Journal of Integrated Pest Management, (2022) 13(1): 24; 1–8
https://doi.org/10.1093/jipm/pmac020
Profile

Identification and Management of *Cydalima perspectalis* (Lepidoptera: Crambidae) in North America

David R. Coyle,[1,7] Jamielee Adams,[1] Erin Bullas-Appleton,[2] Jennifer Llewellyn,[3] Alexander Rimmer,[4] Michael J. Skvarla,[5] Sandy M. Smith,[4] and Juang-Horng Chong[6]

[1]Clemson University, Department of Forestry and Environmental Conservation, Clemson, SC, USA, [2]Canadian Food Inspection Agency, Plant Health Surveillance Unit, Plant Health Science Services Division, Guelph, ON, Canada, [3]Ontario Ministry of Agriculture, Food and Rural Affairs, Guelph, ON, Canada, [4]University of Toronto, Institute of Forestry & Conservation, Toronto, ON, Canada, [5]Pennsylvania State University, Department of Entomology, University Park, PA, USA, [6]Clemson University, Department of Plant and Environmental Sciences, Clemson, SC, USA, and [7]Corresponding author, e-mail: dcoyle@clemson.edu

Subject Editor: Carlos Bogran

Received 21 April 2022; Editorial decision 5 August 2022

Abstract

Boxwood (*Buxus* spp.) is one of the most commonly planted shrubs in urban landscapes across North America, and in Europe *Buxus* species comprise a significant portion of the forest understory. *Cydalima perspectalis* (colloquially known as the box tree moth) is a defoliator capable of causing mortality-inducing damage on boxwood in both natural and managed settings. Native to Asia, *C. perspectalis* is now established in both Europe and Canada and has been detected multiple times in the U.S. Here we review the life cycle and potential impact of *C. perspectalis* in Canada and the U.S. We discuss effective integrated management strategies and provide areas where management and detection could be improved. Rigorous detection systems will be crucial to preventing the establishment and future management of *C. perspectalis* in North America.

Key words: boxwood, *Buxus*, horticulture pest, insecticide, invasive species

Cydalima perspectalis (Walker, 1859) is native to east Asia, including Korea, Japan, China, and India (Hampson 1896, Inoue 1982, Park 2008, Walker 1859), where it primarily feeds on native and ornamental boxwood/box trees (*Buxus* L.; Buxales: Buxaceae). This insect is colloquially known as the box tree moth, though as of August 2022 no official common name has been approved, and the common name for *C. perspectalis* may change in the future. The larvae defoliate boxwood plants, resulting in aesthetic damage but can also lead to plant death when infestations are severe. *Cydalima perspectalis* was accidentally introduced into Europe, where it was first detected in Germany in 2006 and Switzerland and the Netherlands in 2007 (Käpeli 2008, Muss et al. 2009). The moth has been introduced multiple times into Europe from Asia and has likely spread throughout the continent via the nursery trade (Bras et al. 2019), a known pathway for invasive species (Liebhold et al. 2012). Boxwood is a key component of European parks, nurseries, and gardens, as well as the understory in European broadleaf forests (Wan et al. 2014). The prevalence of *Buxus* - and possibly the long time it took to detect *C. perspectalis* after its introduction - likely helped accelerate the rate at which this pest spread throughout Europe. *Cydalima perspectalis* has also been reported from the Russian Far East, where there are no native *Buxus*; likely representing another accidental introduction (Kirpichnikova 2005, Wan et al. 2014).

Cydalima perspectalis was not known to occur in North America until August 2018, when the first report from Toronto, Ontario, Canada was posted to iNaturalist (a social network that allows members to post, share and map observations on biodiversity) (https://www.inaturalist.org/observations/15879362). A collaborative monitoring program was immediately established by the Canadian Food Inspection Agency in 2019 to determine the extent of the population (Wiesner et al. 2021a). Based on results from the collaborative monitoring project and community science reports, its range expanded throughout the Greater Toronto Area between 2019 and 2021. In May 2021, the U.S. Department of Agriculture (USDA) announced that plants infested with *C. perspectalis* had been shipped from a nursery in St. Catharines, Ontario, Canada to six U.S. states and confirmed the discovery of specimens in Michigan, Connecticut, and South Carolina (USDA APHIS 2021a). In July and August 2021, *C. perspectalis* adults and larvae were also captured in New York (NYS-DA 2021, USDA APHIS 2022a). However, as of October 2021, none of the populations in the U.S. are known to be established or have sustaining populations. This article is intended as a resource for the management of *C. perspectalis* populations in North America.

Taxonomy and Identification

Cydalima perspectalis was originally described as *Phakellura perspectalis* (Walker) within the family Crambidae (grass moths) and the subfamily Spilomelinae (Mally and Nuss 2010). However, the species was subsequently placed in a number of spilomeline genera, including *Palpita*, *Diaphania*, and *Glyphodes* (Mally and Nuss 2010, Maruyama and Shinkaji 1987, She and Feng 2006). Most recently, a morphological phylogenetic analysis based on wing pattern and genital structures placed *perspectalis* (and four other species) into the genus *Cydalima* (Mally and Nuss 2010).

Several morphological characteristics distinguish *C. perspectalis* from related species (Fig. 1). The uncus attachment to male tegumen is narrow in *Agrioglypta*, *Diaphania*, and *Glyphodes*, but broad in *C. perspectalis*. *Diaphania* [such as the melonworm moth, *D. hyalinata* (L.)] are characterized by anal tufts of spatulate scales in both sexes which are absent in *C. perspectalis*. The ductus bursae in the female genitalia of *C. perspectalis* is sclerotized just anterior to the tube connecting to the oviducts (ductus seminalis) (Mally and Nuss 2010). This feature is unique compared to the other spilomeline genera mentioned but is a feature shared with *C.* (*Sisyrophora*) *pfeifferae* (Lederer) and *C. lacitostalis* (Guenée). These features of adult genitalia suggest *C. perspectalis* does not belong within the other spilomeline genera in which it has previously been placed (Mally and Nuss 2010).

Cydalima perspectalis's forewing color pattern forms a triangular white field, which is consistent with *Agrioglypta*, *Cydalima*, *Diaphania*, *Glyphodes*, *Palpita*, and others, supporting the monophyly of this clade (Mally and Nuss 2010, Mally et al. 2019). Additionally, the grey margin around the fore and hind wings supports the close relationship between *Cydalima* and *Diaphania*. However, wing venation in *C. perspectalis* is closed compared to the open state in other closely related genera (Mally and Nuss 2010) and *Cydalima* is also characterized by a white spot in the discoidal cell of the forewing that partly dips into the brown costal margin (Mally and Nuss 2010).

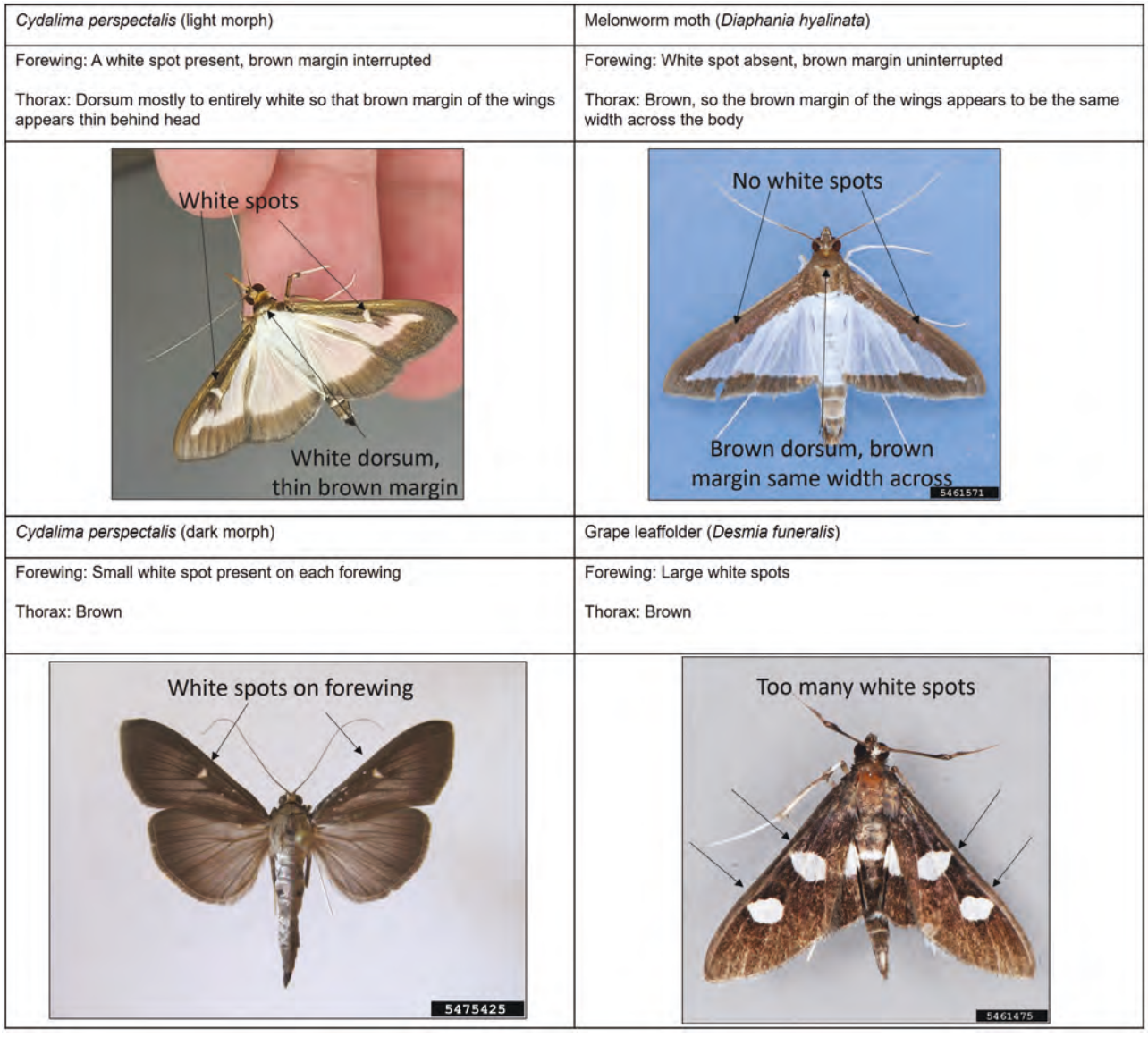

Fig. 1. Adult morphological characteristics to distinguish *C. perspectalis* from common lookalikes. *Cydalima perspectalis* light morph image from A. Rimmer, University of Toronto. Melonworm moth and grape leaffolder images from Mark Dreiling, Bugwood.org. BTM dark morph image from Szabolcs Sáfián, University of West Hungary, Bugwood.org.

In North America, *C. perspectalis* is most likely to be confused with native *Diaphania* species, especially the melonworm moth (Fig. 1), which feeds on various cucurbits. Melonworm moths occur throughout most of Central and South America and the Caribbean. In North America, they overwinter in parts of Florida and Texas and migrate north every year, reaching as far as northern Maine, Minnesota, and Ontario. Other similarly patterned *Diaphania* species [e.g., *D. indica* (Saunders), *D. infirmalis* (Guenée), and *D. modialis* (Dyar)] are also found in Central and South America but are restricted to Florida, Texas, and other U.S. Gulf Coast states. Light-colored morphs, which account for the majority of *C. perspectalis* specimens (Tuba et al. 2015), can be distinguished from *D. hyalinata* and similarly patterned *Diaphania* (Fig. 1).

Cydalima perspectalis eggs are flat, translucent to pale yellow, about 0.04 in (1 mm) in diameter, and deposited individually or in clusters of 5–20 on the underside of leaves (Leuthardt and Baur 2013, Farahani et al. 2021). Because the chorions are soft, *C. perspectalis* eggs are often described as 'gelatinous' (Fig. 2). As the eggs mature, the black head capsule of neonates can be seen through the chorion. Neonates are about 0.06 in (1.5 mm) long, with a shiny black head and almost no markings on their yellowish bodies. Larvae reach 1.5 in (about 3.5 cm) in length when mature. They have shiny black heads and greenish bodies with white-ringed black dots. Brown to black stripes become more prominent on the bodies as larvae grow. Larvae spin cocoons and wrap themselves in boxwood leaves still on the plant (which may be live, dead, or partially consumed) where they pupate. Pupae are about 0.8 in (2 cm) long, and turn from bright green to green with stripes, and then to brown as they mature. Imagoes can be seen through the pupal skin just before adult eclosion (USDA APHIS 2022b).

Biology and Life Cycle

Cydalima perspectalis overwinters as a 3rd–4th instar tucked within a silken hibernarium constructed over one leaf or between two to three boxwood leaves (Matošević 2013). The larvae resume normal development in spring and develop through up to 7 instars before pupation, and adults eclose in late spring to just after the summer solstice. Female *C. perspectalis* emit sex pheromones consisting of the components (Z)-11-hexadecenal, (E)-11-hexadecenal, and (Z)-11-hexadecenol in a ratio of 5:1.25:1, respectively (Kawazu et al. 2007, Kim and Park 2013). Males use these pheromones to find females and mate. Adults live for about two weeks (USDA Pest Alert 2021). Eggs from the first-generation adults typically hatch in early summer. *Cydalima perspectalis* develop through five to seven instars in 17 to 87 d, depending on temperature (Maruyama and Shinkaji 1991). Pupae typically mature and eclose within six to eight days (Matošević 2013). In populations from western Switzerland, the lower developmental thresholds for eggs, larvae, and pupae are 10.9°C, 8.4°C, and 11.5°C, respectively, and diapause is induced under the day length of 13.5 hr (Nacambo et al. 2014). In central Europe, at a base temperature of 9.5°C, an average of 518 degree-d were required to complete development from overwintering larval to adult stage, whereas an average of 430 degree-d were required for the entire egg to adult development in the second generation (Nacambo et al. 2014).

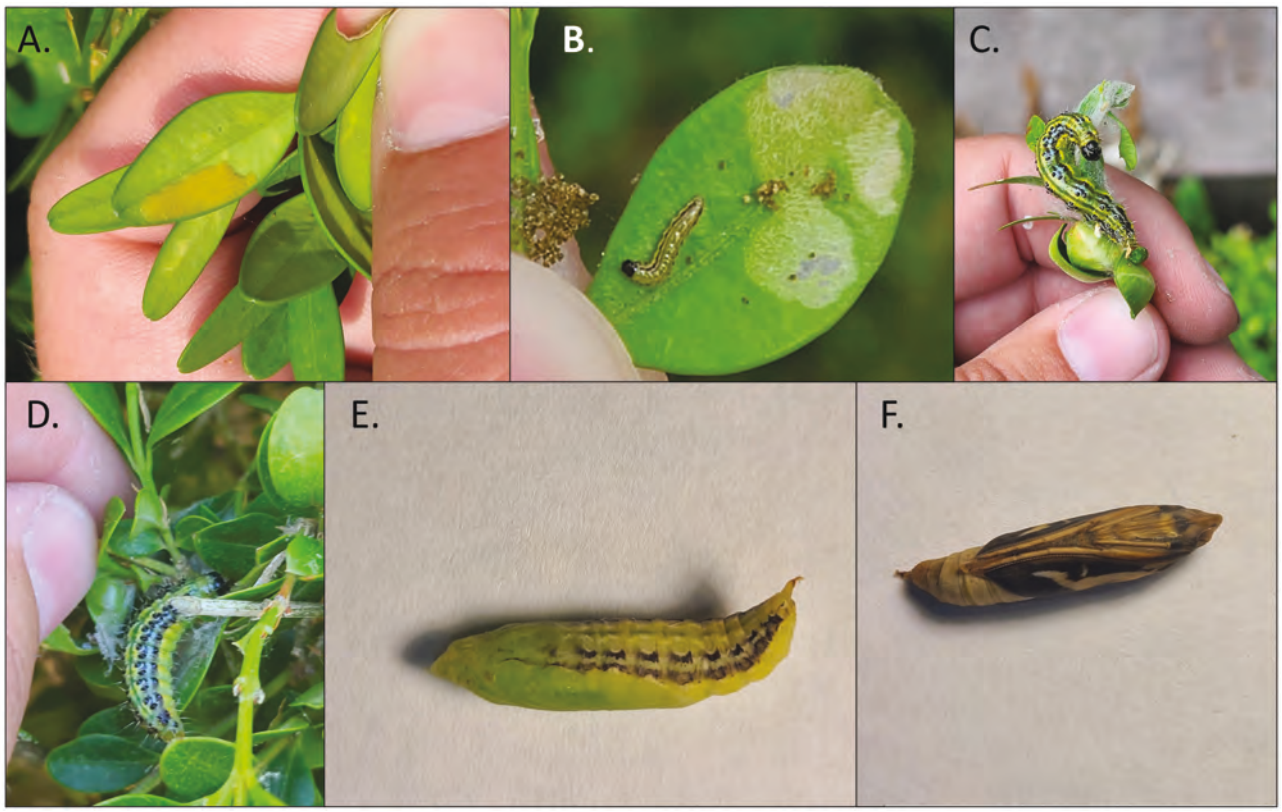

Fig. 2. *Cydalima perspectalis* life stages: A. egg cluster; B. early instar; C. late instar; D. prepupa; E. pupa 3 d after pupation; F. pupa 9 d after pupation, adult wing pattern is noticeable. All photos from A. Rimmer, University of Toronto.

Cydalima perspectalis can have two to five generations per year in its native range depending on the region (Maruyama and Shinkaji 1987, 1993; Wan et al. 2014). In various parts of Europe, this moth has been observed to have two to three generations per year (Bakay and Kollár 2018, Nacambo et al. 2014, Nagy et al. 2017; Santi et al. 2015, Plant et al. 2019). Voltinism, diapause, and developmental duration are dependent on local environmental conditions in Europe (Nacambo et al. 2014), a phenomenon that is similar to what is expected in North America. To date, only two overlapping generations have been observed in Ontario, Canada, with adults active between late June and mid-September (Wiesner et al. 2021a). Larvae in greenhouses are known to emerge from hibernation and initiate feeding earlier than those in outdoor landscapes (Anonymous 2021). The exact voltinism and phenology of *C. perspectalis* in the U.S. are currently unknown. Based on the observed voltinism in Europe and Asia (Maruyama and Shinkaji 1987, 1993; Nacambo et al. 2014, Wan et al. 2014, CABI 2019, Plant et al. 2019), two generations are expected in northern to central U.S. and three to five in central to southern U.S.; however, *C. perspectalis* may also exhibit multiple overlapping generations throughout the growing season (Plant et al. 2019).

Hosts and Damage

The primary hosts of *C. perspectalis* are *Buxus*, including popular ornamental species such as littleleaf boxwood (*Buxus microphylla* Siebold & Zucc.), Japanese boxwood (*Buxus microphylla* Siebold & Zucc. var. *japonica* (Müll. Arg. ex Miq.) Rehder & E. H. Wilson), common boxwood (*Buxus sempervirens* L.), and Korean boxwood [*Buxus sinica* (Rehder & E. H. Wilson) M. Cheng var. *insularis* (Nakai) M. Cheng (=*Buxus microphylla* Siebold & Zucc. var. *insularis* Nakai)]. In Europe, *C. perspectalis* can decimate local *Buxus* populations but does not typically feed on other species used as hosts in its native range (e.g., *Euonymus* and *Ilex*; Ferracini et al. 2022). Several alternate host species have been reported from *C. perspectalis*' native range, including ash (*Fraxinus* L.), mock orange (*Murraya paniculata* [L.] Jack), bramble (*Rubus* L.), maple (*Acer* L.), and smilax (*Smilax excelsa* L.) (Maruyama 1992, Hizal 2012, Trokhov and Kaurova 2014, Matsiakh et al. 2018). Chinese privet (*Ligustrum sinense* Lour.) is reported as a host, but this record is questionable because only adults were observed on the plant (Zhang et al. 2008).

Two native *Buxus* species served as natural hosts and helped facilitate the spread of *C. perspectalis* in Europe once the moths colonized the native ecosystems (Bras et al. 2019, Mitchell et al. 2018). In contrast, there are no native, wild *Buxus* in continental North America, although some alternate host plants are present (e.g., native smilax, invasive Chinese privet). The invasion dynamics of *C. perspectalis* in North America are likely to be different from that in Europe due to the lack of hosts in natural areas; however, this may change if the pest becomes established on alternate hosts. To date, there is no evidence that *C. perspectalis* can successfully complete development on alternate hosts in North America (Wiesner et al. 2021b), although more exploratory work is warranted.

Fig. 3. *Cydalima perspectalis* early instar 'window-pane' feeding damage (A) results from larvae striping off only a portion of the leaf epidermis. Late instar *C. perspectalis* consume most of a boxwood leaf but leave the leaf margins and midrib unconsumed (B and C). The leaf margins and midribs eventually curl, creating the distinctive 'leaf curl' symptom. Extensive *C. perspectalis* feeding can severely damage boxwood hedges (D). Photos A and D by Alex Rimmer, University of Toronto; B and C by Jen Llewellyn, OMAFRA.

The only *C. perspectalis* life stage that causes damage is the larva (Fig. 3). Damage first appears as 'window-pane' feeding on foliage as young larvae remove tissues from the leaf surface. As larvae grow, more foliage tissues are consumed, leaving behind leaf veins and edges that curl naturally and create a distinctive symptom of feeding. Extensive defoliation can remove the majority of foliage, making the infested shrubs appear rugged and unthrifty. Larvae may also feed on the bark after all leaf tissues have been consumed; extensive girdling of the stems can lead to the death of the plant. *Cydalima perspectalis* larvae also spin silk to tie leaves into shelters, within which larvae and pupae seek shelter (Matošević 2013). The web envelops foliage and captures desiccated foliage, frass, and exuviae, further reducing aesthetics of ornamental boxwood shrubs. When infestations are severe, larvae are known to make cocoons on nearby plants (Trokhov and Kaurova 2014, Matošević et al. 2017), thus impacting not only boxwood but the aesthetics of other landscape species.

Several other pests and pathogens can also cause foliar maladies on *Buxus*, including the boxwood leafminer (*Monarthropalpus flavus;* Diptera: Cedidomyiidae), boxwood psyllid (*Psylla buxi,* Hemiptera: Psyllidae), the mite *Eurytetranychus buxi*, Acari: Tetranychidae and several blights (Dhakal et al. 2022). These pests may cause only minor damage or, when pest populations are high, potential dieback and plant mortality.

Management

Regulatory Control

The introduction of *C. perspectalis* throughout Europe and North America has resulted from the trade of live plant materials, particularly of ornamental *Buxus* spp. (Bras et al. 2019, Plant et al. 2019). To prevent the introduction of *C. perspectalis* and other pests, some countries (e.g., the U.S.) have imposed strict regulations or certification requirements for the importation of host plants for *C. perspectalis* (USDA APHIS 2021b). As demonstrated by the detection of *C. perspectalis* on imported boxwood plants in the U.S., interceptions and introductions occur despite the regulators' best efforts. Surveys to detect *C. perspectalis* continue in many states and provinces, and if this pest is found, coordinated delimitation surveys are conducted to determine the extent of the infestation (USDA APHIS 2022b).

Prevention

Preventing the introduction of *C. perspectalis* or *C. perspectalis*-infested plant materials is the first step in a successful management program. Nurseries and landscape installation operations should purchase plants from a propagator or producer who has been certified by federal, provincial, or state certification programs as *C. perspectalis*-free. A nursery and greenhouse that does not propagate its own plants should establish quarantine and holding for liners, cuttings, or finished plants of *C. perspectalis* host species from an outside source. Quarantines could also be implemented at the state or federal level (USDA APHIS 2022a). All incoming plant material should be inspected for infestation or damage by *C. perspectalis*, and then moved into a holding area that is located away from the production area and where monitoring for *C. perspectalis* infestation and damage can continue for several days before the plant materials are allowed into the production area. To simplify the tracking process, plant materials from different sources should be placed in different parts of the holding area. For growers, landscape care professionals, and homeowners, infestations should be reported to federal, provincial, or state regulators immediately. Order, shipping, and scouting records should be maintained so the information can be shared with regulators. After reporting to the appropriate regulatory officials, any infested plant should be destroyed immediately according to an established disposal protocol.

Operations may consider propagating their own liners or cuttings to avoid introducing *C. perspectalis* from outside sources. For these operations, stock plants should be maintained free of *C. perspectalis* inspected regularly to detect any insect or damage during periods with active *C. perspectalis* (see Monitoring section below) and treated as soon as an infestation is detected (see Cultural control, Biological control, and Chemical control sections below). It is a grower's responsibility to ensure plants produced by the greenhouse or nursery are *C. perspectalis*-free. Therefore, plants should be inspected regularly during production and treated immediately as needed. It is recommended to avoid shipping during periods of adult activity (Anonymous 2021). Inspection of finished plants should also be conducted within two days of the expected shipping date. Any infested plants should be immediately destroyed and the remaining plants should be thoroughly inspected and treated. Plants confirmed to be *C. perspectalis*-free and ready for shipment should be placed in a staging area that is clean of all debris and other plants, and isolated from the production area or uninspected plants to prevent infestation. All production and shipping records should be maintained and made available to plant inspectors and regulators.

Monitoring

Cydalima perspectalis infestation and damage can be visually detected during regular inspection or scouting of highly susceptible plants (USDA APHIS 2022a). Scouting should be conducted weekly during *C. perspectalis* activity periods. In Ontario, weekly scouting is recommended between 1 May and 30 September for field production or landscape environments, 1 April–31 October for greenhouse or polyhouse production, and biweekly for the remainder of the year (Anonymous 2021). Scouts should have access to extension agents or specialists who may assist in confirming the identification of *C. perspectalis*. We do not yet know enough about *C. perspectalis* phenology to have monitoring recommendations in the southern part of North America.

Adult flight activity can be monitored throughout the year or during known adult activity periods with pheromone-baited traps (e.g., Ferracini et al. 2022) of which several types (including milk carton trap, general moth trap, or Unitrap) are available commercially. Traps should be placed around the perimeter of a production area or a landscape at the density and placement recommended by the manufacturers. In a nursery, four traps may be placed per hectare of production area at a distance of 100 m between traps. The traps should be examined and captures recorded weekly; the lures and traps should be serviced and replaced at the manufacturers' specified interval. Scouts or staff should be trained to inspect and service the pheromone traps, and on *C. perspectalis* biology, detection, and management to identify adult male *C. perspectalis* (which is the only life stage and sex to be attracted by the pheromone-baited traps). They should also learn to identify other major pests, and to deploy and interpret catches of the *C. perspectalis* pheromone traps. A clear channel of communication should also be established between the scouts and pest managers so management decisions can be made without confusion and delay. *Cydalima perspectalis* is a good candidate for citizen science monitoring programs and has been successfully used to monitor populations in Europe and Canada (Kazilas et al. 2021), thus, outreach and education initiatives should be considered to help track range expansion of this species.

Cultural Control

There are few options for cultural control in greenhouse and nursery production areas (Cook et al. 2021). Infested plants in production environments should be destroyed immediately. Small infestations in the landscape can be removed by carefully pruning out and destroying infested material. Continuous monitoring for additional infestations should be conducted after plant removal to ensure complete eradication of the local population. Insecticide treatment may be necessary to prevent severe infestation and the death of the boxwood shrubs or hedges.

After the infested or dead boxwood has been removed, homeowners and landscape care professionals should consider alternative ornamental plants as a replacement. Some popular replacements for boxwood include inkberry holly (*Ilex glabra* (L.) Gray), Japanese holly (*Ilex crenata* Thunb.), yaupon holly (*Ilex vomitoria* Sol. Ex Aiton), yew (*Taxus* spp.) and globe- or hedge-type arborvitae (*Thuja* spp.) (Pennisi et al. 2017). Selection of the replacement plant species and cultivar should consider the function and aesthetic of the replacement.

Biological Control

Cydalima perspectalis is attacked by several natural enemies (Wan et al. 2014) including parasitic wasps and flies that attack eggs [e.g., *Chelonus tabonus* Sonan (Hymenoptera: Braconidae) and *Trichogramma* spp. (Hymenoptera: Trichogrammatidae)], larvae (e.g., *Compsilura concinnata* (Meigen) (Diptera: Tachinidae) and *Casinaria* spp. (Hymenoptera: Ichneumonidae), and pupae (e.g., *Brachymeria lasus* (Walker) (Hymenoptera: Chalcididae). These natural enemies are not currently commercially available, and the efficacy of commercially available species of *Trichogramma* against *C. perspectalis* is unknown. The most widely used biological control agent for *C. perspectalis* is *Bacillus thuringiensis* (subsp. *aizawai* and *kurstaki*) that is available in several commercial biopesticide formulations. *Bacillus thuringiensis* is reported to be highly effective against young *C. perspectalis* caterpillars in Europe (Guérin 2018) and is recommended as part of a management plan in Canada (Wiesner et al. 2021a). Commercially available formulations of neem and entomopathogenic nematodes have also been effective in controlling *C. perspectalis* larvae (Choo et al. 1991; Göttig and Herz 2018), as was the *Anagrapha falcifera* nucleopolyhedrovirus (AnfaNPV; Rose et al. 2013) - though AnfaNPV is not yet commercially available. The use of biological control agents for *C. perspectalis* is an emerging field that shows great promise, as several new species are being discovered and evaluated for use as management tools (e.g., Ghavamabad et al. 2021, Hulujan et al. 2021, Zemek et al. 2020).

Chemical Control

In Canada, a deltamethrin formulation (DeltaGard) was granted emergency, short term registration for use against *C. perspectalis* (https://www.environmentalscience.bayer.ca/-/media/prfcanada/product-labels/deltagard_sc_boxwood_label_2021july_en.ashx) and a biological insecticide containing *Bacillus thuringiensis* var. *kustaki* (Btk) is now labeled for use against *C. perspectalis* (https://horttrades.com/dipel-fully-registered-for-box-tree-moth). Multiple insecticides are registered for management of caterpillars on ornamental plants grown in nurseries, greenhouses, and landscapes in the U.S. (Cook et al. 2021, Dhakal et al. 2022). While none of these products are registered for the management of *C. perspectalis* at this time, three active ingredients (Btk, chlorantraniliprole, and spinosad) are now proposed by federal entities as viable chemical treatment options (USDA APHIS 2022a). Unfortunately, their efficacy against *C. perspectalis* is unknown because comprehensive testing is not possible without an established population in the U.S.

Insecticides such as pyrethroids, spinosyns, and organophosphates have been used in Europe and Asia to control *C. perspectalis* larvae (Fora et al. 2016). Insecticide efficacy against eggs and pupae may be low because eggs are laid on the underside of leaves and pupae are protected within cocoons and webs that limit their contact with insecticides. Several essential oils derived from plants in the families Asteraceae, Apiacaea, and Lamiaceae have also shown promise as potential chemical controls of larval *C. perspectalis* (Gokturk et al. 2021).

Conclusions

Given that *C. perspectalis* is a relatively new invasive species to North America, knowledge in several key areas is still needed for effective monitoring, management, and impact assessment (Dhakal et al. 2022). A poor understanding of the phenology and life cycle of *C. perspectalis* in North America limits the effectiveness of chemical management and monitoring programs at this time. Additional research on the life cycle of *C. perspectalis*, particularly with the aid of pheromone monitoring, will help establish the appropriate timing for specific management tactics (Santi et al. 2015). Further, few pesticides are registered for *C. perspectalis* in North America and we lack data on the efficacy of additional management strategies (Dhakal et al. 2022). Ultimately, a combination of quarantine, surveys, host removals, and pesticide applications will likely be necessary for effective *C. perspectalis* control (USDA APHIS 2022a).

While *C. perspectalis* will use native *Buxus* as a host in Europe, it has not shown any evidence of host plant switching to native flora (Ferracini et al. 2022). We lack information regarding the potential of *C. perspectalis*' to alternate hosts in North America. Without such data, we cannot predict the potential damage caused by *C. perspectalis* in natural areas, nor can we conduct an analysis of its potential impact on the North American horticultural or landscape industries.

In summary, comprehensive outreach and communication programs are integral to *C. perspectalis* management. Resources to support timely and accurate citizen reports, engagement via social media, and products designed for interest groups and stakeholders are critical for early detection and response to *C. perspectalis*, as was shown in Poland where officials engaged gardening groups to help monitor and track *C. perspectalis* (Bereś et al. 2022) in Greece where citizen reports were used to monitor *C. perspectalis* movement (Kazilas et al. 2021).

Acknowledgments

We thank two anonymous reviewers for the time they spent helping us to improve this manuscript. We also thank Steven Long, Clemson DPI, for discussions regarding *C. perspectalis* regulatory issues.

References Cited

Anonymous. 2021. Box tree moth best management practices for growers. Available at: https://landscapeontario.com/box-tree-moth-best-management-practices-for-growers (accessed 27 October 2021).

Bakay, L. and J. Kollár. 2018. The spread rate of Cydalima perspectalis (Walker 1859) in Slovakia (2013–2015). In plants in urban areas and landscapes. In: Rovná, K., Kollár, J., (Eds.) *Slovak University of Agriculture in Nitra*: *Nitra, Slovakia*, 2018; pp. 51–54.

Bereś, P. K., P. Ziętara, M. Nakonieczny, L. Kontowski, M. Grzbiela, and M. Augustyniak. 2022. *Cydalima perspectalis* in Poland—8 years of invasion against the background of three other invasive species. Diversity. 14(1):22. doi: 10.3390/d14010022

Bras, A., D. N. Avtzis, M. Kenis, H. Li, G. Vétek, A. Bernard, C. Courtin, J. Rousselet, A. Roques, and M. -A. Auger-Rozenberg. 2019. A complex invasion story underlies the fast spread of the invasive box tree moth (*Cydalima perspectalis*) across Europe. J. Pest Sci. 92: 1187–1202.

CABI. 2019. *Cydalima perspectalis* (box tree moth). Original text by Florine Leuthardt. *In* Invasive species compendium. CAB International, Wallingford, UK. Retrieved from: https://www.cabi.org/ISC/datasheet/118433 (accessed 29 October 2021).

Choo, H. Y., H. K. Kaya, S. M. Lee, T. O. Kim, and J. B. Kim. 1991. Laboratory evaluation of entomopathogenic nematodes, *Steinernema carpocapsae* and *Heterorhabditis bacteriophora* against some forest insect pests. Kor. J. Appl. Entomol. 30: 227–232.

Cook, J.C., T. Culliney, C.F. Funaro, J.B. van Kretchmar. 2021. New pest response guidelines: *Cydalima perspectalis*, box tree moth. U.S. Department of Agriculture Report, 54 p. Available at https://www.aphis.usda.gov/plant_health/plant_pest_info/box-tree-moth/box-tree-moth-nprg.pdf (accessed 29 October 2021).

Dhakal, K., R. Bika, B. Ghimire, M. Parajuli, S. Neupane, K. Neupane, K. M. Addesso, and F. Baysal-Gurel. 2022. Arthropod and disease management in boxwood production. J. Integr. Pest Manage. 13: 18. doi: 10.1093/jipm/pmac013

Farahani S., M. Salehi, M. E. Farashiani, F. Kazerani, M. Kouhjani-Gorji, S. N. Khaleghi Trujeni, Y. Ahangaran, M. R. Vabaei, H. Yarmand, R. Omid, and A. A. Talebi. 2021. Life cycle of Cydalima perspectalis (Walker, 1859) (Lepidoptera: Crambidae), an Invasive Exotic Pest in Hyrcanian Forests of Iran. J. Agric. Sci. Technol. 23: 361-370.

Ferracini, C., C. Pogolotti, P. Mancardi, M. Miglio, S. Bonelli, and F. Barbero. 2022. The box tree moth: an invasive species severely threatening *Buxus* natural formation in NW Italy. Forests. 13: 178. doi: 10.3390/f13020178

Fora, C. G., L. Sasu, D. Poşta, and C. Berar. 2016. Chemical possibilities of *Cydalima perspectalis* Walk. (Lepidoptera: Crambidae) control. J. Hort. For. Biotechnol. 20: 31–34.

Ghavamabad, R. G., A. A. Talebi, M. Mehrabadi, M. E. Farashiani, and M. Pedram. 2021. First record of *Oscheius myriophilus* (Poinar, 1986) (Rhabditida: Rhabditidae) from Iran; and its efficacy against two economic forest trees pests, *Cydalima perspectalis* (Walker, 1859) (Lepidoptera: Crambidae) and *Hyphantria cunea* (Drury, 1773) (Lepidoptera: Erebidae) in laboratory condition. J. Nematol. 53: e2021–e2035. doi: 10.21307/jofnem-2021-035

Gokturk, T., N. Chachkhiani-Anasashvili, S. Kordali, G. Dumbadze, and A. U. Bozuyuk. 2021. Insecticidal effects of some essential oils against box tree moth (*Cydalima perspectalis* Walker (Lepidoptera: Crambidae)). Int. J. Trop. Insect Sci. 41: 313–322. doi: 10.1007/s42690-020-00209-5

Göttig, S., and A. Herz. 2018. Susceptibility of the box tree pyralid *Cydalima perspectalis* Walker (Lepidoptera: Crambidae) to potential biological control agents neem (NeemAzal®-T/S) and entomopathogenic nematodes (Nemastar®) assessed in laboratory bioassays and field trials. J. Plant Dis. Prot. 125: 365–375.

Guérin, M. 2018. Panorama of the research studies control of box-tree pyralid, pp. 125–145. *In* Végéphyl – Colloque Scientifique sur les Bioagresseurs du Buis. Tours, France.

Hampson, G. F. 1896. Moths 4. The Fauna of British India, including Ceylon and Burma. Taylor & Francis, London, xxviii + 594 pp.

Hizal, E. 2012. Two invasive alien insect species, *Leptoglossus occidentals* (Heteroptera: Coreidae) and *Cydalima perspectalis* (Lepidoptera: Crambidae), and their distribution and host plants in Istanbul Province, Turkey. Fla. Entomol. 95: 344–349.

Hulujan, I. B., T. Florian, V. C. Florian, and I. Oltean. 2021. Zoophagous entomofauna and entomopathogenic agents reported on *Cydalima perspectalis* (Walker, 1859) in north-western of Romania. Not. Bot. Horti Agrobot. Cluj Napoca. 49: 11786. doi: 10.15835/nbha49111786

Inoue, H. 1982: Pyralidae, pp. 307–404 (vol. 1), 223–254; 36–48, 228, 296–314 (vol. 2). *In* H. Inoue, S. Sugi, H. Kuroko, S. Moriuti, **and** A. Kawabe (eds.), Moths of Japan, vols. 1 and 2. Kodansha, Tokyo.

Käppeli, F. 2008. Der Buchsbaumzünsler – Im Eiltempo durch Basler Gärten. g'plus – die Gärtner-Fachzeitschrift (Zürich). 20: 33.

Kawazu, K., H. Honda, S. Nakamura, and T. Adati. 2007. Identification of sex pheromone components of the box tree pyralid, *Glyphodes perspectalis*. J. Chem. Ecol. 33: 1978–1985.

Kazilas, C., K. Kalaentzis, J. Demetriou, E. Koutsoukos, I. Strachinis, and P. Andriopoulos. 2021. Utilization of citizen science data to monitor alien species: the box tree moth *Cydalima perspectalis* (Walker, 1859) (Lepidoptera: Crambidae) invades natural vegetation in Greece. BioInvasions Rec. 10: 1032–1044.

Kim, J., and I. K. Park. 2013. Female sex pheromone components of the box tree pyralid, *Glyphodes perspectalis*, in Korea: Field test and development of film-type lure. J. Asia Pac. Entomol. 16: 473–477.

Kirpichnikova V.A. 2005. Pyralidae. In: Ler, P.A. (eds.) *Key to the Insects of Russian Far East*, 5. Vladivostok, Russia: Dal'nauka, pp. 526–539.

Liebhold, A. M., E. G. Brockerhoff, L. J. Garrett, J. L. Parke, and K. O. Britton. 2012. Live plant imports: the major pathway for forest insect and pathogen invasions of the US. Front. Ecol. Environ. 10: 135–143.

Leuthardt F. L. G. and B. Baur. 2013. Oviposition preference and larval development of the invasive moth Cydalima perspectalis on five European box-tree varieties. J Appl Entomol 137: 437-444. doi:10.1111/jen.12013

Mally, R., J. E. Hayden, C. Neinhuis, B. H. Jordal, and M. Nuss. 2019. The phylogenetic systematics of Spilomelinae and Pyraustinae (Lepidoptera: Pyraloidea: Crambidae) inferred from DNA and morphology. Arthropod Syst. Phylogeny. 77: 141–204.

Mally, R., and M. Nuss. 2010. Phylogeny and nomenclature of the box tree moth, *Cydalima perspectalis* (Walker, 1859) comb. n., which was recently introduced into Europe (Lepidoptera: Pyraloidea: Crambidae: Spilomelinae). Eur. J. Entomol. 107: 393–400.

Maruyama, T. and N. Shinkaji. 1987. Studies on the life cycle of the box-tree pyralid, *Glyphodes perspectalis* (Walker) (Lepidoptera: Pyralidae). I. Seasonal adult emergence and developmental velocity. Japan. J. Appl. Entomol. Zool. 31: 226–232 (in Japanese with English abstract).

Maruyama, T. and N. Shinkaji. 1991. The life-cycle of the box-tree pyralid, *Glyphodes perspectalis* (Walker) (Lepidoptera: Pyralidae). II. Developmental characteristics of larvae. Japan. J. Appl. Entomol. Zool. 35: 221–230 (in Japanese with English abstract).

Maruyama T. and N. Shinkaji. 1993. The life cycle of the box-tree pyralid, Glyphodes perspectalis (Walker) (Lepidoptera: Pyralidae). III. Photoperiodic induction of larval diapause. Japanese J. Appl. Entomol. Zool. 37: 45–51.

Maruyama, T. 1992. Difference in injury levels caused by the box-tree pyralid, *Glyphodes perspectalis* (Walker) (Lepidoptera: Pyralidae) on various box-trees. Japan. J. Appl. Entomol. Zool. 36: 56–58.

Matošević, D. 2013. Box Tree Moth (*Cydalima perspectalis*, Lepidoptera; Crambidae): new invasive insect pest in Croatia. South-East Eur. For. 4: 89–94.

Matsiakh, I., V. Kramarets, and G. Mamadashvili. 2018. Box tree moth *Cydalima perspectalis* as a threat to the native populations of *Buxus colchica* in Republic of Georgia. J. Entomol. Res. Soc. 20: 29–42.

Mitchell, R., S. Chitanava, R. Dbar, V. Kramarets, A. Lehtijärvi, I. Matchutadze, G. MamadashviliIryna, I. Matsiakh, S. NacamboIrena, I. Papazova-Anakieva, *et al*. 2018. Identifying the ecological and societal consequences of a decline in *Buxus* forests in Europe and the Caucasus. Biol. Invasions. 20: 3605–3620.

Muus, T. S. T., E. -J. Van Haaften, and L. J. Van Deventer. 2009. De buxusmot *Palpita perspectalis* (Walker) in Nederland (Lepidoptera: Crambidae). Entomol. Ber. 69: 66–67.

Nacambo, S., F. L. G. Leuthardt, H. Wan, H. Li, T. Haye, B. Baur, R. M. Weiss, and M. Kenis. 2014. Development characteristics of the box-tree moth *Cydalima perspectalis* and its potential distribution in Europe. J. Appl. Entomol. 138: 14–26.

Nagy A., I. Szarukan, J. Csabai, A. Molnar, B. P. Molnar, Z. Karpati, S. Szanyi and M. Toth. 2017. Distribution of the box tree moth (Cydalima perspectalis Walker 1859) in the north-eastern part of the Carpathian Basin with a new Ukrainian record and Hungarian data. Bulletin OEPP/EPPO, 47: 279–282. doi:10.1111/epp.12384

National Pesticide Information Center. 2015. *Bacillus thuringiensis* (Bt). Available online at http://npic.orst.edu/ingred/bt.html (accessed 29 October 2021).

(NYS-DA) New York State Department of Agriculture. 2021. NYS Department of Agriculture confirms box tree moth found in Western New York. Available online at https://agriculture.ny.gov/news/nys-department-agriculture-confirms-box-tree-moth-found-western-new-york?fbclid=IwAR2PkLUmwcIOtTTeh3Ua-qrjE5ihDI7NJolQkHzur-uonW7Vx7zlEYh6puw (accessed 29 October 2021).

Park, I. -K. 2008. Ecological characteristic of *Glyphodes perspectalis*. Kor. J. Appl. Entomol. 47: 299–301.

Plant, C. W., C. Poole, A. Salisbury, and S. Bird. 2019. The box-tree moth *Cydalima perspectalis* (Walker, 1859) in Britain: an overview of its spread and current status. Entomol. Record J. Var. 131: 122–147.

Pennisi, B.V., G. Huber, and G. Peiffer. 2017. Think outside the boxwood: alternative plants for gardens and landscapes. Circular 1107. University of Georgia Extension, Athens, GA. Available at: https://extension.uga.edu/publications/detail.html?number=C1107&title=Think%20Outside%20the%20Boxwood:%20Alternative%20Plants%20for%20Gardens%20and%20Landscapes (accessed 27 January 2022).

Rose, J., R. G. Kleespies, Y. Wang, J. T. Wennmann, and J. A. Jehle. 2013. On the susceptibility of the box tree moth *Cydalima perspectalis* to *Anagrapha falcifera* nucleopolyhedrovirus (AnfaNPV). J. Invert. Pathol. 113: 191–197.

Santi, F., P. Radeghieri, G. I. Sigurta, and S. Maini. 2015. Sex pheromone traps for detection of the invasive box tree moth in Italy. Bull. Insectol. 68: 158–160.

She, D., and F. Feng. 2006. Bionomics and control of *Diaphania perspectalis* (Walker). J. Zhejiang For. Sci. Tech. 26: 47–51 (in Chinese).

Trokhov, Y., and Z. Kaurova. 2014. Boxwood moth – an invasive species parasite of boxwood groves, pp. 28–36. *In* XXII-XXIII Student International Correspondence Scientific and Practical Conference, 28 October 2014, Russia, Novosibirsk.

Tuba, K., G. Kelemen, and M. Molnár. 2015. Colour and sex ratios in different box tree moth (*Cydalima perspectalis*) populations, pp. 247–253. *In* D. Marčić, M. Glavendekić, **and** P. Nicot (eds.), Proceedings of the 7th Congress on Plant Protection. Plant Protection Society of Serbia, IOBC-EPRS, IOBC-WPRS, Belgrade.

(USDA APHIS) United States Department of Agriculture, Animal and Plant Health Inspection Service 2021a. Pest alert. Box Tree Moth. *Cydalima perspectalis*. Available online at https://www.aphis.usda.gov/publications/plant_health/alert-box-tree-moth.pdf (accessed 29 October 2021).

(USDA APHIS) United States Department of Agriculture, Animal and Plant Health Inspection Service. 2021b. Plants for planting manual. Available: https://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/plants_for_planting.pdf (accessed 29 october 2021).

(USDA APHIS) United States Department of Agriculture, Animal and Plant Health Inspection Service 2022a. Box Tree Moth (*Cydalima perspectalis*) cooperative control program in select counties in New York State. Draft environmental assessment. Available: https://www.aphis.usda.gov/plant_health/ea/downloads/2022/box-tree-moth-select-counties-ny-state-ea.pdf (accessed 7 April 2022).

(USDA APHIS) United States Department of Agriculture, Animal and Plant Health Inspection Service 2022b. New pest response guidelines. *Cydalima perspectalis*, Box Tree Moth. Available online at https://www.aphis.usda.gov/plant_health/plant_pest_info/box-tree-moth/box-tree-moth-nprg.pdf (accessed 29 October 2021).

Walker F. 1859: List of the specimens of Lepidopterous insects in the collection of the British Museum. Part XVIII. Pyralides. British Museum (Nat. Hist.), London, pp. 509–798.

Wan, H., T. Haye, M. Kenis, S. Nacambo, H. Xu, F. Zhang, and H. Li. 2014. Biology and natural enemies of *Cydalima perspectalis* in Asia: is there biological control potential in Europe? J. Appl. Entomol. 138: 715–722.

Wiesner, A., J. Llewellyn, S.M. Smith, C. Scott-Dupree. 2021a. Biology and distribution of box tree moth (*Cydalima perspectalis*) (Walker, 1859) in southern Ontario. *In* Proc. of the 1st International Electronic Conference on Entomology, 1–15 July 2021. MDPI, Basel, Switzerland, doi: 10.3390/IECE-10514.

Wiesner, A., J. Llewellyn, S. M. Smith, and C. Scott-Dupree. 2021b. Suitability of Euonymus spp. for box tree moth (*Cydalima perspectalis*) survival and development. *In* 18th annual pandemic shift – the changing path of pest management, Virtual Conference (Zoom).

Zemek, R., J. Konopická, and Z. Ul Abdin. 2020. Low efficacy of *Isaria fumosorosea* against box tree moth *Cydalima perspectalis*: are host plant phytochemicals involved in herbivore defence against fungal pathogens? J. Fungi. 6: 342. doi: 10.3390/jof6040342

Zhang Y.Z., J. L. Hanula and J. H. Sun. 2008. Survey for potential insect biological control agents of Ligustrum sinense (Scrophulariales: Oleaceae) in China. Florida Entomologist. 91: 372–382. doi:10.1653/0015-4040(2008)91[372:SFPIBC]2.0.CO;2