 see 155.02.06 under Ulmus	Yes	Eggs	Zhou 1992 in Liu et al 2019
Viburnum prunifolium	L2 see 155.02.06 under Viburnum USA only	Yes	Eggs	Liu et al 2019
Vitis spp.	L2,L3 see 155.02.06 under Vitis	No	Not reported	Dara *et al.* 2015
Zanthoxylum bungeanum	Requires assessement	n/a	Eggs	Gao et al 1993 in Liu et al 2019
Zelkova serrata	L3 see 155.02.06 under Planera	Yes	Eggs	Dara *et al.* 2015

Entry of nymphs and adults

Spotted lanternfly nymphs are highly mobile. Early instar nymphs will drop off host plants when they encounter an obstacle or are disturbed (Kim *et al.* 2011). Later instar nymphs hop away from disturbance and adults may either hop or fly away. It is possible that nymphs that have hatched in transit may remain associated with Nursery Stock. However, a Basic requirement for Nursery Stock is that it is accompanied by a phytosanitary certificate confirming it is free from quarantine pests. This certificate should only be issued after a visual inspection, which should be sufficient to detect egg masses prior to shipping.

Of the insecticides recommended for the treatment of Nursery Stock deltamethrin, imidacloprid, and thiacloprid have been demonstrated to result in 100, 85 and 75% mortality of a small (n=90) sample of *L. delicatula* nymphs.

Given that:

- *Lycorma delicatula* adults and nymphs are only likely to be associated with whole plants
- *Lycorma delicatula* nymphs and adults are highly mobile
- Whole plants is a comparatively low volume pathway
- Whole plants must be insecticide treated as part of the Basic entry conditions
- Whole plants are visually inspected on arrival and subject to a minimum of 3 months PEQ
- *Lycorma delicatula* egg masses may be difficult to see on some hosts
- Many insecticides are ineffective against *L. delicatula* egg masses

The likelihood that *L. delicatula* nymphs or adults would enter on the Nursery Stock Pathway is considered **Very Low** to **Negligible**

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The likelihood that *L. delicatula* egg masses would enter on the Nursery stock pathway is considered **Low** to **Very Low**.

5.1.2.5 Cut Flowers and Foliage

The Import Health Standard (IHS) for Cut Flowers and Foliage (Standard 155.02.04) manages imports by country rather than by commodity. It is a requirement of the IHS that all incoming cut flowers or foliage are free from regulated pests. If pests such as *Lycorma delicatula* are detected during inspection on arrival, the importer is obliged to treat, reship or destroy the consignment they were found on.

Spotted lanternfly adults and nymphs are highly mobile. Early instar nymphs will drop off host plants when they encounter an obstacle or are disturbed (Kim *et al.* 2011). Later instar nymphs hop and adults fly away from disturbance. It is possible that nymphs that have hatched from egg masses in transit may remain associated with cut flowers or foliage. However as cut flowers and foliage are typically transported by air rather than sea, the window for this to occur is extremely narrow and the likelihood that eggs will hatch in transit is therefore considered very low.

Lycorma delicatula typically lays its eggs on smooth stems or smooth barked plants. To date, *L. delicatula* egg masses have been recorded on 53 host species (see Table 4).There is no import health standard to import cut flowers or foliage from any of these species.

Of the countries where *L. delicatula* is reported to be present, Cut flowers and foliage may only be imported from India and the USA. The only known host of *L. delicatula* that may be imported as cut flowers or foliage is *Rosa* spp. from India. To date, *Rosa* spp. has not been reported to be an oviposition host of *L. delicatula*. However, 22 new oviposition hosts were recently described (Liu, 2019), which suggests that the full extent of *L. delicatula*'s oviposition hosts remains unknown. Furthermore, there have been numerous records of inanimate objects such as fence posts, steel and stone being used as an oviposition substrate. With this in mind, it seems likely that any plant meeting the requirements of smooth bark and stem diameter >1cm could potentially be an oviposition host.

There has been only one record of *L. delicatula* in India to date. The record (Distant 1906) is based on "a doubtful locality of Atkinson, though there is every probability it occurs in the confines of British India". It appears that the inclusion of India in the distribution of *L. delicatula* is based citations of this report and there do not appear to be any reports of *L. delicatula* from India subsequent to it. It is therefore uncertain whether *L. delicatula* is *actually* present in India. This in combination with *Rosa* spp. never having been recorded as an oviposition host and of the absence of interceptions of *L. delicatula* on this pathway suggest that the likelihood of contamination by *L. delictula* in roses from India is **Very Low**.

Given that:

- Of the countries where *L. delicatula* is reported to occur, only India and the USA have IHSs for cut flowers and foliage.
- *Lycorma delicatula* adults and nymphs are highly mobile and easily disturbed
- None of the known oviposition hosts of *L. delicatula* may be imported under the cut flowers and foliage IHS

- The only known host of *L. delicatula* that may be imported as cut flowers and foliage is *Rosa* spp.
- Rosa spp. may only be imported as cut flowers and foliage from India
- The presence of *L. delicatula* in India is uncertain
- *Rosa* spp. is not a known oviposition host for *L. delicatula*

The likelihood of *Lycorma delicatula* entering New Zealand on Cut flowers and Foliage is considered **Negligible.**

5.1.2.6 Personal effects and Luggage

Between October 2016 and October 2017; 3,688,013 overseas visitors were recorded entering New Zealand. Of the top 30 countries of origin, 6 are countries where spotted lanternfly is reported to occur (China, India, Japan, South Korea, Taiwan and the USA) equating to 1,017,264 visitors from countries where spotted lanternfly is present in one year (Stats NZ, 2017). The peak period for arrival of visitors from overseas is November to March.

MPI applies interventions at a range of points in the passenger arrival process to manage biosecurity risk. All passengers are exposed to communications describing biosecurity requirements and are required to fill in the Passenger Arrivals Card (PAC) before arriving. Upon arrival all passengers pass through immigration and collect their baggage from the carousel. During this process, passengers may be screened by detector dogs. However, there are currently no dogs trained to detect spotted lanternfly.

All passengers are then assessed by a Quarantine Inspector and will either be referred to full inspection, x-ray, and item inspection or, if eligible, may be cleared to use the Green Lane ("Nothing to Declare") exit. Inspected items may be treated or destroyed. Items may also be held at the airport for the passenger to retrieve on their departure (MPI 2013).

Entry of Eggs

Lycorma delicatula typically lays its eggs on smooth barked trees, but may oviposit on inanimate objects. The eggs are deposited in clusters of 30-50 protected by a grey waxy oothecal, which may make them harder to see. It is possible that eggs could be deposited on luggage or personal effects that are infrequently used such as camping equipment particularly if they are stored outside between August and November.

Entry of Nymphs

Lycorma delicatula nymphs, while flightless, are highly mobile and hop or drop away when disturbed. Nymphs will primarily be seeking food and are unlikely to linger on personal effects if they do not offer sustenance. It is therefore considered unlikely that nymphs would remain associated with luggage or personal effects.

Entry of Adults

Lycorma delicatula adults are highly mobile and easily disturbed. Adults will be looking for food and mates and are unlikely to linger where there is no food or potential mates. Adult females will be seeking suitable oviposition sites between August and November. Though

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unlikely, the possibility that a gravid female could become trapped in personal effects cannot be discounted.

Given that

- *Lycorma delicatula* adults and nymphs are mobile and easily disturbed
- *Lycorma delicatula* nymphs and adults will primarily settle on food sources
- *Lycorma delicatula* deposits eggs on smooth surfaces between August and November
- Eggs masses are covered by a waxy grey ootheca

The likelihood of *L. delicatula* adults or nymphs entering in personal effects is considered **Very Low**.

The likelihood that *L. delicatula* egg masses could enter on personal effects, such as camping equipment that have been stored outside between August and November is considered **Low**.

5.1.2.7 Vehicles Machinery and Equipment

Entry of Adults and Nymphs

Lycorma delicatula nymphs emerge in May (spring) and are active until their moult into adulthood in July (summer). Adults actively feed, search for mates and adult females deposit eggs during autumn, generally from late September until November. Both adults and nymphs are highly mobile and easily disturbed. For this reason it is not considered likely that they would remain associated with vehicles and equipment, although it is possible that individuals may occasionally become trapped. However, in the absence of food, adults and nymphs are not expected to survive longer than five days – particularly at higher (>25°C) temperatures.

Entry of Eggs

Lycorma delicatula eggs are deposited in clusters of 30-50 on smooth barked host trees (Kim *et al.* 2011). Egg masses may also be deposited on smooth inanimate objects such as fence posts, stones, outdoor equipment (Dara *et al.* 2015) and potentially vehicles and equipment.

In general, the hold temperatures of a vessel travelling from the Northern Hemisphere to New Zealand range between 25° and 40°C, with temperature peaking as the vessel moves through the tropics where the ambient temperature is at its highest. Additional heat is generated by two major sources, the heating of fuel oil (so that it can be pumped from the storage tanks to the engine room) and by operating integrated refrigerated containers. Hold areas with no fuel tanks below them will likely be at the lower end of this temperature range. Those housing active integrated refrigerated containers or situated above fuel tanks are likely to be at the higher end of the temperature range (Bruce Hunter – Maersk NZ Port Captain Pers. Com.).

Hatching rates of *L. delicatula* eggs have been demonstrated to decrease from ~62% to 30% with an increase in temp from 15°C to 25°C and between zero (Choi et al. 2012) and <27% (Song 2010) hatching rates was have been reported at 30°C. It is highly likely that *L. delicatula* eggs exposed to prolonged periods at 30°C in transit will be non-viable. Eggs exposed to temperatures between 15°C and 25°C are likely to remain viable and, based on experimental results, it is possible that development may be completed in transit at temperatures around 25°C in 10 (Song et al. 2010) to 22 days (Choi et al. 2012). However, based on the same experimental results hatching rates could be expected to be lower than 32%. Should this be the case, emerging nymphs are not expected to live longer than five days in the absence of suitable food.

Hatching rates of eggs collected from the field and incubated at 25°C have been observed to increase the later in the season the eggs are collected. Shim and Lee (2015) reported hatching rates ranging from 14.2% in November to 88.8% in March. These observations are analogous to the length of cold diapause experienced by eggs prior to containers being loaded on to a vessel where they are exposed to elevated temperatures. Based on the results of Shim and Lee (2015), it may be expected that viability of eggs will be greater if they are exported from the donor country in March than if they are exported in November. In South Korea and the USA, eggs are typically deposited during autumn between late September and early October (Shin *et al.*2015) but have been reported to be deposited as early as August and as late as November (Kim *et al.*2011).

The IHS for Vehicles, Machinery and Equipment (VME) stipulates that all VME must be cleaned thoroughly inside and out. This cleaning may include disassembly. In addition to these requirements, VME exported between the 1st of September and the 30th of April from countries listed in schedule 3 of the IHS must have been subject to an MPI approved treatment. These treatments include heat treatment (> 56°C) or fumigation with methyl bromide.

Of the countries where spotted lanternfly is known to occur, only USA is listed in Schedule 3. However comparable measures are also required for VME exported from Japan.

Given that *Lycorma delicatula*:
- adults and nymphs are mobile and easily disturbed
- adults and nymphs are phloem feeders and are unlikely to encounter suitable food associated with vehicles, machinery and equipment
- nymphs are not expected to live more than five days without food
- adults are not expected to live more than three days without food
- overwinter as eggs in a state of developmental diapause
- eggs may be deposited on any smooth vertical surface
- eggs are covered by a greyish brown waxy layer
- eggs take 56 days to hatch at 15°C, 10 to 22 days at 25°C and 10 days with negligible to low (0-<27%) hatching rates at 30°C
- eggs hatching rates increase with time in diapause
- temperatures on vessels are likely to be higher than encountered while naturally overwintering and may be sufficient to complete incubation of eggs
- overwintering eggs would be moving from Northern Hemisphere autumn/winter to Southern Hemisphere spring/summer

The likelihood of live adult SLF or nymphs entering New Zealand associated with Vehicles, machinery and equipment is considered **Very Low** to **Negligible**

The likelihood that SLF egg masses entering New Zealand on Vehicles, machinery and equipment contents is considered **Low**

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5.1.2.8 Wood Packaging

Hong *et al.* (2012) identified wood packaging as one of the likely pathways that spotted lanternfly entered South Korea from China.

The Import Health Standard for Wood Packaging Material from All Countries stipulates that all wood packaging must be free from regulated pests, and must be either treated in accordance with ISPM 15, phosphine fumigated or subjected to chemical preservation to full sapwood penetration with either Boron, Copper + didecyldimethyl ammonium chloride (DDAC), Copper azole, Copper Chrome Arsenic (CCA) or Propiconaole and Tebuconazole. Such treatment would likely kill any egg masses already associated with packaging, but is unlikely to deter new oviposition.

Entry of Eggs

Lycorma delicatula is known to deposit eggs on smooth vertical surfaces. Stacked wooden pallets and other packaging materials potentially provide a suitable site for oviposition. Eggs are typically deposited between September and November and overwinter in a state of diapause until May, when temperatures increase. Hatching occurs between 10 and 22 days at 25°C and 56 days at 15°C.

Hatching times of *L. delicatula* eggs vary dependent on temperature. Vessel hold and container temperatures are often greater than 15°C and may exceed 30°C at some times of year (Grier and Chan, 1970; Weiskircher 2008). In general the hold temperature of a vessel travelling from the Northern Hemisphere to New Zealand range between 25° and 40°C, with temperature peaking as the vessel moves through the tropics where the ambient temperature is at its highest. Additional heat is generated by two major sources, the heating of fuel oil (so that it can be pumped from the storage tanks to the engine room) and by operating integrated refrigerated containers. Hold areas with no fuel tanks below them will likely be at the lower end of this temperature range. Those housing active integrated refrigerated containers or situated above fuel tanks are likely to be at the higher end of the temperature range (Bruce Hunter – Maersk NZ Port Captain Pers. Com.).

Hatching rates of *L. delicatula* eggs have been demonstrated to decrease from ~62% to 30% with an increase in temp from 15°C to 25°C and between zero (Choi et al. 2012) and <27% (Song 2010) hatching rates was have been reported at 30°C. It is highly likely that *L. delicatula* eggs exposed to prolonged periods at 30°C in transit will be non-viable. Eggs exposed to temperatures between 15°C and 25°C are likely to remain viable and, based on experimental results, it is possible that development may be completed in transit at temperatures around 25°C in 10 (Song et al. 2010) to 22 days (Choi et al. 2012). Based on the same experimental results, hatching rates could be expected to be lower than 32%. Should hatching occur in transit, emerging nymphs are not expected to live longer than five days in the absence of suitable food.

Hatching rates of eggs collected from the field and incubated at 25°C have been observed to increase the later in the season the eggs are collected. Shim and Lee (2015) reported hatching rates ranging from 14.2% in November to 88.8% in March. These observations are analogous to the length of cold diapause experienced by eggs prior to containers being loaded on to a vessel where they are exposed to elevated temperatures. Based on the results of Shim and Lee (2015), it may be expected that viability of eggs will be greater if they are exported from the donor country in March than if they are exported in November.

Shipping times to New Zealand vary from approximately 16-19 days from Japan, 28 days from China, and between 12 days from the West Coast, and 25 days from the East Coast of USA (Championfreight NZ, 2019). It is possible that *L. delicatula* eggs could remain unhatched during the course of a voyage.

Entry of Adults and Nymphs

Lycorma delicatula nymphs emerge in May and develop through to adulthood by July. During this time they are actively seeking food. All nymphal instars are highly mobile and are easily disturbed. They will either drop or hop away from the source of a disturbance. For this reason. *L. delicatula* nymphs are not considered likely to remain associated with wood packaging.

Lycorma delicatula moult into adults in July and actively feed, seek mates and oviposit through to November. Adults are mobile and easily disturbed and will fly away from the source of disturbance. For this reason, adults are not considered likely to remain associated with wood packaging.

Given that:

- Treatment to ISPM 15 is unlikely to deter oviposition
- Hatching times may exceed 56 days at lower temperatures
- Most sea voyages take less than 56 days
- Adult and nymphal *L. delicatula* are highly mobile and easily disturbed
- In the absence of food adults are not expected to live longer than 3 days and nymphs no more than five days

The likelihood that *Lycorma delicatula* egg masses may enter on wood packaging is considered **Low**

The likelihood that *L. delicatula* nymphs or adults will enter on wood packaging is considered **Very Low** to **Negligible.**

5.1.2.9 Sawn Wood

The IHS for Sawn wood from all countries stipulates freedom from live regulated pests and contaminants (e.g. leaves, soil). The maximum acceptable contamination rate is up to 0.01% weight/weight. In addition all wood must be bark free. Timber must be packed and/or shipped in a manner that prevents infestation and/or contamination by live regulated pests, if packaged prior to shipping. All sawn wood is subject to visual inspection on arrival.

Mandatory treatment is required for any sawn timber of *Pinus* species not sourced from an approved pest free area for *Fusarium circinatum*. These approved *F. circinatum* free countries are: Argentina, Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, Germany, Greece, Hungary, Ireland, Luxembourg, Netherlands, Norway, Poland, Slovakia, Switzerland, Sweden, Turkey, and United Kingdom. Spotted lanternfly is not known to be present in any of these approved countries, therefore treatment of sawn

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timber of *Pinus* species is currently mandatory for all countries where *L. delicatula* is known to occur.

The approved treatments for *Pinus* spp. sawn wood are:

Fumigation with methyl bromide or sulphuryl fluoride of filleted (separated vertically or horizontally by a minimum of 5mm of airspace in one dimension, every 200mm) at:

i) 80 g/m3 for more than 24 continuous hours, and in a minimum temperature of 10°C;

OR

ii) heat treatment (or kiln drying) at one of the following minimum continuous core temperature and minimum time combinations presented in Table 5 below:

Table 5. Heat treatment (temperature) and time in minutes for treatment of sawn timber

Core temperature (°C)	Time(minutes)
70	240
80	120
90	60
100	30
110	20
120	15

Or

iii) chemical preservation of sawn wood to full sapwood penetration using one of the chemicals as specified in Table 6.

Table 6. Chemical treatments and minimum retentions for treatment of sawn timber

Chemical	**Minimum Retention**
Boron compounds (insecticidal and limited fungicidal protection)	0.1% Boric Acid equivalent minimum loading in the sapwood core
Copper + didecyldimethyl ammonium chloride (DDAC) *(insecticidal & fungicidal protection)*	0.35% mass/mass OR 2.8 kg/m3 in softwood timbers, 5.60 kg/m3 in hardwood timbers.
Copper azole *(insecticidal & fungicidal protection)*	0.27% mass/mass OR 1.35 kg/m3 in softwood timbers, 2.7 kg/m3 in hardwood timbers.
Copper Chrome Arsenic (CCA) (insecticidal & fungicidal protection)	0.27% mass/mass OR 3kg/m3 minimum preservative retention
Arsenic (insecticidal protection only)	0.04% minimum preservation loading in sapwood core
Permethrin (insecticidal protection only)	Minimum retention of not less than 0.06% mass/mass

Entry of Eggs

Lycorma delicatula is known to deposit eggs on smooth vertical surfaces > 1cm in diameter. Stacked sawn wood potentially represents a suitable site for oviposition. Eggs are typically deposited between September and November and overwinter in a state of diapause until May when temperatures increase. Hatching occurs between 10 and 22 days at 25°C and 56 days at 15°C (Choi *et al.*2012). Eggs do not hatch at temperatures below 12°C or above 33°C (Park 2015).

Hatching times of *L. delicatula* eggs vary dependent on temperature. Vessel hold and container temperatures are typically greater than 15°C and may exceed 30°C at some times of year (Grier and Chan, 1970; Weiskircher 2008). In general hold temperature of a vessel travelling from the Northern Hemisphere to New Zealand range between 25° and 40°C, with temperature peaking as the vessel moves through the tropics where the ambient temperature is at its highest. Additional heat is generated by two major sources, the heating of fuel oil (so that it can be pumped from the storage tanks to the engine room) and by operating integrated refrigerated containers. Hold areas with no fuel tanks below them will likely be at the lower end of this temperature range. Those housing active integrated refrigerated containers or situated above fuel tanks are likely to be at the top end of the temperature range (Bruce Hunter – Maersk NZ Port Captain Pers. Com.).

Temperatures inside a container are highest when it is on the wharf awaiting loading or during unloading when it may be exposed to direct sunlight (Weiskircher, 2008). In-container temperatures have been reported to range from -21°C in January to 57°C in July in containers awaiting unloading and inspection in Memphis (Weiskircher, 2008).

Shipping times to New Zealand vary from approximately 16-19 days from Japan, 28 days from China, and between 12 days from the West Coast, and 25 days from the East Coast of USA (Champion freight NZ, 2019). Based on reported development rates at these temperatures, and voyage lengths, and estimated hold temperatures there is a Low likelihood that eggs will complete their development during the voyage at lower temperatures (15°C) and a Moderate likelihood that eggs will complete their development during the voyage at higher temperatures (~25°C).

While there are no mandatory treatment requirements for sawn wood of taxa other than *Pinus* spp., there is a **Moderate** likelihood that hold temperatures will exceed the upper threshold for continued development of SLF eggs on some voyages. For example, Nixon *et al*. (2019), simulated vessel temperatures to examine in transit mortality of the brown marmorated stink bug (*Halyomorpha halys*). The simulation was based on data provided by Wallenius Wilhelmsen Logistics collected across three decks of a container vessel travelling from Baltimore, USA to New Zealand between January and February. The reported temperatures on the decks were 12°C at the beginning of a journey, increasing to 30°C over 7 days, holding at 30°C for 12 days and decreasing to 23°C over a further 7 days.

There is a high likelihood that the heat treatment and methyl bromide fumigation options for treatment of *Pinus* sawn wood will kill *L. delicatula* eggs. However, insecticide dose rates required for effective control of the egg stages of insects may be significantly higher than those required for effective control of nymphs or adults. For example, the required dose for sulfuryl fluoride needed to effectively control eggs may be 29 times greater than that required for adults (Ormsby, 2018). There is limited information available that is specific to the

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treatment of spotted lanternfly eggs, however as the embryo is in a state of developmental diapause, which is accompanied by a reduced metabolic and respiration rate, and is protected by the egg chorion, which is in turn protected by a waxy coat, insecticide efficacy is likely to be significantly reduced.

While there does not appear to be specific information on the effectiveness of permethrin against *L. delicatula* eggs, other synthetic pyrethroids have been demonstrated to perform poorly. Shin *et al.* (2011) reported mortality rates ranging of 0% (deltamethrin and esfenvalerate), 8.2% bifenthrin and 30.2% etofenprox when *L. delicatula* eggs were treated with synthetic pyrethroids administered as either wettable powders or emulsifiable concentrates.

Entry of Adults and Nymphs

Lycorma delicatula nymphs emerge in May and develop through to adulthood by July. During this time they are actively seeking food. All nymphal instars are highly mobile and are easily disturbed. They will either drop or hop away from the source of a disturbance. For this reason. *L. delicatula* nymphs are not considered likely to remain associated with sawn wood.

Lycorma delicatula moult into adults in July and actively feed, seek mates and oviposit though to November. Adults are mobile and easily disturbed and will fly away from the source of disturbance. For this reason, adults are not considered likely to remain associated with sawn wood.

On arrival all untreated timber is subject to a 10% break bundle inspection (i.e. 10% of the consignment is broken apart from its bundle and subject to visual inspection on all faces of each piece of sawn timber).

Sawn wood that has been pre-treated is subject to exterior inspection only

Given that:

- *Lycorma delicatula* deposits egg masses on smooth surfaces >1cm in diameter
- there are no mandatory treatment requirements for sawn wood of taxa other than *Pinus*
- shipping times are typically longer than egg development times at or above 25°C
- the effectiveness of some fumigants on *L. delicatula* eggs is unknown
- pyrethroid efficacy against *L. delicatula* eggs has been shown to be low.
- *Lycorma delicatula* adults and nymphs are mobile and irritable

The likelihood that *L. delicatula* nymphs or adults will enter on sawn timber is considered **Negligible**

The likelihood that *L. delicatula* eggs will enter on sawn timber is considered **Low**.

5.1.2.10 Poles, Piles, Rounds and Sleepers

The IHS for poles, piles, rounds and sleepers stipulates freedom from live regulated pests and contaminants (e.g. leaves, soil). The maximum acceptable contamination rate is up to 0.01%; weight/weight. In addition all wood must be bark free. Timber must be packed and/or shipped in a manner that prevents infestation and/or contamination by live regulated pests, if packaged prior to shipping. All sawn wood is subject to visual inspection on arrival.

Pre-export treatment is mandatory for any pole, pile or round that is greater than 300mm in diameter and for all sleepers, irrespective of thickness.

Treatment options are as follows:
a) Fumigation with methyl bromide or sulphuryl fluoride of filleted (separated vertically or horizontally by a minimum of 5mm airspace in one dimension, every 200mm) at:
i) 160 g/m3 for more than 48 continuous hours, at a temperature between 10°C and 15°C; or
ii) 120 g/m3 for more than 48 continuous hours, at temperatures 15.1°C and above.
OR
b) Heat treatment (or kiln drying) at one of the following minimum continuous core temperature and minimum time combinations (Table 7).

Table 7. Core temperature °C and time (minutes for heat treatment of poles, piles, rounds and sleepers

Core temperature (°C)	Time(minutes)
70	240
80	120
90	60
100	30
110	20
120	15

Entry of Eggs

Lycorma delicatula is known to deposit eggs on smooth vertical surfaces >1cm in diameter. Stacked poles, piles, rounds or sleepers could potentially provide a suitable site for oviposition. Eggs are typically deposited between September and November and overwinter in a state of diapause until May when temperatures increase. Hatching occurs between 10 and 22 days at 25°C and 56 days at 15°C (Choi *et al.* 2012). Eggs do not hatch at temperatures below 12°C or above 33°C (Park 2015).

In general hold temperature of a vessel travelling from the Northern Hemisphere to New Zealand range between 25° and 40°C, with temperature peaking as the vessel moves through the tropics where the ambient temperature is at its highest. Additional heat is generated by two major sources, the heating of fuel oil (so that it can be pumped from the storage tanks to the engine room) and by operating integrated refrigerated containers. Hold areas with no fuel tanks below them will likely be at the lower end of this temperature range. Those housing active integrated refrigerated containers or situated above fuel tanks are likely to be at the top end of the temperature range (Bruce Hunter – Maersk NZ Port Captain Pers. Com.).

Hatching times of *L. delicatula* eggs vary dependent on temperature. Shipping times to New Zealand vary from approximately 16-19 days from Japan, 28 days from China, and between 12 days from the West Coast, and 25 days from the East Coast of USA (Championfreight NZ,

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2019). Given that hatching has been reported to occur within 10-22 days at 25°C, there is a **Moderate** to **High** likelihood that *L. delicatula* eggs would hatch during the course of a voyage. If this is the case, emerging nymphs are not expected to survive more than five days in the absence of a suitable food source.

There is a high likelihood that the heat treatment and methyl bromide fumigation options for treatment of *Pinus* sawn wood will kill *L. delicatula* eggs.

Entry of Nymphs

Lycorma delicatula nymphs emerge in May and develop through to adulthood by July. During this time they are actively seeking food. All nymphal instars are highly mobile and are easily disturbed. They will either drop or hop away from the source of a disturbance. For this reason. *L. delicatula* nymphs are not considered likely to remain associated with poles, piles, rounds and sleepers. Should nymphs emerge from eggs that hatch in transit, there is a very low likelihood that they would find suitable food resources on board the vessel. Without suitable food, nymphs are not expected to survive longer than 4-5 days. For these reasons, the likelihood that nymphs will enter New Zealand associated with poles piles, rounds and sleepers is considered **negligible**.

Entry of Adults

Lycorma delicatula moult into adults in July and actively feed, seek mates and oviposit through to November. Adults are mobile and easily disturbed and will fly away from the source of disturbance. For this reason, adults are not considered likely to remain associated with poles, piles, rounds and sleepers.

On arrival all untreated timber is subject to a 10% break bundle inspection (i.e. all 10% of the consignment is broken apart from its bundle and subject to visual inspection on all faces of each piece of sawn timber).

Poles, piles, rounds and sleepers that have been pre-treated are subject to exterior inspection only.

Given that:

- eggs take 56 days to hatch at 15°C, 10 to 22 days at 25°C and 10 days with negligible to low (0-<27%) hatching rates at 30°C
- vessel hold temperatures typically range between 25 and 40°C
- shipping times are typically longer than egg development times at these temperatures
- the effectiveness of some fumigants on *L. delicatula* eggs is unknown
- pyrethroid efficacy against *L. delicatula* eggs has been shown to be low.
- *Lycorma delicatula* adults and nymphs are mobile and irritable

The likelihood that *L. delicatula* eggs will enter on poles, piles, rounds and sleepers is considered **Low**.

The likelihood that *L. delicatula* nymphs or adults will enter on poles, piles, rounds and sleepers is considered **Negligible**.

5.1.2.11 Vessels and Aircraft

Vessels

Nixon *et al*. 2019, simulated vessel temperatures to examine in transit mortality of the brown marmorated stink bug (*Halyomorpha halys*). The simulation was based on data provided by Wallenius Wilhelmsen Logistics collected across three decks of a container vessel travelling from Baltimore, USA to New Zealand between January and February. The reported temperatures on the decks were 12°C at the beginning of a journey, increasing to 30°C over 7 days, holding at 30°C for 12 days and decreasing to 23°C over a further 7 days. However, while this data is representative of conditions on a longer voyage during peak Southern Hemisphere summer temperatures it may not accurately reflect conditions on shorter voyages or those occurring earlier in the spotted lanternfly's overwintering period.

In general hold temperature of a vessel travelling from the Northern Hemisphere to New Zealand range between 25° and 40°C, with temperature peaking as the vessel moves through the tropics where the ambient temperature is at its highest. Additional heat is generated by two major sources, the heating of fuel oil (so that it can be pumped from the storage tanks to the engine room) and by operating integrated refrigerated containers. Hold areas with no fuel tanks below them will likely be at the lower end of this temperature range. Those housing active integrated refrigerated containers or situated above fuel tanks are likely to be at the top end of the temperature range (Bruce Hunter – Maersk NZ Port Captain Pers. Com.).

Entry of Eggs

As hatching rates of *L. delicatula* eggs have been demonstrated to decrease from approximately 62% to 30% between 15°C and 25°C and as zero hatching was observed at 30°C (Choi *et al.*2012), there is a High likelihood that *L. delicatula* eggs exposed to at least 12 days at ~30°C will have low viability. For eggs exposed to temperatures between 15°C and 25° C in transit, there is a High likelihood they would remain viable. Hatching has been reported to occur between 10 and 22 days at 25°C and 56 days at 15°C (Choi *et al.* 2012). Shipping times to New Zealand vary from approximately 16-19 days from Japan, 28 days from China, and between 12 days from the West Coast, and 25 days from the East Coast of USA (Championfreight NZ, 2019). Based on reported development rates at these temperatures, voyage lengths, and estimated hold temperatures here is Moderate likelihood that eggs will complete their development during the voyage at temperatures around 25°C. Nymphs hatching in transit in the absence of food or water, would not be expected to survive longer than four or five days (Lee *et al.* 2009).

Entry of Nymphs

First instar nymphs are polyphagous (Kim *et al.* 2011). It is unlikely that nymphs would encounter suitable food hosts on board a ship. Under experimental conditions, Lee *et al.*(2009) demonstrated that when spotted lanternfly nymphs held at 25 ± 2 ℃, 50 ~ 60% relative humidity and under 16L: 8D photoperiod conditions and fed only water they survived only four or five days (Lee *et al.*2009).

Entry of Adults

Adult *L. delicatula* are active between July and November. During this period, adults are actively feeding, seeking mates and eventually producing eggs. Spotted lanternfly are not strong flyers, typically travelling less than 40m in a single flight (Myrick and Baker, 2019). There is a very low likelihood that they would move from host material and across a body of

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water to become associated with a vessel. If they were to become associated with a vessel, there is a low likelihood that adult *L. delicatula* would find sufficient suitable food sources on board. Under experimental conditions, Lee *et al.*(2009) demonstrated that when spotted lanternfly adults held at 25 ± 2 °C, 50 ~ 60% relative humidity and under 16L: 8D photoperiodic conditions were fed only water they survived only two or three days. However, under the same conditions adults fed on an aqueous solution of fructose, glucose and sucrose (in a ratio comparable to the sap of tree of heaven), only survived between 6 and 8 days. The comparatively short survival of adults fed a sugar combination suggests factors other than carbohydrate availability may influence mortality, but the results suggest that absence of food on a vessel would be a limiting factor to survival of a voyage, particularly at higher temperatures.

Should a gravid female become associated with a vessel, there is a high likelihood that she would oviposit on board. However, given the combination of hold temperatures and *L. delicatula*'s apparent requirement for a period at low temperature during overwintering, the likelihood that such eggs would remain viable is considered very low.

Aircraft

Entry of Eggs

It is possible that *L. delicatula* egg masses could be laid on aircraft exteriors or in wheel wells. External in flight temperatures on an international flight may reach -50°C and temperatures in wheel wells have been reported to fall as low as -12.4°C or -18°C (Perry, 2002). However, a study of insect (mosquito, housefly and flour beetle) survival in the wheel wells of Boeing 747 aircraft travelling for >8 hours found that survival rates ranged between 67.5 and 97.5%, and that temperatures in wheel bays did not fall below 8°C (Russel, 1987). As the lower lethal temperature for *L. delicatula* has been estimated to be -11°C, the likelihood that eggs laid on the exterior of aircraft would survive is considered **Negligible**.

Given that there appears to be considerable variation in wheel well temperature ranges, the likelihood that egg mass deposited in wheel wells would survive is considered **Moderate** with high uncertainty.

There is a **Very Low** likelihood that aircraft would remain in New Zealand longer than 24 hours before commencing their next flight. Should eggs hatch during this period, there is a **Very Low** likelihood that emergent nymphs would find suitable food resources in the airport or hangar.

Entry of Nymphs

Nymphs are unlikely to become associated with aircraft as they are flightless and predominantly arboreal, crossing the ground only to reach other host plants.

Entry of Adults

Adult *L. delicatula* are only likely to become associated with aircraft holds or interiors inadvertently when the insect is on the wing in search of food or mates. Generally, as aircraft are situated on tarmac surrounded by unsuitable vegetation for *L. delicatula* this would be a very rare occurrence.

Aircraft interiors are required to be treated with a residual insecticide. The active ingredient of these insecticides is typically a pyrethroid such as Permethrin or d-phenothrin. Spotted lanternfly nymphs and adults are reportedly highly susceptible to pyrethroid based insecticides (Dara *et al.* 2015). For example, treatment with Deltamethrin resulted in 100% mortality within two hours (Park *et al.* 2009). However, there is no data available on the effectiveness of either Permethrin or d-phenothrin.

Given that:

- Vessel hold temperatures have been reported to reach 30°C for prolonged periods in January and February on some voyages.
- Hatching rates of *L. delicatula* eggs decrease with increasing temperature and cease development at 30°C
- Exterior temperatures on aircraft fall to -50°C
- Aircraft wheel well temperatures may range from 8°C to -18°C,
- The lower lethal temperature for *L. delicatula* eggs has been reported to be -11°C
- Aircraft holds are sprayed with residual insecticide.
- *Lycorma delicatula* is a phloem feeding insect
- There is unlikely to be suitable food or water for *L .delicatula* nymphs or adults on a vessel, aircraft or airport
- In the absence of food or water *L. delicatula* adults and nymphs die within 4-8 days

The likelihood of *L. delicatula* eggs entering New Zealand on a sea vessel is considered **Low** to **Very Low**

The likelihood of *L. delicatula* eggs entering New Zealand on a commercial aircraft is considered **Low** to **Very Low**

The likelihood of *L. delicatula* nymphs or adults entering New Zealand on a sea vessel is considered **Very Low**

The likelihood of *L. delicatula* nymphs or adults entering New Zealand on a commercial aircraft is considered **Negligible**

5.2 Exposure assessment

5.2.1 Containers and containerised goods (Hitchhiker pathway)

Lycorma delicatula nymphs emerge in May (spring) and forage for food until July (summer). Adult *L. delicatula* are actively foraging or seeking mates between July (summer) and November (autumn). Individual nymphs or adults may occasionally become associated with containers or their contents. On arrival in New Zealand, they are unlikely to encounter climatic conditions that are favourable as they would be moving from Northern Hemisphere spring and summer to New Zealand autumn and winter.

Eggs masses are typically deposited on smooth bark or smooth surface and may be associated with containers or containerised goods that have been stored in or near an infested area. Containers are moved from the point of first arrival to a secure transitional facility for

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devanning and inspection of the goods contained therein by a quarantine officer or accredited person. Egg masses would be moving from Northern Hemisphere winter to Southern Hemisphere summer. There is a High likelihood temperatures across New Zealand would be higher than the minimum developmental threshold temperature for *L. delicatula* eggs (Appendix Table 2).

After inspection the container and its contents are released into the New Zealand environment. As *L. delicatula* nymphs are highly polyphagous, there is a high likelihood that emerging nymphs from undetected egg masses would encounter a suitable food source.

Given that:

- containers remain sealed and are placed on a clean pad for a period of no more than 48 hours before being moved to a secure transitional facility.
- nymphs and adults would be moving from the Norther Hemisphere spring/summer to New Zealand's autumn/winter.
- after inspection containers and cargo are released into the New Zealand environment
- eggs would be moving from Northern Hemisphere winter to New Zealand Summer
- temperatures in New Zealand would be above the lower developmental threshold for *L. delicatula* eggs.
- emerging nymphs are highly polyphagous and mobile.

Likelihood of exposure of adults or nymphs to suitable environment is considered **Negligible.**

Likelihood of exposure of eggs to suitable environment and emergent nymphs to suitable food resources is considered **Moderate.**

5.2.2 Air containers

There is a very low likelihood that air containers will harbour *L. delicatula* eggs, nymphs or adults. However, the likelihood is not negligible.

All air containers are opened and inspected by an accredited person, unless the importer decides to fumigate without inspection. Both nymphs and adults are visually conspicuous and are likely to be detected during a visual inspection, which would require mandatory fumigation.

Nymphs would be moving from Northern Hemisphere spring to Southern Hemisphere autumn and adults would moving from summer to winter. The lower temperature threshold for development of *L. delicatula* nymphs estimated to be 11.13° (Park, 2009). Average monthly temperatures in Auckland are above this threshold between May and July, whereas temperatures in Christchurch fall below the threshold (Table A2). *L. delicatula* nymphs have been reported on approximately 65 different host species of which 35 are present in New Zealand. However, it is unlikely that these species (which include kiwifruit, roses, weeping willows and grapevine) would be present either in or near and airport. It is uncertain whether *L. delicatula* nymphs can complete development on other taxa that may be present.

Adult *L. delicatula* would be moving from Northern Hemisphere Summer to New Zealand winter. Ambient temperatures are not expected to be directly lethal, but adults might be expected to be sluggish. Thirteen plant species have been reported to be hosts of adult *L.*

delicatula, of which seven are present in New Zealand. However, it is unlikely these would be present in an airport environment.

Overwintering eggs would arrive in New Zealand summer. It is uncertain whether eggs require a period of chilling to complete development, but this has been suggested to be the case (Shim *et al.* 2015). While there is a high likelihood that eggs would encounter temperatures suitable for them to complete development, emergent nymphs would be unlikely to find suitable hosts within an airport environment and such hosts may not be present within a distance that nymphs could realistically travel without feeding.

Given that

- Nymphs would be moving from Spring to autumn
- Autumn temperatures in much of New Zealand are below the developmental threshold for nymphs
- Suitable hosts are unlikely to be present in an airport environment
- Adults would be moving from summer to winter
- Winter temperatures may impede movement.
- Adult host range is limited and few hosts are present in New Zealand
- Eggs would arrive in New Zealand summer and encounter suitable temperatures for development

The likelihood of *L. delicatula* nymphs being exposed to suitable environmental conditions is considered **Very Low.**

The likelihood of *L. delicatula* adults being exposed to suitable environmental conditions is considered **Negligible.**

The likelihood of *L. delicatula* eggs being exposed to suitable environmental conditions is considered **Low.**

5.2.3 Courier

Once it has cleared customs at the sorting depot, a courier package may be transported to any point in New Zealand. The likelihood of exposure of spotted lanternfly to the New Zealand environment is dependent on where the package is opened. It is expected that most packages would be opened indoors.

Lycorma delicatula nymphs and adults including gravid females are likely to occur from May and adults including gravid females from July until and October in the Northern Hemisphere. Any nymphs or adults associated with personal effects would be moving from the Northern Hemisphere spring/summer to New Zealand's Autumn/Winter where temperature and food availability may be limiting.

Any spotted lanternfly nymphs or adults in courier packages are likely to exit and seek food by crawling, hopping, or flying as soon as the package is opened. As spotted lanternfly nymphs and adults are comparatively large, with distinctive markings and, in the case of adults and fourth instar nymphs, brightly coloured, they should be easily noticeable and unlikely to be released into the environment.

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The likelihood of exposure of egg masses to suitable environment is dependent on what they are on and where it is used. Couriered items intended for outside use offer the highest likelihood of exposure to a suitable environment. For egg masses, moving from the Northern Hemisphere winter to New Zealand spring/ summer is potentially favourable. There is evidence that suggests hatching rates in spotted lanternfly eggs increase with duration of overwintering (Shim and Lee 2015). Assuming the egg mass has been subject to sufficient overwintering, temperatures on arrival in New Zealand are likely to be higher than the minimum developmental threshold. Emerging nymphs are highly polyphagous. There is a high likelihood that they would find suitable host material.

Given that:

- A large proportion of courier packages will be opened indoors
- *Lycorma delicatula* adults and fourth instar nymphs are brightly coloured and are likely to be conspicuous
- A proportion of goods arriving by courier may be intended for outdoor use
- Egg masses on some substrates may be cryptic
- *L. delicatula* eggs would be moving from winter to summer

The likelihood that *L. delicatula* nymphs and adults arriving by the courier post pathway would be exposed to suitable environmental conditions is considered **Very Low.**

The likelihood that *L. delicatula* eggs arriving by the courier post pathway would be exposed to suitable environmental conditions is considered **Low** to **Moderate.**

5.2.4 Nursery Stock

Spotted lanternfly are only likely to be associated with Nursery Stock as egg masses imported on whole plants. Prior to arrival, whole plants are required to undergo methyl bromide fumigation, hot water dipping or insecticide spraying. These treatments should greatly reduce the eggs likelihood of hatching, however it is worth noting that several approved insecticides are ineffective against spotted lanternfly eggs.

Whole plants would be de-vanned in a transitional facility for inspection by an accredited person, loaded into a secure vehicle after inspection and moved to a post entry quarantine facility where they would be de-vanned in a secure environment.

Any spotted lanternfly egg masses associated with incoming Nursery Stock should remain contained in the transitional facility, transit vehicle or PEQ site.

Post entry quarantine (PEQ) facilities may be several kilometres from the port of entry. Known hosts of *L. delicatula* would enter Level 2 (bounded by 0.6mm mesh) to Level 3B (high efficiency particulate air filtering) PEQ. Any PEQ facility that is Level 2 (bounded by 0.6mm mesh) or above should be sufficient to contain spotted lanternfly egg masses and any subsequent life stages.

Given that:

- Spotted lanternfly are unlikely to be associated with plants in tissue culture, dormant cuttings or bulbs;
- Spotted lanternfly egg masses could be associated with whole plants imported as Nursery Stock;
- All whole plants must be fumigated, dipped, or sprayed with insecticide;
- Whole plants are inspected in a secure transitional facility (TF), transported from the TF to a post entry quarantine (PEQ) facility in a secure vehicle and de-vanned under quarantine conditions and would remain in PEQ for a minimum of three months during which they would be regularly inspected;

The likelihood of spotted lanternfly being exposed to the New Zealand environment on the Nursery Stock pathway is considered **Negligible**.

5.2.5 Cut Flowers and Foliage

Cut Flowers and Foliage may only be imported from two countries where spotted lanternfly has been reported to occur. Both of these countries (the USA and India) are in the Northern Hemisphere. Because of their ephemeral nature, cut flowers and foliage are imported by air rather than by sea. They may be refrigerated at temperatures <9°C prior to export. On arrival, the flowers or foliage may either be inspected at the point of entry or transported from the point of entry to a transitional facility where they are subject to visual inspection.

Eggs develop between 15° and 25°C and can take between 10 and 73 days to hatch dependent on temperature and origin (Song 2010; Choi *et al.* 2012, Park 2015). The forward hold of an aircraft is held at approximately 10°C and the aft is typically held at 18°C, though this may vary by as much as 17° depending on position in the hold (Emond *et al.* 1999). While aft temperatures fall within the range for development, the flight duration is likely to be less than one day and it is unlikely that eggs would complete development in transit. If they remain unnoticed eggs could complete their development whilst on sale and subsequently on display after purchase.

Spotted lanternfly typically deposit eggs on stems that are greater than 1cm diameter (EPPO 2016). This may limit the number of suitable oviposition substrates available on the Cut Flowers and Foliage pathway.

Generally, cut flowers and foliage will be sold and displayed indoors. Emerging nymphs would require a source of fresh sap to feed on, which is likely to be in limited supply in a market or home environment. Once the cut flowers and foliage has wilted it may be discarded into a compost or landfill. At this point there is a moderate likelihood that any unhatched eggs or recently emerged nymphs would be exposed to suitable host material and environmental conditions to complete development.

Given that:

- Cut flowers and foliage are moved from the Place of first arrival (POFA) to a secure transitional facility where they are subject to visual inspection
- After receiving biosecurity clearance cut flowers and foliage are generally moved to an indoor place of sale or display such as a supermarket, florist or home where fresh sap may be in limited supply.

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- Spotted lanternfly egg masses are typically laid on stems > 1cm in diameter
- Cut flowers and foliage may be discarded in domestic compost or sent to landfill

The likelihood that spotted lanternfly entering New Zealand associated with cut flowers and foliage being exposed to suitable hosts and environmental conditions is considered **Very Low**.

5.2.6 Personal effects and Luggage

Personal luggage may be transported from the point of first entry to any point in New Zealand. The likelihood of exposure of spotted lanternfly to the New Zealand environment is dependent on the type of luggage or personal effects being carried.

Eggs may be associated with personal effects, particularly if they have been stored outside between September and November in an infested area. There is evidence to suggest hatching rates of *L. delicatula* eggs increase significantly with increasing time spent in diapause (Shim and Lee 2015). It has been suggested that *L. delicatula* eggs require a minimum of 15 days at 5°C after midwinter and a longer period at a lower temperature prior (Park 2015). Eggs associated with personal effects and luggage would be moving from the Northern Hemisphere winter to New Zealand summer. The likelihood that eggs would be exposed to the requisite period of cold temperature would be diminished by this movement. If the suggested need for a period at lower temperatures is corrected, then there is a high likelihood that the viability of eggs may be compromised, however there is a high level of uncertainty around this.

Lycorma delicatula nymphs are likely to occur from May and adults including gravid females from July until October in the Northern Hemisphere. Any nymphs or adults associated with personal effects would be moving from the Northern Hemisphere spring/summer to New Zealand's Autumn/Winter where temperature and food availability may be limiting.

Personal luggage such as suitcases and other baggage is likely to be opened and unpacked indoors, in a house or hotel which limits exposure potential. Any spotted lanternfly nymphs or adults in bags, their linings, or in clothing are likely to exit and seek food by crawling, hopping, or flying. As spotted lanternfly nymphs and adults are comparatively large, with distinctive markings and, in the case of adults and fourth instar nymphs, brightly coloured, they should be easily noticeable.

Outdoor equipment, such as tents may be carried among personal effects. Such items are likely to be opened and used outdoors. Adult SLF are disturbed by handling and are capable of flight over short distances. However as adults are typically observed in the Northern Hemisphere between July and October, there is a low to very low likelihood they would find suitable environmental conditions for feeding, reproduction and oviposition under these circumstances.

Given that:

- Most luggage will be unpacked indoors in a house or hotel
- Some luggage contains equipment that will be unpacked outdoors

- Hatching rates of *Lycorma delicatula* eggs increase with time spent in cold diapause
- nymphs and adults would be moving from the Northern Hemisphere spring/summer to the New Zealand autumn or winter
- spotted lanternfly adults and nymphs are comparatively large, mobile and easily visible to the naked eye,

The likelihood of adults and nymphs being exposed to suitable environmental conditions on the personal effects pathway is considered **Very Low.**

The likelihood of eggs being exposed to suitable environmental conditions on the personal effects pathway is considered **Low.**

5.2.7 Vehicles Machinery and Equipment

It is a requirement that vehicles, machinery and equipment are free from biosecurity contaminants and regulated pests and are subject to an external inspection within 12 hours of being unloaded. Used vehicles, machinery and equipment must be thoroughly cleaned internally and externally before arrival in New Zealand. This cleaning may include disassembly if necessary. Detection of any live animal on arrival is considered a compliance failure and vehicles machinery and equipment must be either treated or reshipped.

Vehicles, machinery and equipment, may harbour overwintering *L. delicatula* eggs. *Lycorma delicatula* adults that are actively foraging or seeking mates and actively feeding nymphs are unlikely to remain associated with vehicles machinery and equipment. The possibility that an individual, including a gravid female may become trapped cannot be discounted. However, in the absence of suitable food such an individual would not be expected to survive a journey longer than three days.

Vehicles and machinery may be moved from the port of entry for inspection anywhere within New Zealand.

For egg masses, moving from the Northern Hemisphere winter to New Zealand spring/ summer is potentially favourable. There is evidence that suggests hatching rates in spotted lanternfly eggs increase with duration of overwintering (Shim and Lee 2015). Assuming the egg mass has been subject to sufficient overwintering and has not hatched in transit, temperatures on arrival in New Zealand are likely to be higher than the minimum developmental threshold. Emerging nymphs are highly polyphagous. There is a high likelihood that they would find suitable host material.

Given that:

- *Lycorma delicatula* nymphs would be moving from Northern Hemisphere spring to New Zealand autumn
- Adult *L. delicatula* would be moving from Northern Hemisphere summer to New Zealand winter
- Egg masses would be moving from the Norther Hemisphere winter to the Southern Hemisphere Summer

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- Summer temperatures in New Zealand are typically higher than the lower developmental threshold temperature for *L. delicatula* egg development

The likelihood that *L. delicatula* nymphs or adults would be exposed to suitable environmental conditions is considered **Negligible**.

The likelihood that *L. delicatula* egg masses associated with Vehicles Machinery and Equipment arriving in New Zealand would be exposed to suitable environmental conditions and emerging nymphs to suitable hosts is considered **Moderate** to **High**.

5.2.8 Wood Packaging

Items on wooden pallets or other wooden packaging may either be removed from the packaging for inspection or remain associated with it in a transitional facility. A quarantine officer or accredited person will conduct a visual inspection of both goods and packaging. Pallets may be stored outdoors after unpacking. Should a spotted lanternfly egg mass go undetected, there is a high likelihood that it would be exposed to suitable climatic conditions for development to continue between October and March. Emerging nymphs have a broad host range, there is a moderate to high likelihood that they would be able to find suitable host material to continue development.

Given that:

- Used wood packaging may be stored outdoors
- Spotted lanternfly egg masses associated with wood packaging are likely to arrive between October and May
- Temperatures across New Zealand between October and May are likely to be higher than the lower development threshold for SLF eggs and nymphs
- First instar nymphs are mobile and highly polyphagous

The likelihood that *L. delicatula* egg masses associated with wood packaging would be exposed to suitable environmental conditions and emerging nymphs to suitable hosts is considered **Moderate**.

5.2.9 Sawn wood

Sawn wood may be moved from the facility overland in an open sided vehicle and deposited at a builders supplies. Such wood may be stored outside, in a warehouse or remain in a container. The likelihood that unhatched eggs arriving in New Zealand before March would be exposed to temperatures and day-lengths suitable for hatching is dependent on which storage option is used. However the likelihood that any unhatched eggs on timber stored outside would be exposed to suitable environmental conditions is considered high.
On emergence nymphs would fall to the ground and seek a suitable host. Given the broad range of known hosts, the likelihood that nymphs would find suitable host material is considered moderate, dependent on where the sawn timber is stored.

Given that:

- Sawn wood may be stored outdoors
- Spotted lanternfly egg masses associated with sawn wood are likely to arrive between October and May
- Temperatures across New Zealand between October and May are likely to be higher than the lower development threshold for SLF eggs and nymphs
- First instar nymphs are mobile and highly polyphagous

The likelihood that *L. delicatula* egg masses associated with sawn wood would be exposed to environmental conditions and emerging nymphs to suitable hosts is considered **Moderate.**

5.2.10 Poles, piles, rounds and sleepers

Poles, piles, rounds and sleepers may be moved from the facility overland in an open sided vehicle and deposited at a builders supplies. Such wood products may be stored outside, in a warehouse or remain in a container. The likelihood that unhatched eggs arriving in New Zealand before March would be exposed to temperatures suitable for hatching is dependent on which storage option is used. However, the likelihood that any unhatched eggs on timber products stored outside would be exposed to suitable environmental conditions is considered high.

On emergence, nymphs would fall to the ground and seek a suitable host. Given the broad range of known hosts, the likelihood that nymphs would find suitable host material is considered moderate, dependent on where the sawn timber is stored.

Given that:

- Poles, piles, rounds and sleepers may be stored outdoors
- Spotted lanternfly egg masses associated with poles, piles, rounds and sleepers are likely to arrive between October and May
- Temperatures across New Zealand between October and May are likely to be higher than the lower development threshold for SLF eggs and nymphs
- First instar nymphs are mobile and highly polyphagous

The likelihood that *L. delicatula* egg masses associated with poles, piles, rounds and sleepers would be exposed to favourable environmental conditions and emerging nymphs to suitable hosts is considered **Moderate.**

5.2.11 Vessels and Aircraft

Adult spotted lanternfly are not strong flyers and have been reported to cover no more than 40m in a single flight (Myrick and Baker, 2019). Adult SLF have been demonstrated to die within 2-5 days in the absence of food and water. As SLF are phloem feeders they would be unlikely to have had access to suitable food on board a sea vessel.

It is expected that any SLF adults arriving would prioritise finding food. As there is limited vegetation at commercial ports and airports the likelihood of adult SLF finding suitable feeding conditions is considered **Low** to **Very Low**.

Spotted lanternfly nymphs are flightless. Nymphs have been demonstrated to die within 4-8 days in the absence of food and water. As SLF are phloem feeders they would be unlikely to

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have had access to suitable food on board a sea vessel or aircraft. It is expected that any SLF nymphs arriving would prioritise finding food. The nymph would need to exit the vessel or aircraft cross the wharf or runway to find suitable food. As there is limited vegetation at commercial ports and airports the likelihood of adult SLF finding suitable feeding conditions is considered **Very Low**.

Hatching rates of *Lycorma delicatula* eggs have been reported to increase with time spent in cold diapause. (Shim and Lee, 2015). As egg masses being transported on a sea vessel or aircraft would be moving from Northern Hemisphere autumn/winter to New Zealand spring/summer, this requirement may not necessarily be met. On arrival in New Zealand, there is a high likelihood that any viable eggs would be exposed to temperatures exceeding the minimum threshold for development. However, on hatching first instar nymphs must find food within four or five days. The likelihood that this would occur on a vessel is considered **Very Low.** There is a **High** likelihood that transit time by plane would be too short for eggs to complete development.

Given that:

- Spotted lanternfly adults are not strong flyers and nymphs are flightless
- Wharves typically contain limited vegetation
- Spotted lanternfly egg masses associated with Vessels and Aircraft are likely to arrive between October and May
- Temperatures across New Zealand between October and May are likely to be higher than the lower development threshold for SLF eggs and nymphs
- Suitable food is unlikely to be present on vessels or aircraft

The likelihood that spotted lanternfly adults or nymphs arriving on a sea vessel or aircraft would be exposed to suitable hosts and environmental conditions is considered **Very Low.**

The likelihood that spotted lanternfly egg masses and newly emerged nymphs arriving on a sea vessel would be exposed to suitable hosts and environmental conditions is considered **Very Low**.

5.3 Assessment of Establishment and Spread

5.3.1 Establishment

Based on climate matching (CMI 0.7-0.8) with *L. delicatula*'s known distribution (Figure 1.), climate is unlikely to be limiting to the establishment of the spotted lanternfly in at least some parts of New Zealand.

CLIMEX modelling conducted by Jung *et al.* (2017) indicates that much of New Zealand is suitable for *L. delicatula* to establish, particularly the North Island (Figure 6).

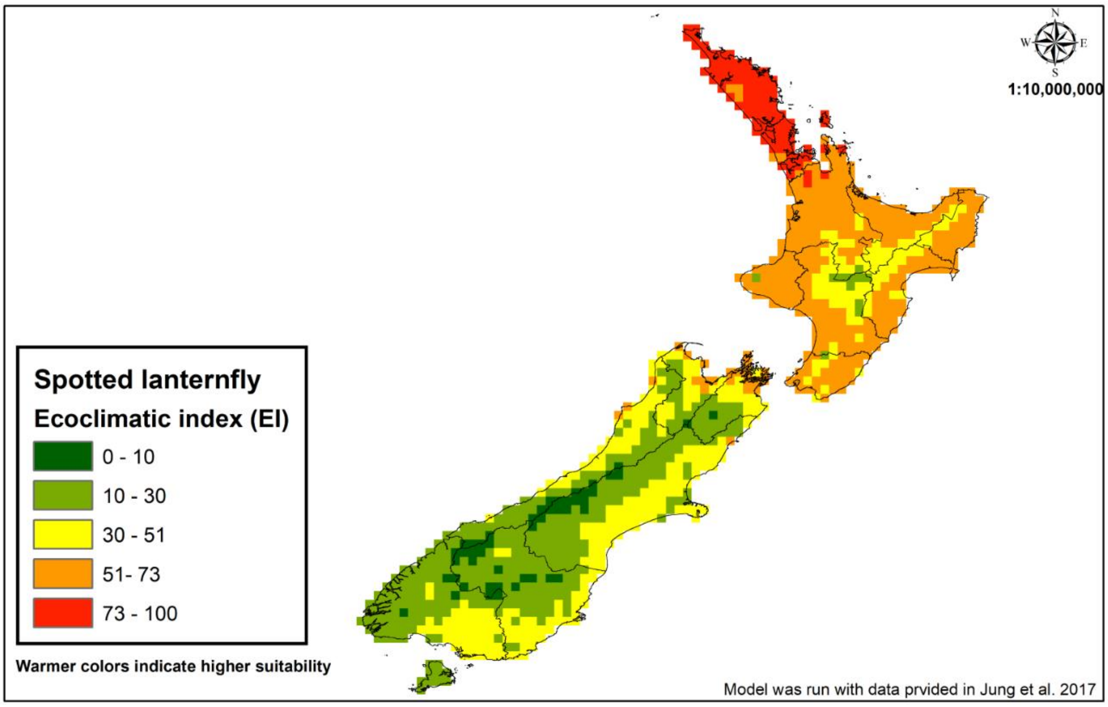

Figure 6. Potential distribution of *L. delicatula* based on parameters modelled in CLIMEX by Jung *et al.* 2017. The higher the Ecoclimatic index value, the more suitable an area is predicted to be. Values below 5 are considered to be marginal for establishment. (Map: Narouei-Khandan, 2019)

Given the broad host range of *L. delicatula* and the presence of many of these hosts, including species indicated to be associated with egg laying (Kim *et al.* 2011), the likelihood that lack of hosts would be limiting to the establishment of *L. delicatula* is considered **Very Low.**

In particular, the tree of heaven (*Ailanthus altissima*), a preferred host plant of *L. delicatula* may be found across New Zealand (Figure 7), particularly throughout the areas where CLIMEX modelling suggests spotted lanternfly is most likely to establish. The relationship between *A. altissima* and infestation of commercial hosts is discussed in the EPPO PRA of *L. delicatula*. It has been suggested that control of *A. altissima* in South Korea drove *L. delicatula* onto grape and peach. However, Park (unpublished, in EPPO 2018) reports a reduction in *L. delicatula* on *Vitis* spp. when *A. altissima* plants within 30 metres were removed. It should be noted this effect was only observed when *L. delicatula* was at low abundance and the relationship between *L. delicatula* abundance, *A. altissima* and host switching is not well understood.

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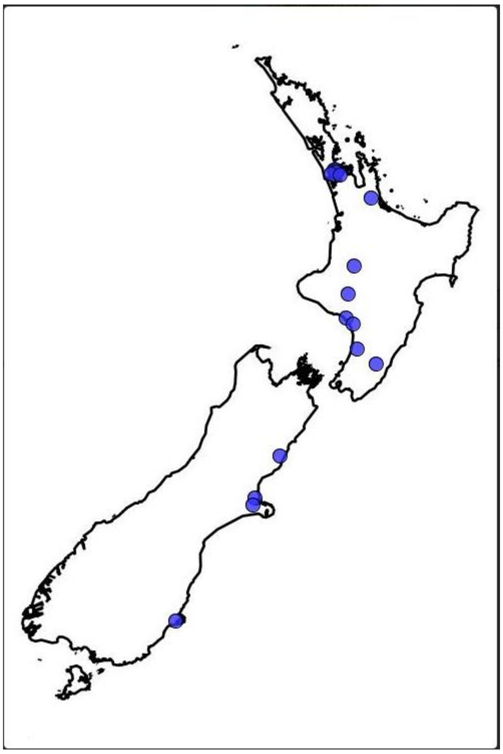

Figure 7. Distribution of *Ailanthus altissima* in New Zealand. The tree of heaven (*A. altissima*) is a preferred host of *L. delicatula* (NZ Flora, 2019)

5.3.2 Spread

The spotted lanternfly has been observed to expand its distribution in its invaded range over a comparatively short period of time. Myrick and Baker (2019), describe the lanternfly's spread from a small portion of one Pennsylvania County in 2014 to13 counties covering more than 15, 000km^2 in 2017.

Lycorma delicatula nymphs are flightless and adults are not strong flyers and (Myrick and Baker, 2019). From shortly after their emergence in July, adult spotted lanternfly undertake flights over short distances between host plants to feed. In mid-September in Pennsylvania, USA, a large scale synchronised dispersal event has been observed involving adult *L. delicatula* that had not yet mated (Myrick and Baker 2019). During this period adults launch themselves from an elevated position in the canopy, into the prevailing wind and fly up to 40 metres in a single flight. Adults are unable to generate much lift and are generally observed flying in a straight or descending trajectory and it is not clear how many flight bouts are undertaken prior to settling and feeding or mating (Myrick and Baker 2019). By the end of the dispersal period (late-September), females were observed to have become "plump" to the point where they had difficulty flying or walking (Myrick and Baker 2019). For these reasons it is considered that natural spread would be slow.

Spread over significant distances is most likely to occur when overwintering egg masses are inadvertently moved along with the items they are deposited on (EPPO 2016). Any potted shrub with a stem diameter greater than 1cm is a candidate, as are non-biotic items such as garden furniture, machinery or landscaping materials. Human mediated transportation of overwintering egg masses is considered to be the main factor driving rapid spread of *L. delicatula*.

Given that:

- Climate matching with *L. delicatula*'s known distribution returns a 70-80% similarity with New Zealand climate
- CLIMEX modelling based on a combination of abiotic and biotic predictors indicates much of New Zealand is suitable for a population of SLF to establish
- The spotted lanternfly has a comparatively broad host range
- Many of *L. delicatula*'s known hosts are present in New Zealand including *Ailanthus altissima,* which has been identified as a preferred host.

The likelihood that *Lycorma delicatula* could establish and spread in New Zealand is considered **High**.

5.4 Consequence assessment

5.4.1 Economic consequences

Spotted lanternfly pierce their hosts' stems to feed from phloem tissue. The lanternfly excretes large quantities of honeydew, which promotes growth of sooty mould that covers the host reducing its available photosynthetic area and compromises growth. In the absence of natural predators the insect can infest hosts in large numbers causing disease in the plant and in some cases death (Anonymous, 2017).

Lycorma delicatula has the potential to have a negative impact on the grape and fruit tree industries (Barringer *et al.* 2015) and feeding damage has been reported on *Actinidia chinensis (kiwifruit)*, *Juglans* spp. (walnut), *Malus* spp. (apple), *Prunus* spp. (stonefruit), *Rosa* spp. (rose) , and *Vitis* spp. (grapevine) (Dara *et al.* 2015)

Damage to grape vines has been reported in South Korea (Kim *et al.* 2011) and the lanternfly has been observed feeding on wild *Vitis* spp., in Pennsylvania (Barringer *et al.* 2015). Song (2010) reported that only 19.2 % of grapes in organic vineyards in South Korea could be sold as fruit because of sooty mould contamination, the remainder could only be sold for juice after they had been washed. In conventional vineyards 79.1% remained saleable as fresh fruit.

It has also been suggested that nymphs and particularly adults collected and pressed with grapes for production of wine may result in spoiling because of the alkaloids sequestered from host plants for defence (Parra *et al.* 2017). This suggestion does not appear to be supported by any published evidence however.

Based on the economic value of some of the known hosts of *L. delicatula*, for example in 2018 exports of kiwifruit generated $1.860.7 million, Apple $732.9 million, Stone-fruit $88 Million (plus a further $62.2 million in domestic sales) and Grapevine (wine) $1692.9 million (Fresh Facts, 2018), and percentage losses reported in the spotted lanternfly's native and invaded range, the potential economic consequence for New Zealand are considered **Moderate to High** with moderate uncertainty.

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5.4.2 Environmental consequences

There is no available evidence to suggest that *L. delicatula* would have significant environmental consequences if it were to establish in New Zealand. *Lycorma delicatula* has been suggested to cause digestive problems in birds, however birds more typically reject *L. delicatula* after the first peck or vomit immediately after consuming a lanternfly (Kang *et al.* 2011).

In China, *L. delicatula* is considered a pest of *A. ailanthus* heavily infesting adult trees and covering stems and leaves of seedlings with honeydew, which leads to development of sooty mould and failed recruitment (Ding *et al.* 2006). As *A. ailanthus* is considered an unwanted organism listed by the National Plant Pest Accord (NPPA) in New Zealand this may be viewed as environmentally beneficial.

Fagus grandifolia (American beech) has been recorded as an oviposition host for L. delicatula (Dara *et al.* 2015). Given the early nymphal stages are highly polyphagous (Kim *et al.* 2011), it is possible that *Fuscospora* spp.and *Lophozonia* spp. (both formerly *Nothofagus* – southern beech species) could act as hosts in New Zealand. The New Zealand native scale insect *Ultracoelostoma assimile* (Maskell) infests the trunks and branches of the beech species *Fuscospora fusca*, *F. cliffortiodes*, *F. solandri* and *F. truncata*, (but seldom Lophozonia menziesii), and produces copious quantities of honeydew (Morales et al., 1988). This honeydew production has been associated with the establishment and proliferation of the invasive common wasp (*Vespula vulgaris*) (Moller and Tilley, 1989) in *Fuscospora* dominated forests. Whether *L. delicatula* could act as a competitor for *U. assimile* in these forests or could facilitate spread of wasps into forests where *Lophozonia menziesii* dominates is unknown.65

The possibility that the greatest environmental impact of spotted lanternfly will be indirect should also be considered. Given that chemical treatment of SLF has been found to be effective only in the short term, because of new recruitment from surrounding areas, it is likely that increased frequency of insecticide treatment may be necessary to manage populations of *L. delicatula*. Such high frequency chemical treatment is likely to have associated environmental costs. For example, consequences such as increased greenhouse gas emissions (Heimpel *et al.* 2013) and non-target effects on pollinators (Brittain and Potts 2010) have been demonstrated in the chemical management of other invasive pest species.

The environmental impacts of spotted lanternfly are considered **Low** with high uncertainty.

5.4.3 Socio-cultural consequences

The spotted lanternfly is damaging to a number of plants grown by domestic gardeners including *Rosa* spp. (rose), *Malus* spp, (apple), *Prunus* spp. (stonefruit), and *Vitis* spp. (grapevine). As such, an established population of *L .delicatula* in an urban setting would represent a potential nuisance pest.

The potential socio-cultural consequences within New Zealand are considered to be **Low.**

5.4.4 Human health consequences

No record of any detrimental effects of *L. delicatula* on human health were found. *Lycorma delicatula*, may however have medicinal properties. Baek *et al.* (2018) report that desiccated

L. delicatula served in an aqueous solution have positive anti-inflammatory and anti-oxidant properties.

Given that:

- there have been no reports of human health effects associated with spotted lanternfly

The potential human health consequences within New Zealand are considered to be **Negligible.**

5.5 Risk estimation

The likelihood of entry is considered to range from **Negligible** to **Low** depending on life stage and pathway. There is a **Low** likelihood that overwintering egg masses could become associated with a pathway of entry into New Zealand. This pathway is most likely to be inanimate including Containers and containerised, and goods, Vehicles, Machinery and Equipment. Eggs are deposited on smooth vertical surfaces from September to November and remain in a state of developmental diapause until late April or early May when first instar nymphs emerge. The risk of entry is considered to be greatest during this overwintering period. The likelihood of that nymphs or adults could enter New Zealand in significant numbers is considered **Very Low** to **Negligible.**

The likelihood of exposure is considered to vary from **Negligible** to **High** and most likely for overwintering egg masses coming from Northern Hemisphere winter into New Zealand summer.

Based on a combination of environmental factors and host availability, the likelihood of spotted lanternfly establishing is considered **High**. Once established, the likelihood of spread is also considered **High**. Based on host range and damage reported from the SLF's invaded range, the potential economic consequences are considered moderate to **High** with moderate uncertainty. The environmental consequences are considered **Low** with high uncertainty. The socio-cultural consequences are considered low and the human health consequences are considered **Negligible**.

Table 8. Risk estimation table

***Lycorma delicatula* on all pathways**						
Risk assessment stage	**Pathway**	**Considered to be:**				
		Negligible	**Very Low**	**Low**	**Moderate**	**High**
Likelihood of entry	Inanimates			■		
	Air containers		■			
	Courier	■	■			
	Nursery stock		■	■		
	Cut Flowers and Foliage	■				
	Passenger Personal Effects		■	■		
	Forest Products			■		
	Vessels and Aircraft		■	■		

Likelihood of entry of specific life stages	Egg masses			■		
	Nymphs	■	■			
	Adults	■	■			
Likelihood of exposure	Inanimates				■	■
	Air containers	■	■			
	Courier			■	■	
	Nursery Stock	■				
	Cut Flowers and Foliage		■			
	Passenger Personal Effects		■	■		
	Forest Products				■	
	Vessels and Aircraft	■	■			
Likelihood of establishment	Adults			■	■	
	Egg masses					■
	Nymphs			■	■	
Likelihood of spread	Established populations				■	■
Potential magnitude of consequences	Economic				■	■
	Environmental			■		
	Socio-cultural			■		
	Health	■				

6 Surveillance and risk management options

6.1 Surveillance Options

Monitoring

To date, there are no commercially available monitoring tools for *L. delicatula*, and many agencies are reliant on visual inspection. There are, however several potential monitoring tools that are being explored and these are detailed below.

Light traps

Lycorma delicatula is attracted to short wavelength blue light. This preference may be suitable for exploitation as a monitoring tool. Under laboratory conditions, Jang *et al.* (2013) demonstrated that third and fourth instar nymphs and adults were attracted to ultra violet light (wavelength 385-410 nm) in preference to white light. This preference was common to both sexes and the life stages tested. In addition, given the choice between chambers lit with, white, yellow, green or blue light, *L. delicatula* consistently stayed longer in blue lit chambers. Again this preference was common to all life stages and both sexes. However, the efficacy of blue light traps has been questioned, based on a lack of catches in UV traps during field experiments conducted in South Korea and Virginia (Lee *et al.* 2019).

Adhesive bands

Adhesive bands placed round the base of host trees provide an effective means of monitoring for spotted lanternfly. In colour preference tests conducted in South Korea, brown coloured bands have been demonstrated to be more effective than blue or yellow (Choi *et al.*2012) and captured both nymphs and adults.

Variation in the efficacy of different brands of adhesive brands is reported in (Cooperband *et al* 2019). Only early instar nymphs were captured by Korea Beneficial Insects Lab Co. (KBIL) sticky bands, later instars were not trapped, even though they were observed in abundance nearby. It was suggested that the nymphs may either test a substrate before stepping on it, or were sufficiently strong to pull themselves free of the adhesive on the band. Web-Cote Industries Tree Band (TB50M-2159; Hamburg, NJ) were found to be most efficient at trapping *L. delicatula* adults and nymphs (Cooperband *et al* 2019).

A subsequent study (Francese *et al* 2020) compared five traps' effectiveness at capturing *L. delicatula*: Web-Cote 'Sticky Tree Bands', BugBarrier Tree Bands (which differ from Web-Cote traps in that the adhesive faces inward to the trunk), modified pecan weevil traps (circle trunk trap), flight intercept panel traps, and tall prism traps. The study found that BugBarrier Tree Bands accumulated less dust and debris and also had fewer non-target catches than the outward facing Web-Cote trap. The circle trunk trap was found to be significantly more effective in catching fourth instar nymphs and adults than the Bug–Barrier bands, but no better at catching earlier instars. Intercept panel traps, and tall prism traps were found to be less effective than tree band traps and it was suggested that this might have been because they did not present a large or attractive enough substrate for *L. delicatula* that were in flight.

Attractants

Several candidate attractants for *L. delicatula* have been identified. These attractants have potential for use as monitoring tools or in attract and kill traps placed in orchards and other areas infested with *L. delicatula*.

The effectiveness of plant volatiles isolated from tree of heaven (*Ailanthus altissima*) and grapevine (*Vitis vinifera*) as attractants of *L. delicatula* was examined by Cooperband et al. (2019). The three most abundant compounds isolated were methyl salicylate, (Z)-3-hexenol, and (E, E)-α-farnesene. In laboratory behavioural bioassays, these compounds were found to be highly attractive to SLF. Methyl salicylate was attractive to all stages of *L. delicatula*, whereas (Z)-3-hexenol or (E, E)-α-farnesene were not as attractive to early instar nymphs. Methyl salicylate also attracted a greater number of *L. delicatula* than the other compounds

In field trials, traps baited with methyl salicylate showed a two- to four-fold greater number of captures compared with unbaited controls. The field testing also revealed a significant positive dose response (Cooperband *et al*. 2019).

The attractant properties of ten plant essential oils on *L. delicatula* were tested: cinnamon bark, black pepper, caraway, cardamom, coriander, eucalyptus, neem, pine needle, sage, and spearmint. Moon *et al.* (2011), found that small doses (5µl) of spearmint oil were highly attractive to both *L. delicatula* nymphs and adults.

Lee and Park (2013) found that chloroform extracted isolates of *A. altissima* (tree of heaven) also have potential as an attractant for *L. delicatula*.

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6.2 Management Options

Biological control

Three potential biological controls have been identified for *L. delicatula:*

Anastatus orientalis (Hymenoptera: Eupelmidae) Yang et Gibson is an egg parasitoid of *L. delicatula* which has been reported to parasitise up to 68.96% of eggs (Choi *et al.* 2014). Rates of parasitism were found to vary by location and by the host plant species the *L. delicatula* eggs were deposited on. Lowest parasitism rates were observed on *Ailanthus altissima* (tree of heaven) (Choi *et al.* 2014). *Lycorma delicatula* adults are known to sequester alkaloids from *A. altissima* as a means of protection from predators, it is possible that some protection against parasitism is afforded to the eggs.

Dryinus browni (Hymenoptera: Dryinidae) is a nymphal parasitoid native to China that has been found to attack 2nd and 3rd instar *L. delicatula* nymphs in Beijing and Shandong (Houping *et al.* 2017). This parasitoid is part of a classic biological control research programme that was submitted to the USDA in 2017.

Ooencyrtus kuvanae (Hymenoptera: Encyrtidae) has been recovered from *Lycorma delicatula* eggs in North America (Liu 2019). Mean parasitism rates of 35.4% of egg masses were observed. This is the first parasite of *L. delicatula* eggs to be detected in North America, its life cycle is well synchronised with *L. delicatula* and has been suggested to have significant potential as a biological control agent (Liu 2019).

Chemical control

Many insecticides are ineffective against *L. delicatula* eggs. A comparative study of insecticides conducted by Shin *et al.* (2011), applied a variety of treatments to *L. delicatula* eggs at recommended concentrations. Low (typically < 50%) egg mortality was demonstrated in response to treatment with carbamate, pyrethroid, neonicotinoid and insect growth regulator based insecticides. Mortality in response to treatment with several organophosphate based insecticides was similarly low, however a Chlorpyrifos wet powder treatment resulted in 100% mortality (Table 3). Mortality rates in response to Chlorpyrifos treatments were found to reduce to approximately 50% in eggs collected later in the season (May) compared to those collected in February (Shin *et al.* 2011).

Lycorma delicatula adults and nymphs are susceptible to broad spectrum pyrethroid, neonicotinoid and organophosphate based insecticides. However, it was found in field trials that beneficial insects were also killed and crops were rapidly reinfested from surrounding forested areas (Dara *et al.* 2015). Bifenthrin has been demonstrated to have high (100%) immediate and residual (100% seven days after spraying and between 78.8 and 94% after fourteen days) efficacy against SLF nymphs when applied at label rates in trials on peach and grape (Penn State Extension, 2019).

Plant based extracts including pyrethrum, *Sophora* and neem have also proven effective in control of *L. delicatula* killing up to 95% of adults treated however treatment of nymphs was less effective (Lee *et al.* 2011; Choi *et al.* 2012, 2015). However, reinfestation rates following treatment were high as new recruitment from forests surrounding the treated area occurred rapidly (Dara *et al.* 2015).

Insect growth regulators have been found to be ineffective on *L. delicatula* (Dara *et al.* 2015).

Repellents

Laboratory and field trials indicate lavender oil acts as a repellent against *Lycorma delicatula*. The effect increases with the concentration of the oil in the application, with 20µl and 30 µl treatments showing a significant repellent effect on adult *L. delicatula* (Yoon *et al.* 2011).

Host removal

Removing the key hosts, such as *Ailanthus altissima* (tree of heaven), from the environment may limit the ability of *L. delicatula* to form populations large or concentrated enough to cause significant impacts on economic activities. The link between *L. delicatula* population growth and *A. ailanthus* is understood to be through the sequestration of alkaloids for defence (Kim *et al.* 2011). These alkaloids, limit predation of adults by birds (Kang et al. 2011) and may afford protection to eggs from parasitoids (Choi *et al.* 2014). Such protection may allow for more rapid population growth. However, it should be noted that *A. altissima* is not an obligate host of *L. delicatula* (Liu 2019). Furthermore, the relationship between *L. delicatula* abundance, *A. altissima* and host switching is not well understood and it has been suggested that control of *A. altissima* in South Korea drove *L. delicatula* onto grape and peach crops (EPPO 2018).

As *A. ailanthus* is considered an unwanted organism listed by the National Plant Pest Accord (NPPA) in New Zealand, increasing efforts to control the plant pest would likely be supported by regional councils.

7 Conclusions of the Risk Assessment

The overwintering behaviour of *Lycorma delicatula* and its broad range of economically significant hosts, identifies it as a potentially significant hitchhiker pest for New Zealand.

The spotted lanternfly is native to China, Taiwan and Vietnam, may be present in India and is invasive in South Korea, Japan, and the USA. The most likely life stage to enter New Zealand is considered to be overwintering egg masses that may be associated with a number of inanimate pathways including containers and their contents, vehicles machinery and equipment, forest products and personal effects. However, the likelihood of entry is considered Low, based on a combination of egg development time, hold temperatures and life expectancy ofnymphs in the absence of food. Should spotted lanternfly arrive in New Zealand, climate matching with its known distribution indicates that climate is unlikely to be a barrier to establishment. In addition, many of *L. delicatula*'s known hosts, including its preferred host, *Ailanthus altissima*, the tree of heaven, are present in New Zealand. The likelihood of establishment is therefore considered Moderate to High

The lanternfly's feeding behaviour is associated with damage and mortality to a wide range of hosts in its invaded range, however the extent of this damage has not been fully quantified. Given the number of commercially significant hosts, there is a high likelihood that these impacts would be Moderate to High.

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8 Uncertainties and research gaps

Shim and Lee (2015) report that hatching rates in *L. delicatula* increase significantly with time spent over wintering and suggest that a minimum chilling period of five months is necessary for successful diapause termination. However, no temperature threshold is reported and no direct link between exposure to cold and diapause termination is presented. The implications of such a requirement would be significant for New Zealand biosecurity.

If SLF require five months at 5°C (as indicated by Park, 2015) to break diapause, then egg masses transported to New Zealand in vessels that are likely to have ambient temperatures > 5°C may not be viable. Assuming cold diapause begins in October in the Northern Hemisphere, then the requisite 5 months chilling will not have occurred until March. Egg masses that begin their journey in March are unlikely to arrive in New Zealand before Mid-April. It is uncertain whether post diapause eggs would be exposed to sufficiently warm temperatures at this time of year to complete development through four nymphal instars into adulthood.

However, the extent of *L. delicatula*'s distribution appears to be uncertain. Confirmation of its presence in Taiwan, Vietnam and India is needed, as it is unlikely that *L. delicatula* would experience prolonged periods at <5°C in these regions. This would suggest that there is population level variation in cold diapause requirements and that the risk of establishment of *L. delicatula* from different populations would vary. It would therefore be very useful to confirm whether *L. delicatula* does require a chilling period of five months during diapause and, if so, at what temperature. It would also be helpful to know whether *L. delicatula* eggs can remain in diapause for more than the eight months that is usual in the Northern Hemisphere and remain viable.

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10 Appendix

Table A1: a list of the known hosts of the spotted lanternfly (*Lycorma delicatula*), with life stages associated (where known) and whether they are present in New Zealand.

Scientific Name	Import Specification for Nursery Stock	Life Stage associated	Reference	Present in NZ (NZOR)
Acacia auruiculiformis	L2 see 155.02.06 under Acacia	Not specified	Li *et al.* 1997	Yes
Acacia confusa	No record	Not specified	Li *et al.* 1997	Unknown
Acacia farnesiana	L2 see 155.02.06 under Acacia	Not specified	Li *et al.* 1997	Yes
Acasia mearnsii	L2 see 155.02.06 under Acacia	Not specified	Li *et al.* 1997	Yes
Acer buergerianum	L2, L3 see 155.02.06 under Acer	Adults and nymphs	Zhou (1992) in Liu (2019)	Yes
Acer negundo	L2, L3 see 155.02.06 under Acer	Eggs	Liu 2019	Yes
Acer palmatum	L2,L3 see 155.02.06 under Acer	Eggs	Dara *et al.* 2015	Yes
Acer pictum subsp. mono	L2, L3 see 155.02.06 under Acer	Adults and nymphs	Zhou (1992) in Liu (2019)	Not found NZOR or NZPCN
Acer platanoides	L2, L3 see 155.02.06 under Acer	Eggs	Liu 2019	Yes
Acer rubrum	L2,L3 see 155.02.06 under Acer	Eggs	Dara *et al.* 2015	Yes
Acer saccharum	L2,L3 see 155.02.06 under Acer	Eggs	Dara *et al.* 2015, Liu 2019	Yes
Actinidia chinensis	see MPI.IHS.ACTINIDIA.PFP	Nymph	Dara *et al.* 2015; Park *et al.*2009	Yes
Ailanthus altissima	Entry prohibited	eggs/adults/nymphs	Dara *et al.* 2015; Park *et al.*2009	Yes
Albizia julibrissin	L2 see 155.02.06 under Hebe	Adults and nymphs	Zhou (1992) in Liu (2019)	Yes
Alnus hirsuta	L2 see 155.02.06 under Acacia	Nymph	Dara *et al.* 2015; Park *et al.*2009	Yes
Alnus incana	L2 see 155.02.06 under Acacia	Nymph	Dara *et al.* 2015	Yes
Angelica dahurica	Not Listed	Nymph	Dara *et al.* 2015; Park *et al.*2009	No
Aralia cordata	Not Listed	Nymph	Dara *et al.* 2015; Park *et al.*2009	No
Aralia elata	Not Listed	Nymph	Dara *et al.* 2015; Park *et al.*2009	Yes
Arctium lappa	Requires assessment	Nymph	Dara *et al.* 2015; Park *et al.*2009	Yes
Betula alleghaniensis	L2 (Basic)	Eggs	Liu 2019	Yes
Betula lenta	L2 (Basic)	Eggs	Liu 2019	Yes
Betula nigra	L2 (Basic)	Eggs	Liu 2019	Yes
Betula platyphylla (synonym of Betula pendula subsp. Mandshurica)	L2 (Basic)	Eggs	Dara *et al.* 2015; Park *et al.*2009	Yes
Buxus sinica	Not listed	Adults and nymphs	Zhou (1992);Chou et al. (1985) in Liu (2019)	Yes as *Buxus microphylla* subsp. *sinica*
Canabis sativa	Not listed	Adults and nymphs	Zhou (1992);Chou et al. (1985) in Liu (2019)	Yes
Carpinus caroliniana	L2 see 155.02.06 under Carpinus	Eggs	Liu 2019	Yes
Carya ovata	L2 see155.02.06 under Carya	Eggs	Liu 2019	Not found NZOR or NZPCN
Castanea crenata	L3 see 155.02.06 under Castanea from selected countries of which only USA has SLF	Eggs	Lee et al. 2011 in Liu 2019	Yes
Catalpa bungei	L2 see 155.02.06 under Hebe	Adults and nymphs	Zhou (1992) in Liu (2019)	Yes

Cedrela fissilis	Requires assessment	Adults and nymphs	Dara *et al*. 2015; Park *et al*.2009	No
Cornus florida	L2 see 155.02.06 under Acacia	Eggs	Liu 2019	Yes
Diospyros kaki	L3 see 155.02.06 under Diospyros	Eggs	Zu 1992 in Liu 2019	Yes
Evodia danielli (synonym of Tetradium daniellii)	Not Listed	Adults and nymphs	Lee *et al*.2009	Yes
Fagus grandifolia	L2 see 155.02.06 under Fagus	Eggs	Dara *et al*. 2015	Yes
Firmiana simplex	Requires assessment	Nymph	Dara *et al*. 2015; Park *et al*.2009	No
Fraxinus americana	L2 see 155.02.06 under Aesculus	Eggs	Liu et al 2019	Yes
Glycine max	Requires assessment	Adults and nymphs	Chou et al. (1985) in Liu (2019)	Yes
Juglans hindsii	L3 see 155.02.06 under Juglans	Adults and nymphs	Zhang (2001) in Liu (2019)	Not found NZOR or NZPCN
Juglans major	Not listed	Adults and nymphs	Zhang (2001) in Liu (2019)	Not found NZOR or NZPCN
Juglans Mandschuria	Not Listed	Adults and nymphs	Dara *et al*. 2015; Park *et al*.2009	No
Juglans microcarpa	L3 see 155.02.06 under Juglans	Adults and nymphs	Zhang (2001) in Liu (2019)	Not found NZOR or NZPCN
Juglans nigra	L3 see 155.02.06 under Juglans	Nymph	Dara *et al*. 2015; Park *et al*.2009	Yes
Juglans sinensis (synonym of J. regia)	Not Listed	Adults and nymphs	Dara *et al*. 2015; Park *et al*.2009	Yes
Juniperus chinensis	L3 see 155.02.06 under Juniperus	Adults and nymphs	Li et al. (2013) in Liu (2019)	Yes
Ligustrum lucidum	Entry prohibited	Adults and nymphs	Zhou (1992) in Liu (2019)	Yes
Lindera benzoin	L2 (Basic)	Eggs	Liu 2019	Yes
Liriodendron tulipifera	L2, L3 see 155.02.06 under Carya ovata	Eggs	Dara *et al*. 2015	Yes
Maackia amurensis	Not Listed	Nymph	Dara *et al*. 2015; Park *et al*.2009	No
Magnolia kobus	L2 see 155.02.06 under Arbutus	Nymph	Dara *et al*. 2015; Park *et al*.2009	No
Magnolia obovata (= *Magnolia hypoleuca*)	L2 see 155.02.06 under Arbutus	Nymph	Dara *et al*. 2015; Park *et al*.2009	Not found NZOR or NZPCN
Mallotus japonicus	Requires assessment	Adults and nymphs	Tomisawa et al. (2013) in Liu (2019)	Not found NZOR or NZPCN
Malus spectabilis	L2,L3 see 155.02.06 under Malus	Adults and nymphs	Zhou (1992) in Liu (2019)	Yes
Malus spp.	L2,L3 see 155.02.06 under Malus	Not reported	Dara *et al*. 2015	Yes
Melia azedarach	L2 see 155.02.06 under Araucaria	Eggs	Chu 1930 in Liu 2019	Yes
Metaplexis japonica	Not Listed	Nymph	Dara *et al*. 2015; Park *et al*.2009	Not found NZOR or NZPCN
Morus alba	L2 see 155.02.06 under Hydrangea	Nymph	Dara *et al*. 2015; Park *et al*.2009	Yes
Morus bombycis	Not Listed	Nymph	Dara *et al*. 2015; Park *et al*.2009	Not listed
Ostrya virginiana	L2, L3 see 155.02.06 under Carya ovata	Eggs	Liu 2019	No
Parthenocissus quinquefolia	L2 see 155.02.06 under Acacia	Adults and nymphs	Dara *et al*. 2015; Park *et al*.2009	Yes
Paulownia kawakamii	L2 see 155.02.06 under Paulownia	Adults and nymphs	Zhou (1992) in Liu (2019)	Not found NZOR or NZPCN

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Phellodendron amurense	Requires assessment	Adults and nymphs	Dara *et al*. 2015; Park *et al*.2009	Yes
Philadelphus schrenkii	L2 see 155.02.06 under Acacia	Nymph	Dara *et al*. 2015; Park *et al*.2009	Not listed
Picrasma quassioides (= *Picrasma ailanthoides*)	L2 (Basic)	Adults and nymphs	Dara *et al*. 2015; Park *et al*.2009	No
Pinus strobus	Requires assessment	Eggs	Liu 2019	Yes
Platanus ×acerifolia	L2 see 155.02.06 under Platanus	Adults and nymphs	Zhou (1992) in Liu (2019)	Yes
Platanus occidentalis	L2 see 155.02.06 under Platanus	Eggs	Dara *et al*. 2015	Yes
Platanus orientalis	L2 see 155.02.06 under Platanus	Not reported	Dara *et al*. 2015	Yes
Platycarya strobilacea	L3 see 155.02.06 under Juglans	Adults and nymphs	Zhou (1992) in Liu (2019)	Not found NZOR or NZPCN
Populus alba	L3 see 155.02.06 under Populus	Eggs	Dara *et al*. 2015	Yes
Populus koreana	L3 see 155.02.06 under Populus	Adults and nymphs	Dara *et al*. 2015; Park *et al*.2009	Not found NZOR or NZPCN
Populus sp.	L3 see 155.02.06 under Populus	Adults and nymphs	Zhou (1992) in Liu (2019)	Yes
Populus tomentiglandulosa	Not Listed	Eggs	Dara *et al*. 2015, Lee et al 2011 in Liu 2019	Not found NZOR or NZPCN
Prunus armeniaca	L2,L3 see 155.02.06 under Prunus	Eggs	Chou et al. 1985 in Liu et al 2019	Yes
Prunus avium	L2,L3 see 155.02.06 under Prunus	Eggs	Liu 2019	Yes
Prunus mume	L2,L3 see 155.02.06 under Prunus	Not reported	Dara *et al*. 2015	Yes
Prunus persica	L2,L3 see 155.02.06 under Prunus	Not reported	Dara *et al*. 2015	Yes
Prunus salicina	L2,L3 see 155.02.06 under Prunus	Not reported	Dara *et al*. 2015	Yes
Prunus serotina	Entry prohibited	Eggs	Dara *et al*. 2015	Yes
Prunus serrulata	L2,L3 see 155.02.06 under Prunus	Eggs	Dara *et al*. 2015	Yes
Prunus x yedoensis	L2,L3 see 155.02.06 under Prunus	Eggs	Dara *et al*. 2015	
Pterocarya stenoptera	L2 (Basic)	Nymph	Dara *et al*. 2015; Park *et al*.2009	Yes
Punica granatum	L2 see 155.02.06 under Epipremnum	Eggs	Hou 2013 in Liu 2019	Not found NZOR or NZPCN
Pyrus sp.	Pathway suspended	Eggs	Yang et al 2015 in Liu 2019	Yes
Quercus acutissima	L3 see 155.02.06 under Quercus	Eggs	Tomisawa et al. 2013 in Liu 2019	Yes
Quercus aliena	L3 see 155.02.06 under Quercus	Nymph	Dara *et al*. 2015; Park *et al*.2009	Not found NZOR or NZPCN
Quercus montana	Not Listed	Eggs	Dara *et al*. 2015	Not found NZOR or NZPCN
Quercus rubra	L3 see 155.02.06 under Quercus	Eggs	Liu 2019	Yes
Quercus sp.	L3 see 155.02.06 under Quercus	Adults and nymphs	Zhou (1992) in Liu (2019)	Yes
Rhus chinensis	Requires assessment	Nymph	Dara *et al*. 2015	Not found NZOR or NZPCN
Rhus javanica	Not Listed	Nymph	Lee *et al*.2009	Not found NZOR or NZPCN
Rhus verniciflua (=Toxicodendron vernicifluum)	Requires assessment	Nymph	Lee *et al*.2009	Yes
Robinia pseudoacacia	L2 (Basic)	Eggs	Dara *et al*. 2015, Tomisawa et al. 2013 in Liu 2019	Yes

Rosa crataegifolius	Not Listed	Nymph	Dara *et al*. 2015	Not found NZOR or NZPCN
Rosa hybrida	L2 see 155.02.06 under Rosa	Nymph	Dara *et al*. 2015; Park *et al*.2009	Not found NZOR or NZPCN
Rosa multiflora	L2 see 155.02.06 under Rosa	Nymph	Dara *et al*. 2015; Park *et al*.2009	Yes
Rosa rugosa	L2 see 155.02.06 under Rosa	Nymph	Dara *et al*. 2015; Park *et al*.2009	Yes
Rubus crataegifolius	Not Listed	Adults and nymphs	Dara et al. 2015; Park et al.2009	Not found NZOR or NZPCN
Salix babylonica	L3 see 155.02.06 under Salix	Adults and nymphs	Lieu(1934) in Liu (2019)	Yes
Salix matsudana	L3 see 155.02.06 under Salix	Not reported	Dara *et al*. 2015	Yes
Salix spp	L3 see 155.02.06 under Salix	eggs/adults/nymphs	Dara *et al*. 2015	Yes
Salix udensis	L3 see 155.02.06 under Salix		Dara *et al*. 2015	Yes
Sassafras albidum	See 155.02.06 under Hebe	Eggs	Liu 2019	Yes
Sorbaria sorbifolia	L2 (Basic)	Nymph	Dara *et al*. 2015; Park *et al*.2009	Not found NZOR or NZPCN
Sorbus commixta	L2,L3 see 155.02.06 under Crataegus	Nymph	Dara *et al*. 2015; Park *et al*.2009	Yes
Styphnolobium japonicum	Not listed	Eggs	Zhou 1992 in Liu 2019	Not found NZOR or NZPCN
Styrax japonicum	L2 (Basic)	Adult/nymph	Dara *et al*. 2015; Park *et al*.2009	Not found NZOR or NZPCN
Styrax obassia	L2 (Basic)	Nymph	Dara *et al*. 2015; Park *et al*.2009	Not found NZOR or NZPCN
Syringa vulgaris	L2 see 155.02.06 under Aesculus	Eggs	Dara *et al*. 2015	Yes
Tetradium daniellii	Requires assessment	Eggs/Nymphs	Dara *et al*. 2015	Yes
Toona sinensis	Requires assessment	Adult/nymph/ egg	Li *et al*. 1997; Park *et al*.2009; Dara *et al*. 2015	Yes
Toxicodendron vernicifluum (=*Rhus verniciflua*)?	Requires assessment	Nymph	Dara *et al*. 2015	Yes
Ulmus spp	L3 see 155.02.06 under Ulmus	Eggs	Zhou 1992 in Liu et al 2019	Yes
Viburnum prunifolium	L2 see 155.02.06 under Viburnum USA only	Eggs	Liu et al 2019	Not found NZOR or NZPCN
Vitis amurensis	L2,L3 see 155.02.06 under Vitis	Adult/nymph	Dara *et al*. 2015; Park *et al*.2009	Not found NZOR or NZPCN
Vitis spp	L2,L3 see 155.02.06 under Vitis	Not reported	Dara *et al*. 2015	Yes
Vitis vinifera	L2,L3 see 155.02.06 under Vitis	Adult/nymph/eggs	Dara *et al*. 2015; Park *et al*.2009, Lee et al 2011 and Chou 1946 in Liu et al 2019	Yes
Zanthoxylum bungeanum	Requires assessment	Eggs	Gao et al 1993 in Liu et al 2019	No
Zelkova serrata	L3 see 155.02.06 under Planera	Eggs	Dara *et al*. 2015	Not found NZOR or NZPCN

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Table A2. Average Monthly temperatures across New Zealand based on data collected between (NIWA 2019 https://www.niwa.co.nz/).

Average Daily temperatures (°C) across New Zealand												
Area	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Kaitaia	19.5	20.0	18.6	17.0	14.8	12.8	12.1	12.2	13.4	14.5	15.8	17.9
Whangarei	19.9	20.2	18.8	16.6	14.4	12.4	11.6	11.9	13.3	14.6	16.4	18.5
Auckland	19.1	19.7	18.4	16.1	14.0	11.8	10.9	11.3	12.7	14.2	15.7	17.8
Tauranga	19.4	19.6	18.0	15.5	13.2	10.8	10.2	10.7	12.3	13.9	15.8	18.0
Hamilton	18.4	18.8	17.1	14.5	11.9	9.5	8.9	9.8	11.6	13.2	14.9	16.9
Rotorua	17.7	17.9	16.0	13.3	10.7	8.5	7.8	8.4	10.2	12.0	13.9	16.2
Gisborne	19.2	19.1	17.5	14.8	12.5	10.3	9.7	10.4	12.0	13.9	15.8	18.1
Taupo	17.0	17.1	14.9	12.0	9.4	7.4	6.5	7.2	9.2	11.1	13.1	15.6
New Plymouth	17.8	18.0	16.8	14.5	12.2	10.4	9.5	10.3	11.5	12.8	14.5	16.3
Napier	19.5	19.4	17.7	15.0	12.4	10.0	9.4	10.3	12.3	14.3	16.1	18.4
Wanganui	18.3	18.5	17.1	14.6	12.4	10.4	9.5	10.2	11.9	13.3	14.8	16.9
Palmerston North	17.8	18.3	16.4	13.6	11.4	9.1	8.6	9.2	11.0	12.4	13.8	16.2
Masterton	18.1	17.7	16.3	13.1	10.5	8.6	7.6	8.4	10.5	12.3	14.2	16.4
Wellington	16.9	17.2	15.8	13.7	11.7	9.7	8.9	9.4	10.8	12.0	13.5	15.4
Nelson	17.8	17.9	16.1	13.2	10.5	7.9	7.2	8.4	10.4	12.4	14.3	16.4
Blenheim	18.0	17.6	15.8	13.0	10.2	7.7	7.0	8.2	10.3	12.2	14.2	16.5
Westport	16.3	16.7	15.3	13.3	11.3	9.3	8.7	9.3	10.7	11.8	13.2	15.0
Kaikoura	16.4	16.4	15.1	13.0	11.2	9.0	8.1	8.8	10.4	11.7	13.2	15.2
Hokitika	15.6	16.0	14.5	12.4	10.2	8.2	7.4	8.4	9.9	11.1	12.6	14.4
Christchurch	17.5	17.2	15.5	12.7	9.8	7.1	6.6	7.9	10.3	12.2	14.1	16.1
Lake Tekapo	15.2	14.8	12.4	9.2	5.9	2.6	1.4	3.6	6.5	8.8	11.1	13.2
Timaru	15.9	15.5	13.8	11.0	8.1	5.6	5.0	6.5	8.7	10.4	12.3	14.4
Milford Sound	14.7	14.8	13.3	11.0	8.4	5.9	5.3	6.9	8.6	10.1	11.8	13.4
Queenstown	15.8	15.6	13.0	9.7	7.0	4.1	3.0	5.0	7.7	9.8	11.6	14.0
Alexandra	18.0	17.4	14.9	10.9	7.6	3.6	2.9	6.0	9.3	11.7	14.0	16.3
Dunedin	15.3	15.0	13.7	11.7	9.3	7.3	6.6	7.7	9.5	10.9	12.4	13.9
Invercargill	14.2	13.9	12.5	10.4	8.0	5.9	5.3	6.6	8.5	9.9	11.4	13.0