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Lycorma delicatula (Hemiptera: Fulgoridae): A New Invasive Pest in the United States

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ABSTRACT. The Pennsylvania Department of Agriculture recently reported the first detection of *Lycorma delicatula* (proposed common name spotted lanternfly), yet another invasive hemipteran pest in the US. While efforts to tackle other invasive hemipterans like the Asian citrus psyllid, *Diaphorina citri* (Kuwayama), the Bagrada bug, *Bagrada hilaris* (Burmeister), and the brown marmorated stink bug, *Halyomorpha halys* (Stål) are still underway, *L. delicatula* is a new pest that could potentially impact industries ranging from lumber to wine. Here we review the literature regarding this insect in its native and invasive range in Asia. We also highlight the pest status and tentative management recommendations for this pest in North America.

Key Words: Spotted lanternfly, *Lycorma delicatula*, exotic pest, tree of heaven, grape

An exotic pest known as the spotted lanternfly, *Lycorma delicatula* (White), was recently detected in Pennsylvania, USA (Barringer et al. 2015). Spotted lanternfly is actually not a fly, but a planthopper of the family Fulgoridae, also referred to as "spot clothing wax cicada" or "Chinese blistering cicada" in the literature. It is called "ggot-mae-mi" in Korea (Han et al. 2008). Fulgorids are moderate to large planthoppers often referred to as lanternflies because the inflated front portion of the head found in some species that was once thought to be luminous. This species has been known in China as a medicinal insect since the twelfth century and is used for relief from swelling (Choi et al. 2002). This species is significant, due to its pest status in Korea, and recent invasive status in North America, where it is a potential threat to grapes, stone fruit, and some ornamental plants. The Pennsylvania Department of Agriculture maintains a website on their project http://www.agriculture.pa.gov/Protect/PlantIndustry/spotted_lanternfly, accessed 3 November 2015.

Origin and Distribution

Spotted lanternfly is native to northern China (Liu 1939). It was first detected as an exotic species in South Korea in 2004, and has since rapidly spread to different parts of that country (Kim and Kim 2005). There are reports of this species distribution extending south to Taiwan and Vietnam (Hua 2000, Han et al. 2008). Reports of this species from India (Han et al. 2008) appear to be unconfirmed. More recently, individuals have been detected in Japan (Kim et al. 2013). Detection of this species in Pennsylvania by the State Department of Agriculture in 2014 was a new continental record (Barringer et al. 2015). It is currently considered established in Berks, Montgomery, and Chester Counties in eastern PA based on observations of overwintering populations in the past year. The Pennsylvania Department of Agriculture has removed over 175,000 individuals so far in 2015 alone and this species is subject to ongoing eradication efforts.

Host Range

Spotted lanternfly feeds on a variety of host plants including fruit trees, ornamental trees, woody trees, and vines (Table 1). Apples, birch, cherry, grapes, lilac, maple, poplar, stone fruits, and tree of heaven are among >70 species of principally woody hosts attacked by this pest. Tree of heaven, *Ailanthus altissima* (Mill.) Swingle, which contains high concentrations of cytotoxic alkaloids (Ohmoto et al. 1981), is one of the favorite hosts and is probably why spotted lanternfly is considered poisonous to humans and used in traditional Chinese medicine for consumption in small nonlethal quantities (Zimian et al. 1997, Han et al. 2008). Other preferred hosts such as Korean Evodia (be-be tree), *Tetradium daniellii* Benn., found in US nurseries and landscapes, are also used in oriental medicine relying on natural toxins (Zimian et al. 1997), suggesting that spotted lanternfly has a high preference for hosts that contain toxic secondary metabolites. Observations in South Korea suggest that this species has a wider host range early in life as young nymphs and the host range narrows as they grow older especially before egg laying (Kim et al. 2011a). As tree of heaven is a preferred host for egg-laying adults, it can be used as a sentinel plant to monitor this species.

Choosing plants with toxic metabolites for egg laying is thought to be a mechanism of defense to protect from feeding by natural enemies. However, grapevine (*Vitis* sp.), which does not have toxic metabolites, seems to be an exception and is another preferred host for spotted lanternfly in studies conducted in South Korea. Sugar content of the host plant also appears to play a role in their choice, with a preference for hosts containing high sucrose and fructose content (Lee et al. 2009). Despite this relatively wide range of hosts from which the spotted lanternfly has been recovered, the number of true reproductive hosts is likely much lower. Lee et al. (2009) reported low preference and rates of development on several ornamental and fruit trees outside of *A. altissima* and *Vitis vinifera*. Additionally, some reported hosts such as sumacs (*Rhus* spp.) and Chinese Mahogany (*Toona sinensis*) closely resemble tree of heaven, and thus might be misreported hosts. Another issue that may exacerbate this confusion is that both tree of heaven and sumac are used as windbreaks or edge trees and are commonly comingled.

Biology and Phenology

In Korea, the species is univoltine, with nymphs emerging in May and becoming adults by late July, and with egg laying from August until early November (Park et al. 2009, Lee et al. 2011). Overwintering occurs as eggs deposited inside oothecae on the trunks of *Ailanthus* spp. and other susceptible trees with smooth bark; rough barked trees are rarely targeted for egg masses. In Korea, up to 3.4 egg masses per tree were observed (Lee et al. 2014). However, much higher numbers have been observed in Pennsylvania, with 197 egg masses observed on a single tree of heaven (Barringer, personal observation). Spotted lanternflies also deposited eggs on surrounding objects, including stones,

Table 1. Reported host plants for *L. delicatula* (White)

Family	Species	Common name[a]	US distribution	Stage (if reported)	Reported from
Aceraceae	*Acer palmatum* Thunb.	Japanese maple	Yes	Eggs	Korea
	Acer rubrum L.	Red maple	Yes	Eggs	USA (PA)
	Acer saccharum Marshall	Sugar maple	Yes		USA (PA)
Actinidiaceae	*Actinidia chinensis* Planch		No	Nymph	China, South Korea
Anacardiaceae	*Rhus chinensis* Mill.	Chinese sumac	No	Nymph	South Korea
	Toxicodendron vernicifluum (Stokes) F.A. Barkley	Chinese lacquer	No	Nymph	South Korea
Araliaceae	*Aralia elata* (Miq.) Seem.	Japanese angelica	Yes	Nymph	South Korea
	Aralia cordata Thunb.	Udo	No	Nymph	South Korea
Asclepiadaceae	*Metaplexis japonica* (Thunb.) Makino	Rough potato	Yes	Nymph	South Korea
Betulaceae	*Alnus incana* (L.) Moench	Grey alder	Yes	Nymph	South Korea
	Betula platyphylla Sukaczev	Asian white birch	Yes	Eggs	South Korea
Compositae	*Arctium lappa* L.	Greater burdock	Yes	Nymph	South Korea
Fabaceae	*Maackia amurensis* Rupr. & Maxim.	Amur maackia	No	Nymph	South Korea
	Robinia pseudoacacia L.	Black locust	Yes		China
Fagaceae	*Quercus aliena* Blume	Oriental white oak	No	Nymph	South Korea
	Fagus grandifolia Ehrh.	American beech	Yes	Eggs	USA (PA)
	Quercus montana Willd.	Chestnut oak	Yes	Eggs	USA (PA)
Hydrangeaceae	*Philadelphus schrenkii* Rupr.		No	Nymph	South Korea
Juglandaceae	*Juglans mandshurica* Maxim	Manchurian walnut	No	Adult/nymph	South Korea
	Juglans nigra L.	Black walnut	Yes	Nymph	South Korea
	Juglans sinensis (DC) Dode		No	Nymph	South Korea
	Pterocarya stenoptera C. DC.	Chinese wingnut	Yes	Nymph	South Korea
Magnoliaceae	*Magnolia obovata* Thunb.	Japanese bigleaf magnolia	No	Nymph	South Korea
	Magnolia kobus DC.	Kobus magnolia	Yes	Nymph	South Korea
	Liriodendron tulipifera L.	Tuliptree	Yes	Eggs	USA (PA)
Meliaceae	*Cedrela fissilis* Vell.[b]	Argentine Cedar	No	Adult/nymph	South Korea
	Toona sinensis (A. Juss.) M.Roem.[b]	Chinese Mahogany	No	Adult/eggs/nymph	South Korea
Moraceae	*Morus alba* L.	White mulberry	Yes	Nymph	South Korea
	Morus bombycis		No	Nymph	South Korea
Oleaceae	*Syringa vulgaris* L.	Common lilac	Yes	Eggs	South Korea
Platanaceae	*Platanus occidentalis* L.	American sycamore	Yes	Eggs	USA (PA)
	Platanus orientalis L.	Oriental plane	No		South Korea
Rosaceae	*Malus* Mill.	Apple	Yes		China
	Prunus mume Siebold & Zucc.	Japanese apricot	No		China
	Prunus persica (L.) Batsch	Peach	Yes		China
	Prunus salicina Lindl.	Japanese plum	No		China
	Prunus serotina Ehrh.	Black cherry	Yes	Eggs	USA (PA)
	Prunus serrulata Lindl. var. *spontanea*	Japanese flowering cherry	Yes	Eggs	South Korea
	Prunus X Yedoensis Matsum	Hybrid cherry	No	Eggs	South Korea
	Rosa hybrid L.	Rose	Yes	Nymph	South Korea
	Rosa multiflora Thunb.	Multiflora rose	Yes	Nymph	South Korea
	Rosa rugosa Thunb.	Rugosa rose	Yes	Nymph	South Korea
	Rubus crataegifolius Bunge		No	Nymph	South Korea
	Sorbus commixta Hedl.		No	Nymph	South Korea
	Sorbaria sorbifolia (L.) A. Braun	False spiraea	Yes	Nymph	South Korea
Rutaceae	*Tetradium daniellii* (Benn.)[b]	Bee-bee tree	Yes	Eggs/nymph	South Korea
	Phellodendron amurense Rupr.[b]	Amur corktree	Yes	Adult/nymph	South Korea, USA (PA)
Salicaceae	*Populus* spp.	Cottonwoods/poplars	Yes		China
	P. alba L.	White poplar	Yes	Eggs	South Korea
	Populus koreana J. Rehnder	Korean Poplar	No	Adult	South Korea
	Populus tomentiglandulosa T. Lee				South Korea
	Salix matsudana Koidz.	Corkscrew willow	Yes		USA (PA)
	Salix udensis Trautv. & C.A. Mey.		Yes		USA (PA)
	Salix spp.		Yes	Adults/nymph/eggs	China, South Korea
Simaroubaceae	*Picrasma quassioides* (D. Don) Benn.[b]	Nigaki	No	Adult/nymph	South Korea
	Ailanthus altissima (Mill.) Swingle[b]	Tree of heaven	Yes	Adult/eggs/nymph	South Korea, USA (PA)
Sterculiaceae	*Firmiana simplex* (L.) W. Wight	Chinese parasoltree	Yes	Nymph	South Korea
Styracaceae	*Styrax obassia*		No	Nymph	South Korea
	Styrax japonica Siebold & Zucc		Yes	Adult/nymph	South Korea, USA (PA)
Ulmaceae	*Zelkova serrata* (Thunb.) Makino	Japanese zelkova	Yes	Eggs	South Korea
Umbelliferae	*Angelica dahurica* Fisch.ex Hoffm.	Chinese Angelica	No	Nymph	South Korea
Vitaceae	*Parthenocissus quinquefolia* (L.) Planch.[b]	Virginia creeper	Yes	Adult/nymph	South Korea
	Vitis amurensis Rupr.[b]	Amur grape	No	Adult/nymph	South Korea
	Vitis vinifera L.[b]	Wine grape	Yes	Adult/nymph	South Korea, China
	Vitis spp.[b]	Wild grape	Yes		USA (PA)

[a] Host plant list made publically available http://extension.psu.edu/pests/spotted-lanternfly/news/2015/host-plants-used-by-spotted-lanternfly. As new hosts are identified they are added to this site.
[b] Classification and common names of plant species after USDA-NRCS (2015).

fence posts, and outdoor equipment in Pennsylvania. The fact that egg masses can be found on nonplant material adds to the risk of spread. The survival of *L. delicatula* eggs is largely affected by winter temperatures. In the field, egg hatch rates from 60–90% are reported, with lower rates reported in laboratory studies; i.e., eggs hatched 56, 27, and 22 d after incubation at 15, 20, 25°C with hatching rates of 62, 58, and 30%, respectively (Choi et al 2012, Lee et al. 2014). Eggs usually hatch during the early hours of the day. The life cycle of *L. delicatula* in

Pennsylvania is similar to that reported in South Korea and has been documented as follows—eggs on 13 October 2014, first instar on 12 May 2015, second instar on 3 June 2015, third instar on 24 June 2015, fourth instar on 7 July 2015, and adult on 24 July 2015.

Spotted lanternfly develops through four nymphal instars. Both short- and long-range dispersal patterns have been described. Nymphs start climbing up the trees after they emerge and fall off when there is a physical obstacle or disturbance from wind or other factors and start climbing up again. This falling and ascending cycle is thought to facilitate host selection and dispersal in this species (Kim et al. 2011a). Adults are diurnal and may disperse longer distances. Adults do not readily fly away when approached, and may be collected manually from host plants (Park et al. 2013). This species possesses specialized tarsal adhesive pads (arolia), which allow strong climbing characteristics (Frantsevich et al. 2008).

Fig. 1. Egg masses of *L. delicatula* covered by waxy deposits. Photo Credit: Lawrence Barringer.

Description

Eggs

Eggs are deposited in groups of 30–50 and covered in yellowish brown waxy deposits which later hardens to form an oothecum (Fig. 1). Waxy deposits disappear from emerged egg masses revealing brown, seed-like eggs. The remnants of egg masses may be observed on trees for one year or more after hatching.

Fig. 2. *L. delicatula* passes through four nymphal instars. The first three instars (left to right) are black and ornamented with spots. The fourth instar develops red patterning on the dorsal side that covers in part the head, thorax, and abdomen, while still retaining some white spotting. Photo Credit: Lawrence Barringer.

Nymphs

The first three instars have a black body and legs with white spots. The fourth instar retains the spots but has a reddish body with distinctive red wing pads (Fig. 2). The length of immature specimens collected in Pennsylvania range from 3.6–4.4 ($n = 12$), 5.1–6.4 ($n = 10$), 6.9–9.4 ($n = 12$), and 10.9–14.8 mm ($n = 10$) for first, second, third, and fourth instar, respectively.

Adults

Both sexes superficially resemble a moth with a wider abdomen (Fig. 3). Adults are often confused with some moths (especially species of noctuid underwings) due to the strikingly colored hindwing and size. Fulgorids can be differentiated from other planthopper families in North America by their large size (10 mm+), and reticulate wing venation of the hindwings and the forewings, which are often opaque and held tectiform (Bartlett et al. 2014; Fig. 4). Head and legs are dark brown to black. Forewings (tegmina) are greyish, with black spots and hind wings are banded black and white anteriorly, and deep red posteriorly. Tips of the wings show a network of veins (reticulated). Abdomen is yellowish with incomplete black bands (Fig. 3). The male and female can be easily distinguished by size and reddish color of the postero-caudal end of the abdomen in females (Fig. 5). *L. delicatula* are 21–27 mm from head to the end of the folded wing; males are smaller (21–22 mm) than females (24–27 mm). Leg length varies from 15–18 mm in adult males and 18–22 mm in adult females (Frantsevich et al. 2008). Similar measurements for body length, although slightly smaller at 17–25 mm long, were reported by Barringer et al. (2015).

Fig. 3. Dorsal view of an adult female *L. delicatula*. The colorful hindwings and the black and yellow abdomen are not visible at rest. Photo Credit: Lawrence Barringer.

Damage

In China, the spotted lanternfly is a reported pest of a diverse range of shrubs and trees, including tree of heaven (*A. altissima*), Chinese Mahogany (*T. sinensis*), white cedar (*Melia azedarach*), black locust (*Robinia pseudoacacia*), cottonwoods (*Populus* spp.), willows (*Salix* spp.), grapes (*Vitis* spp.), and apples (*Malus* spp.) (Xiao 1992, Zhang 1993). Since its arrival in Korea, this species has caused economic damage in vineyards, while large aggregations on *A. altissima* and other susceptible trees may create a nuisance in urban areas and roadsides (Han et al. 2008, Lee et al. 2009, Park et al. 2009).

Adults and nymphs feed on phloem tissues of young stems and bark tissues with their piercing and sucking mouthparts and excrete large quantities of liquid (Ding et al. 2006). Adults and older nymphs will feed in groups, especially later in the season on preferred hosts. Extensive feeding results in oozing wounds on the trunk (Fig. 6) and wilting and death of branches. Significant honey dew and sooty mold deposits around the base of trees are also noted from feeding of this insect (Fig. 7). Signs of infestation include the presence of ants, bees, hornets or wasps attracted by honeydew and tree sap.

In North America, at least 40 of the known hosts of *L. delicatula* are grown as agricultural crops or landscape plants (U.S. Department of Agriculture–National Resources Conservation Service [USDA-NRCS] 2015), although some are of limited numbers and distribution. Field reports of *L. delicatula* in Pennsylvania are mostly restricted to *A. altissima* *and* wild *Vitis* sp. (Barringer et al. 2015). Since *A. altissima* is invasive and widely established throughout the United States and eastern Canada, it might serve as a likely host for this insect to spread. Spotted lanternfly has also been proposed as a potential biological control agent for *A. altissima* in its invasive range (Ding et al. 2006). Spotted lanternfly might potentially be a nuisance in structures, as there are reports of this insect entering homes in its invasive range in Asia (Han et al. 2008).

Natural Enemies

It is unclear to what extent natural enemies will control *L. delicatula* in North America. Natural enemies of other planthoppers in Pennsylvania, including Dryninidae (Hymenoptera) and Epipyropidae larvae (Lepidoptera), do not appear to control *L. delicatula* (Barringer, personal observations). It is thought that its chemical defenses deter many generalist predators (Xue and Yuan 1996) and birds have been observed vomiting after consumption of this insect (Kang et al. 2011). The latter authors propose that the cryptic forewing of *L. delicatula* is an adaptation to lower detection by predators on the bark of host trees, while the sudden opening of brightly colored hindwings in response to tactile stimulus such as bird pecking serves an aposematic function, warning of unpalatability.

Fig. 4. Lateral view of a resting adult *L. delicatula* on *A. altissima*. Photo Credit: Lawrence Barringer.

Relatively few parasitoids are known to parasitize immature stages of fulgorids. The parasitic wasp *Anastatus orientalis* (Hymenoptera, Eupelmidae) is an egg parasitoid of *L. delicatula* in China, and is considered to be an important biocontrol agent as its parasitism rates reach up to 80% in some regions (Choi et al. 2014). Another *Anastatus* sp. was reported parasitizing overwintering *L. delicatula* egg masses in grape vineyards in South Korea (Kim et al. 2011b). A second parasitoid of *L. delicatula*, *Dryinus browni* Ashmead (Dryinidae), noted from China lays eggs in the wing bud of nymphs and undergoes a single generation per year (Xue-xin and Jun-hua 2006). These parasitoids are not known from North America, and appear to be potential biocontrol agents for release against the spotted lanternfly in other regions.

Management

In Korea, *L. delicatula* is noted to rapidly repopulate pesticide-sprayed vineyards from nearby forested areas which contain suitable host species (Park et al. 2009). Where they are found, preserving natural enemies could significantly lessen the risk of this insects reaching pest status. Understanding the invasion process and dispersal pathways are important for effective quarantine measures for invasive insects such as *L. delicatula*. Genetic studies comparing the similarities of *L. delicatula* populations collected in China, South Korea, and Japan, suggests that long-range dispersal has occurred, most likely via artificial transportation of adults or egg masses on imported products (Kim et al. 2013, Park et al. 2013). Such findings highlight the importance of plant inspections, monitoring and, if needed, quarantines imposed in infested regions for susceptible plant materials. The fact that *L. delicatula* egg masses can be found on nonplant material may increase their risk of spread.

Chemical

Spotted lanternfly is reported to be highly susceptible to broad-spectrum pyrethroids, organophosphate and neonicotinoid insecticides (Park et al. 2009, Shin et al. 2010). Lower activity was reported for insect growth regulators applied against the egg stages (Shin et al. 2010). In Korea, several botanical insecticides were evaluated for toxicity

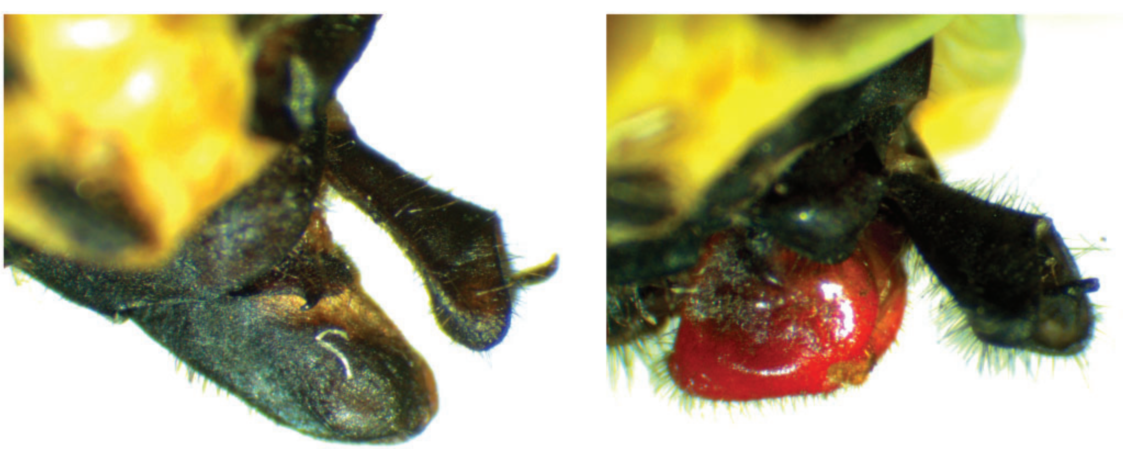

Fig. 5. Lateral views of the caudal end of *L. delicatula*, with the male (left) having an all black appearance and the female (right) having a set of paired red valvifers. Photo Credit: Lawrence Barringer.

Fig. 6. Aggregation of *L. delicatula* on *A. altissima*. The dark liquid is tree sap oozing from feeding wounds caused by *L. delicatula*. Photo Credit: Lawrence Barringer.

Fig. 7. Mold growing at the base of *A. altissima*. Large amounts of bleeding sap will accumulate on tree bases leading to growth of saprophytic fungi, or in extreme cases, thick mats of fungal growth. Photo Credit: Lawrence Barringer.

against *L. delicatula*. Pyrethrum, *Sophora*, and neem extracts (at 1,000 fold dilution) killed $\geq$95% of adults within 48 h, but the extracts tended to be less effective against nymphs in some tests (Lee et al. 2011, Choi et al. 2012). Control with reduced risk materials may be preferred in many urban or environmentally sensitive areas and will help reduce impact to beneficial species, but presumably requiring good coverage.

Trapping

Sticky bands placed around the base of susceptible tree trunks are an effective method to manage this *L. delicatula* in Asia. Traps may be most effective against the highly mobile young nymphs that repeatedly ascend trees as part of their host selection behavior (Kim et al. 2011a). Choi et al. (2012) reported that brown sticky bands were more attractive to *L. delicatula* compared with blue and yellow and captured hundreds of insects in a short time period.

There appears to be potential to use attractants and repellants to develop improved traps for monitoring or control purposes, although to our knowledge this has not been tested. In the laboratory Moon et al. (2011) reported that both nymphs and adults were highly attracted to spearmint oil at low doses (5 µl), which could be used to augment their control. Lee and Park (2013) also demonstrated attraction of this insect to a methanol extract of its preferred host *A. altissima*. Jang et al. (2013) reported that this species had a preference for lights with shorter wavelengths such as UV and blue lights. Yoon et al. (2011) evaluated several essential oils for repellency against *L. delicatula*. Only lavender oil displayed significant repellent activity in olfactometer tests against all stages at a concentration of 5 µl with the constituent linalool showing a response in electroantennograph tests. Field tests showed fewer insects were caught in traps containing lavender oil.

Summary

In summary, *L. delicatula*, proposed common name spotted lanternfly, is an important planthopper in several Asian countries, with prospects to establish and threaten vineyards and other crops and ornamental plants in North America. The distinctive and sedentary nature of this large insect, along with its tendency to aggregate, should make future detections and interest among the general public likely, should it become further established in North America.

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