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Spotted lanternfly (*Lycorma delicatula*) biology, ecology and awareness in the Australian environment

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Contents

1. Executive Summary

Incursions of exotic pest species place pressure on biosecurity resources globally and measures to understand and prepare for priority exotic pests are a crucial aspect of any biosecurity system. Global costs associated with incursions of exotic pest species have been estimated to have reached at least US$1.288 trillion from 1970-2017 according to a study by Diagne et al., (2020).

The spotted lanternfly, *Lycorma delicatula* (White) (Hemiptera: Fulgoridae), is a hemimetabolous insect that is native to China, Vietnam & India. In 2004, the first specimen-confirmed report of this pest outside its native range was from South Korea, followed by sudden *L. delicatula* outbreaks in Hakusan, Japan in 2008, although sporadic occurrences were thought to have occurred within limited geographic areas since the 1930's. In 2014, *L. delicatula* invaded North America, Berks County, Pennsylvania, US, and has since spread to several other states. This invasive pest is not currently known to occur in Australia.

The Australian Plant Biosecurity Science Foundation and the Chief Environmental Biosecurity Office, Department of Agriculture, Water and the Environment contracted Cesar Australia to undertake a review of *L. delicatula's* biology, host plants, invasive pathways and management in addition to the potential seasonal distribution of the pest in Australia. Further, development of educational resources and targeting of high influence communication pathways undertaken during this project support wide dissemination of the project outputs. Resources were supplied to project partners that included Ms Jo Chong Wah and Sarah Brown, Urban Plant Health Network (Agriculture Victoria), Dr Angus Carnegie, New South Wales Department of Primary Industries (NSWDPI), Dr's Daniela Carnovale and Sharyn Taylor, Botanic Gardens Biosecurity Network (Plant Health Australia) and Ms Michelle Smith and Ruth Luckner, Peri-urban Environmental Biosecurity Network (NSW Department of Primary Industries), and Mr John McDonald (Greenlife Industry Australia).

The review into *L. delicatula* resulted in an output in which the most current knowledge of *L. delicatula* phenology, host plants, surveillance options and management was compiled, with key insights included below.

- *Lycorma delicatula* has over 180 recorded host plants. The 'Tree of Heaven' (*Ailanthus altissima*) (Mill.) Swingle (Simaroubaceae), a preferred host plant, is widely naturalised throughout the coastal and sub-coastal regions of south eastern Australia and is regarded as an environmental weed in most states and territories. Should the pest incur, its potential host plant range is likely to expand due to the unique Australian flora that does not occur within its current distribution.

- In Australia, as in other parts of the world, *L. delicatula* is likely to complete only one generation per year (univoltine) over much of its range, although it remains unconfirmed whether the pest is multivoltine in warmer climates.

- *Lycorma delicatula* is a known 'hitchhiker' due to its non-discriminatory egg laying behaviour. Eggs laid on containers and their contents, vehicles, machinery, equipment, nursery stock, fresh produce, cut flowers and foliage, forest products and passenger luggage have the potential to be transported into Australia.

- Adult spread occurs through flight, typically only moving 10-50 m, launching themselves from trees, and other indiscriminate objects. Environmental DNA studies suggest that nymphs may move between hosts more frequently than originally thought.

- The damage caused by *L. delicatula* results from feeding on the phloem of host plants, causing oozing wounds, increasing the risk of secondary impact from disease. The pest excretes large amounts of honeydew when it feeds, promoting the growth of sooty mould that hinders plant photosynthesis and contaminates agricultural and forest crops. This also attracts nuisance pests such ants and wasps.

- In Australia, the pest is expected to be a threat to the nursery, fruits, landscape and hardwood industries. Impacts can also be expected on the livelihoods of local producers and businesses and the quality of life of the residents as it is a nuisance pest on people's properties, congregating on wood piles, garden furniture, fence posts and other inanimate objects.

- A key gap in the surveillance and monitoring of *L. delicatula* is the lack of sensitive sampling/trapping techniques that can detect low population densities, although recent advances in the use of environmental DNA are promising.

- Citizen science can play a significant role in early detection and reporting of the pest, given its conspicuous appearance.

- Current management options are limited, as most of the available information is from invaded regions that are still grappling with the lack of knowledge, and numerous research gaps exist for this pest. Control programs are largely chemical focused, and are likely to remain so until further cultural, genetic and biological options are available.

In addition to the review, a more complete understanding of the seasonal distribution and development of *L. delicatula* in Australian environments was achieved through prediction modelling. This activity provided insights into likelihood of *L. delicatula* survival and development times for Australia. For southern Australia, nymph emergence has been predicted to occur from November with adult development complete in most regions by March. Development is predicted to be delayed in high altitude regions of Australia's southeast, with nymphal emergence not occurring until after January. By April, survival is estimated to be highest in southern coastal regions. In Tasmania, hatching is not predicted to occur in many western areas where temperatures remain too cool.

Sub-tropical latitudes and associated temperatures generally appear suitable for *L. delicatula* development based on laboratory studies, despite few occurrence records in these regions globally, although *A. altissima,* a preferred host, is not found in tropical regions.

The third component of this project involved extension of key information related to *L. delicatula* preparedness, detection and management. Steps towards pre-emptively engaging the public, as well as at risk businesses, on the topic of *L. delicatula* identification, reporting, and transmission risk reduction have been undertaken during this project. Continuing to raise awareness, particularly among influential stakeholders, will be an important contributor to improving the chance of early

detection and limiting risk of transmission. Within this project key influencers and high potential detector groups have been identified, and resources developed and provided to support future education, awareness and monitoring efforts.

Initial investment is required to ensure preparedness for this pest, including monitoring, surveillance and diagnostics at our border. Research is required to better understand the biology and ecology of the pest and how it might behave under Australian conditions, and to identify potential biological controls already found in Australia. Forming key relationships with international experts that can be called upon should the pest arrive would be advantageous.

2. Introduction

The family Fulgoridae is a large group of insects belonging to the Order Hemiptera that is particularly abundant and diverse in the tropics, containing over 125 genera worldwide. The moniker 'lantern fly' comes from the appearance of the head of some species, resembling a snout that, mainly on the authority of Maria Sibylla Merian, was luminous at night in the living insect. This myth (none of this family of insects emit light), was propagated by Carl Linnaeus who adopted the account without question and devised a number of specific names, such as *laternaria, phosphorea* and *Candelaria*.

The planthopper, spotted lanternfly, *Lycorma delicatula* (White) (Hemiptera: Fulgoridae), is a hemimetabolous insect that is native to China, Vietnam & India. With the continual increase in global movement and trade, its status as a 'hitchhiker' has seen it emerge as a pest of agricultural, urban and environmental plant hosts, primarily woody species, beyond its native range.

In 2004, the first specimen-confirmed report of this pest outside its native range occurred in South Korea (Kim & Kim, 2005), where it has since rapidly expanded its geographic distribution (Han et al., 2008; Namgung et al., 2020). This was followed by abrupt *L. delicatula* outbreaks in Hakusan, Japan in 2008 (Lee et al., 2019), although sporadic occurrences were thought to have occurred within limited geographic areas since the 1930's (Kim et al., 2013). In 2014, *L. delicatula* invaded North America, Berks County, Pensylvania, USA and has since spread to several other states (Barringer et al., 2015; Barringer & Smyers, 2016; Dara et al., 2015; Lee et al., 2019). The pest is not known to occur in Australia, however it is of increasing biosecurity concern. A single adult detection has been reported at the Australian border (Greg Chandler pers. comm. 2020).

The 'Tree of Heaven' (*Ailanthus altissima*) (Mill.) Swingle (Simaroubaceae), is considered *L. delicatula's* preferred host plant (Barringer et al., 2015; Dara et al., 2015). Tree of Heaven is widely naturalised throughout the coastal and sub-coastal regions of south eastern Australia and is regarded as an environmental weed in New South Wales, Australian Capital Territory, Victoria, South Australia, Queensland and Western Australia (https://www.lucidcentral.org/, accessed 10 November 2020). This tree is likely to play an important role in facilitating *L. delicatula* establishment and spread if this species were to incur in Australia.

This project reviewed aspects of the pest's biology, ecology, and host plants that are pertinent to preparedness for this pest, in addition to surveillance and management options that could be successfully implemented, and/or that require further development, or modification should the pest incur in Australia. It also modelled predicted seasonal development times and mortality under Australian conditions, which could be used to target surveillance efforts, and developed a suite of extension resources that can be used for ongoing awareness and education among priority stakeholders.

3. Aim

The aim of this investment initiative was to increase key stakeholder knowledge of, and preparedness for *L. delicatula* in the environment and agroecosystems.

4. Methods/Process

The project involved five key activity areas:

1. Review of the literature on *L. delicatula* biology, possible invasive pathways and management.
2. Identification of the potential distribution of *L. delicatula* in Australia using available biological information on climatic tolerances (population growth rates, critical thermal maximum and minimum temperatures) of *L. delicatula*.
3. Mapping of Tree of Heaven (*Ailanthus altissima*) and other potential host plants
4. Compilation of a list of the reported host plants.
5. Development of communication material for distribution to key stakeholders.

Literature review

To identify literature on *L. delicatula*, we used the following search terms in Web of Science: (1) "Lycorma delicatula" and "Spotted lanternfly", which yielded 74 and 49 results in total, respectively. The literature search was conducted in February 2021. Titles and then abstracts of all papers were screened manually to identify potentially relevant sources, which were then explored further. Within each source, we also looked through the text to identify other potential references which may not have been captured in Web of Science and sourced these articles. To identify grey literature, we googled "Lycorma delicatula" and "Spotted lanternfly".

Seasonal distribution

To identify the potential seasonal distribution of *L. delicatula* in Australia we used available biological information on climatic tolerances (development and survival) of all life stages across temperature regimes evident across Australia. Using gridded climatic data we then mapped the developmental sequence of *L. delicatula* across ranges already occupied in China, South Korea, and the United States, as well as the uninvaded Australian range.

Host plant List

To compile a list of the recorded *L. delicatula* host plants, we first adapted a version of the recent host plant list published by (Barringer & Ciafre, 2020), which includes both Asian, and North American host plants. We then cross-checked this with a more recent report (Burne, 2020). A third publication yielded two additional host plants not previously reported as hosts (Liu, 2020).

Host plant map

After compiling the host plant list, we cross-referenced those confirmed at the species levels with records in the Australian Living Atlas. We then mapped the location of these confirmed hosts within Australia, highlighting records for the key species, Tree of Heaven.

Communication and extension

An evaluation of relevant organisations was conducted to identify high benefit / high influence stakeholder types that have the potential to extend resources and messaging throughout their networks (Fig 1). 'High influence' was determined on the basis of potential reach, and the ability of that group to strengthen community social capital (facilitate collaboration; make training opportunities available; provide platforms for communication and knowledge sourcing). Those organisation types that play a knowledge broker role at a community level were included as high influence groups. 'High benefit' was determined by how much that stakeholder would benefit from *L. delicatula* detection and preparedness, or deem a detection to be crucial to the wellbeing/functioning of their organisation or direct stakeholders.

Following the stakeholder group evaluation, a list of key outreach channels and the associated value offering of using each channel was compiled to inform future directed engagement on the topic of *L. delicatula*. A list was also developed to identify individual businesses in temperate regions (where the pest is predicted to be of the most concern) that met the high influence or high benefit criteria.

A short gap analysis was conducted to determine what *L. delicatula* resources are already available, and what information requires greater focus. Based on the gap analysis results, and identified high influence and high benefit stakeholder priorities, educational resources were developed to support continued outreach campaigning for this pest.

Resources were developed based on the outcome of the gap analysis and supplied to project collaborators (Agriculture Victoria, NSWDPI, Plant Health Australia, and Greenlife Industry Australia) as they were developed. These resources were compiled into a final extension pack for continued use by project collaborators.

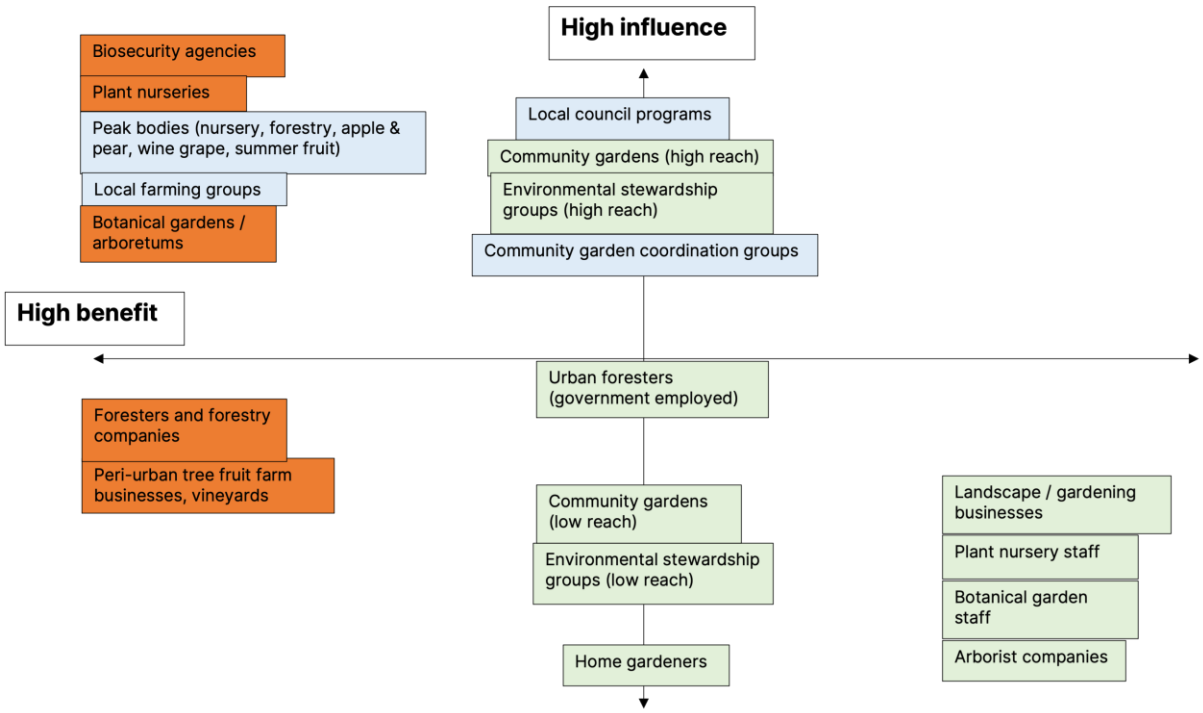

Figure 1. Stakeholder map for *Lycorma delicatula* preparedness and detection. Stakeholders that may contribute important detection services are shown in green. Those stakeholder groups that may significantly contribute to awareness are shown in blue. High potential as a detector and awareness contributor is shown in orange.

5. Achievements, Impacts and Outcomes

This project has launched baseline activities to improve Australia's preparedness for an incursion of *L. delicatula*. Activities used prior research studies and risk assessments to compile the most up to date biological information on this pest, which is crucial to ensuring that further preparedness activities are undertaken with a basis on trusted information. The review into *L. delicatula* has produced an output compiling the most current knowledge of *L. delicatula* phenology, host plants, surveillance options and management. The collation of *L. delicatula* host plants is the most complete reported list and will allow government agencies to design compliance measures related to risk material movement that are in line with the identified risk. In total, we identified 181 plant taxa in 100 genera (with 22 to genus only), and 49 families that are host to *L. delicatula*.

Novel seasonal activity modelling was undertaken, which provides insight into priority regions where *L. delicatula* preparedness and outreach should take place. Predictions of the expected life stage development across various regions throughout the year will help to target surveillance activities. Stakeholder analysis has supported design of outreach targets to ensure that future communication about *L. delicatula* is directed at either high influence groups, which will play an important knowledge broking role, or to high benefit groups, which will play an important detection role. Educational resources have been developed and shared with a selection of high influence groups. Development of educational resources coincided with a Tree of Heaven detection blitz undertaken by the Botanic Gardens Biosecurity Network and a *L. delicatula* detection blitz undertaken by the Urban Plant Health Network and the Peri-Urban Environmental Biosecurity network, thus, this project was able to link with these high influence groups and support them in undertaking these campaigns.

The following outputs were developed as a result of the project:

i. Literature review of *L. delicatula* biology, invasive pathways and management (Appendix A).
ii. Host plant list comprised of 181 plant taxa in 100 genera (Appendix B).
iii. A list of currently known Fulgoridae species in Australia (Appendix C).
iv. A phenology model that predicts seasonal *L. delicatula* development timing and survival across Australia (Appendix D).
v. Stakeholder evaluation that identifies high influence and high benefit groups and outlines key communication channels and associated value offerings for stakeholders associated with those channels (Appendix E).
vi. A list of high influence and high benefit organisations throughout temperate Australia to aid continued outreach of communications materials (Appendix F).
vii. *Lycorma delicatula* identification articles published on the Urban Plant Health Network webpage (view), the Botanic Gardens Biosecurity network (view), the Greenlife Industry Australia news (view) (Appendix G)
viii. A *L. delicatula* featured episode on the Urban Plant Health Network podcast, the Good, the Bad, and the Bug-ly (listen) (Appendix G) .
ix. A *L. delicatula* technical paper developed for the Greenlife Industry Australia Nursery Paper series (Appendix G).
x. A *L. delicatula* extension pack designed to support high influence knowledge brokers and shared with key groups, which included:
    a. An identification video (view) (Appendix G);
    b. *L. delicatula* lifecycle diagram (simple version and detailed version) (Appendix G);
    c. Identification fact sheet for gardeners (Appendix G);
    d. Identification fact sheet for foresters and tree fruit growers (Appendix G);
    e. *L. delicatula* information slide pack with talking points (Appendix G).
xi. Recommendations for further *L. delicatula* preparedness action, derived as a result of gaps and risks identified by the project team throughout the project.
xii. A draft scientific manuscript, detailing the seasonal activity potential of *L. delicatula* in Australia.

6. Discussion and Conclusion

Lycorma delicatula is an invasive, polyphagous pest insect. If it were to incur in Australia, is expected to be a threat to the nursery, fruits, landscape and hardwood industries. Lifestyle impacts can also be expected as it is a nuisance pest on properties, congregating on wood piles, garden furniture, fence posts and other inanimate objects.

The host plant range of *L. delicatula*, is likely to increase as its invasive range increases, particularly when it encounters new potential host plants. Further, the diverse array of substrates on which egg masses can be laid, and the varied landscapes over which *L. delicatula* nymphs and adults feed mean that this pest has the potential to economically impact a broad range of sectors (e.g., there are contamination fears within nurseries). Similar to the US, as all plant products are required to be free of *L. delicatula*, they will either need to be manually removed or sprayed with insecticide to prevent *L. delicatula* entry or spread, thus increasing resource requirements.

Movement of *L. delicatula* is little understood, although most studies suggest that the adults typically move no further than 50m. However, 'swarms' of *L. delicatula* have been observed in the USA, and it is unclear over what distance they have travelled (Urban 2019). A recent study on gut content analysis of nymphs also suggests that there may be more movement at this stage, than previously understood, identifying several host plants in the gut of each nymph. What prompts this movement, and why, is not clear but it could be linked with its preferred host, Tree of Heaven and the use of this plant (and possibly others) to sequester chemical compounds used in its defensive system, as well as the role this tree seems to play in successful reproduction and development.

Management of this pest is currently largely reliant on chemical control options, however there is a considerable force, particularly in the US, that are exploring a range of options from which Australia can benefit.

The pest status as a hitch hiker suggests that there are many plausible pathways by which this pest could enter Australia. In part due to the behaviour of the nymphs and adults to move from substrates when disturbed, it is thought that eggs may be of greatest risk. Indeed, this is believed to be the stage that entered both South Korea, and the US. However, it should be noted that in Australia, the single detection we have observed was of an adult, suggesting other life stages are feasible entrants.

Predictive modelling, undertaken during this project, of the seasonal distribution and development of *L. delicatula* in Australian environments indicated that for southern Australia nymph emergence will occur from November with adult development complete in most regions by March. Development is predicted to be delayed in high altitude regions of Australia's southeast, with nymphal emergence not occurring until after January. By April, survival is estimated to be highest in southern coastal regions. In Tasmania, hatching is not predicted to occur in many western areas where temperatures remain too cool. Sub-tropical latitudes and associated temperatures generally appear suitable for *L. delicatula* development based on laboratory studies (see Appendix D), despite few occurrence records in these regions globally, although *A. altissima,* a preferred host, is not found in tropical regions.

Steps towards pre-emptively engaging the public on the topic of spotted lanternfly identification, reporting, and transmission risk reduction have been undertaken during this project. Continuing to raise awareness, particularly among influential stakeholders, will be important in maximising the chance of early detection and limiting risk of transmission. Within this project key influencers and high potential detector groups have been identified, and resources have been developed to support future education, awareness and monitoring efforts. Working with citizen scientists in this context is a plausible option to increase the chance of detection, and also monitor its spread as slow natural movement speeds and conspicuous appearance will support eradication efforts if they are deemed feasible following an incursion.

This project has also compiled information on *L. delicatula* that will provide a basis for further government preparedness, including determination of international risk pathway compliance measures and pre-emptive design of domestic risk product movement measures. Novel seasonal activity modelling has provided insight into priority regions where *L. delicatula* surveillance, preparedness and outreach should take place into the future.

While longer-term impacts of *L. delicatula* remain speculative in its invasive range, the pest has already caused considerable damage, as well as being a nuisance, particularly in forests, urban and peri-urban areas and agroecosystems, and in vineyards. The environmental impact of *L. delicatula* in Australian environments remains a key area to be more fully understood. The APBSF and DAWE have recognised the importance of being prepared for this pest, through this investment initiative. Further research is warranted, particularly surrounding surveillance programs, to ensure this pest does not reach Australia's shores, and in the case it does, that it can be readily contained and eradicated.

7. Recommendations

There are a number of recommendations that have emerged from this work. They are:

1. Establish relationships with key international *L. delicatula* experts, including researchers and extension officers, to call upon in the event of an incursion and to provide further advice for preparedness planning.

2. Ensure border biosecurity have adequate training on the identification of *L. delicatula* identification, particularly the egg stage – the most likely pathway of entry for this pest into Australia.

3. Use the review findings and prediction modelling to guide surveillance programs to maximum effect and determine best domestic risk product movement conditions that could be implemented quickly in the case of an incursion.

4. Draw on the stakeholder analysis and resources developed in this project to continue to raise awareness through targeted activities, particularly among influential stakeholders, as this will be an important contributor to improving the chance of early detection and limiting risk of transmission.

5. Undertake further investigation into potential impacts on keystone native species to better predict the environmental impact of *L. delicatula* in Australian environments.

6. Proceed with an assessment of Australian biocontrol prospects with a view to identifying any native or endemic parasitoids attacking related planthoppers, or that are known *L. delicatula* parasitoids reported elsewhere.

8. Acknowledgements

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9. Appendices, References, Publications

Appendices

Appendix A. Reynolds O et al. 2021. *L. delicatula* biology, invasive pathways and management. Literature review.

Appendix B. Reynolds O. 2021. *Lycorma delicatula* Host Plant List.

Appendix C. Reynolds O. 2021. Australian Fulgoridae Species List.

Appendix D. Maino J. 2021. Mapping the life-history, development, and survival of spotted lantern fly in Australia. Predictive model.

Appendix E. Lye J. 2021. *Lycorma delicatula* stakeholder and resource analysis.

Appendix F. Lye J. 2021. *Lycorma delicatula* stakeholder list – temperate zone.

Appendix G. Lye J, McGrane L, Lowe L and Reynolds O. 2021. *Lycorma delicatula* outreach resources.

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Publication

Maino J, Lye J, Umina P & Reynolds O. draft. Mapping the life-history, development and mortality of spotted lantern fly in occupied and uninvaded ranges, for journal submission.