

DISTRIBUTION AND ABUNDANCE OF *PSYLLIODES ATTENUATA* (COLEOPTERA: CHRYSOMELIDAE), THE INVASIVE HOP FLEA BEETLE, IN ONTARIO AND QUEBEC COMMERCIAL HOPYARDS

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Abstract

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The univoltine flea beetle *Psylliodes attenuata* Koch (Coleoptera: Chrysomelidae) is a pest of commercial hops (*Humulus lupulus* L.), which was first recorded in North America in 2022. Overwintered adults become active in early spring and feed on basal leaves and emerging hops shoots, causing stunting of the growing bines. The next generation of adults emerges in the summer and feeds on leaves and cones, causing economic loss at high population levels. Here, we report the distribution and relative abundance of *P. attenuata* from the cultivar ‘Cascade’ at nine hopyards in the Canadian provinces of Ontario and Quebec that were sampled June, July, and August in 2022 and 2023 by shaking bines over a large funnel. We found *P. attenuata* at all but the two most southwesterly hopyards in Ontario in 2022. By August 2023, we found *P. attenuata* at all nine hopyards, and 2023 captures were greater than 2022 captures at each hopyard. The numbers of *P. attenuata* at three of the Quebec hopyards (Quebec City/Montreal area) were an order of magnitude greater (100s versus 10s) than at the other six hopyards, and leaf and cone damage was readily apparent at these three hopyards. We found seven other flea beetle (Chrysomelidae: Alticini) species but all at low numbers. It appears that *P. attenuata* has been established in Quebec hopyards longer than in Ontario hopyards and may be spreading from east to west. However, there are few alternate hosts of *P. attenuata*, so initial hopyard introductions on infested planting material and slow beetle population growth may be as plausible as long-distance spread over short time periods. Further research is needed on *P. attenuata* to determine risk of further spread and develop management strategies.

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Introduction

Hops, *Humulus lupulus* L. (Rosales: Cannabaceae), are dioecious plants indigenous to Asia, Europe, and North America (PMC 2022). Perennial female plants are grown in rows in a trellis system, with vines (stems) up to 6.5 m in height. Hop cones (fruiting bodies) are typically harvested in August and September and primarily used in a pelletized form to give flavour to beer. There are over 30 hops cultivars grown in North America, including common cultivars ‘Cascade’, ‘Centennial’, and ‘Chinook’, each with unique flavours and aromas depending on the alpha and beta acid composition of the oils in the cones (Nance and Setzer 2011; Schönberger and Kostelecky 2011). The United States of America and Germany are the leading producers of hops, each harvesting over 20,000 ha (NASS 2023; Raiser 2024), and Canada is a minor producer, with approximately 255 ha and just over \$1 million CAD in farm-gate value as of 2020 (PMC 2022). About 60% of Canadian hectareage is in Ontario and Quebec (PMC 2022).

Psylliodes attenuata Koch (Coleoptera: Chrysomelidae) is native to the Palaearctic region and found in the Middle East, Asia Minor, China, Japan, Siberia, and most of Europe (Rheinheimer and Hassler 2018; Guo *et al.* 2020) and has now been reported in Canada (Douglas *et al.* 2024). It is often called hop flea beetle or hemp flea beetle in its native range, but we prefer invasive hop flea beetle because hop flea beetle is already the official English common name of *Psylliodes punctulata* Melsheimer in Canada. *Psylliodes attenuata* can be recognized by its length (1.6–2.6 mm), green-bronze colour, jumping hind legs, ten antennomeres, and head with ‘x’ shaped grooves (Fig. 1) (Douglas *et al.* 2024). Like most flea beetles, *P. attenuata* is univoltine, with eggs laid in the soil in summer and larvae developing on and inside plant roots. New adults emerge in August, overwinter, and then emerge again in early spring from under plant debris or the soil (Cox 2007). In the spring, *P. attenuata* adults feed on basal leaves and new hop shoots, causing stunting and defoliation. In mid- to late summer, adults feed on lateral shoots and cones, causing cones to brown and holes in plant tissue (Douglas *et al.* 2024). There are no established management practices for flea beetles in hops, although the diamide

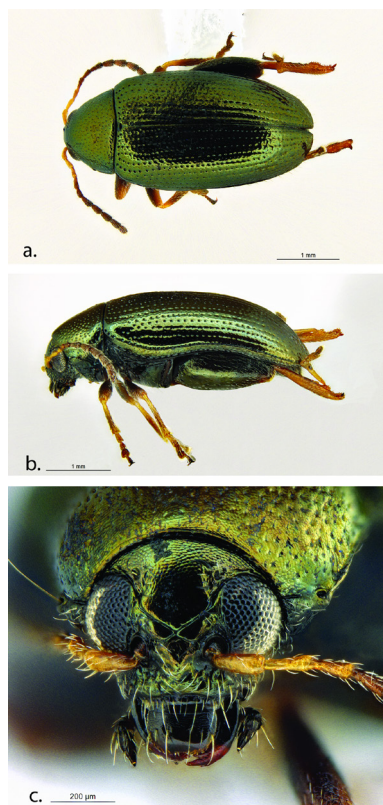


FIGURE 1. Male *Psylliodes attenuata* from Québec, Canada; a: Dorsal habitus; b: Lateral habitus; c: Head, frontal view (Photos: M. Gamman AAFC).

insecticide cyantraniliprole (Exirel®) was recently registered in Canada in hops for flea beetles and other pests.

Spider mites, particularly the two-spotted spider mite, *Tetranychus urticae* Koch (Trombidiformes: Tetranychidae), are common pests of hops, and acaricides are often applied for control (Ndiaye and Welty 2022). The original objective of our project was to characterize mite (primarily Tetranychidae and Phytoseiidae) communities in Ontario and Quebec hopyards. In addition to leaf samples, we collected ‘shake’ samples for potential spider mite predators and for evaluating arthropod diversity. After the 2022 growing season, we identified *P. attenuata* as the predominant flea beetle in our ‘shake’ samples and continued the same sampling procedure in 2023. As a result, we were able to document the distribution and possible spread of *P. attenuata* across nine hopyards, providing new information for furthering research on its pest status and control options.

Materials and methods

Five commercial hopyard sites in Ontario and four in Quebec were sampled once in June, July, and August 2022 and 2023 (Fig. 2; Table 1). Sample sites were widely distributed across agricultural areas of both provinces, with the most distant sites about 1000 km apart. At five of the sites, sampling locations were equally spaced along one row of the cultivar ‘Cascade’. At two sites, two samples were collected from one ‘Cascade’ row and three samples from another because the rows were short (<200 m). At two sites, there were many short rows of ‘Cascade’, so the samples were taken in a transect across five different rows. In all cases, sampling was spaced by at least 20 m. To collect each sample, a four-sided funnel was made from white, corrugated plastic (Plaskolite, Columbus OH, USA) glued and taped together to make a 1 × 1 m top opening and tapering at a 56° angle to a 5 × 5 cm bottom opening (Fig. 3). A deli cup plastic lid was cut and glued and taped at the bottom opening so that a plastic deli cup (1 L) could be attached to hold sampled arthropods. A handle was secured to one side of the funnel. The top of the funnel was placed about 1 m above the ground and angled towards a hop bine. The bine was shaken back-and-forth and up-and-down by-hand for 15 sec. The funnel was tapped on the outside so that arthropods and plant debris remaining on the plastic fell into the deli cup. A sample was three shaken bines, with an unshaken bine between each shaken bine. The funnel was held up, and the deli cup was tapped so that arthropods fell to the bottom before it was quickly removed and sealed with a lid. Samples were labelled, placed in a cooler during transport and kept in a laboratory freezer until processing.

After a few months, samples were thawed and then sieved with a metal sift (6 × 6 mm openings) above a white plastic tray to separate large debris from arthropods. Arthropods were sorted from small debris under a stereomicroscope at 12.5 times magnification, and flea beetles (Alticini) were placed in vials for identification. *Psylliodes attenuata* specimens were identified using Douglas *et al.* (2024), and voucher specimens (CNC5276977–CNC5276984, CNC5277121–CNC5277133, CNC5277142–CNC5277144, CNC5277149, CNC5290573–CNC5290580, CNC5290582–CNC5290584, CNC5290606, CNC5290608–CNC5290615) are deposited at the Canadian National Collection of Insects, Arachnids and Nematodes (CNCI). Other *Psylliodes* species and *Systema frontalis* (Fabricius) (Coleoptera:

Chrysomelidae) were identified by comparison to identified specimens at CNCI. Other flea beetles were identified using LeSage and Savard (2012), Parry (1986), Smith (1985), and White (1996). The mean number of *P. attenuata* per sample per site for each month was calculated.

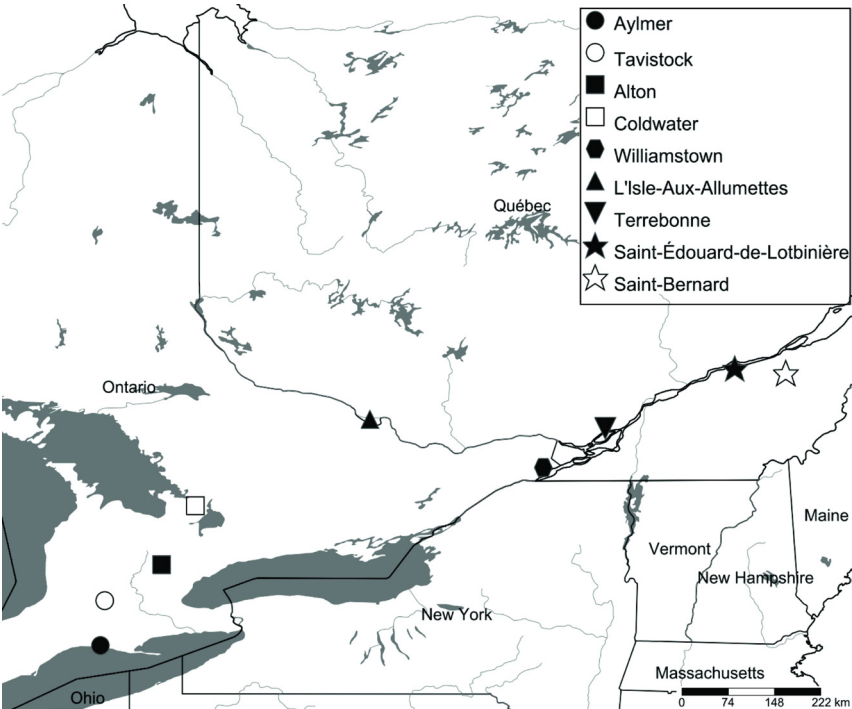


FIGURE 2. Map depicting locations of nine commercial hopyards (*Humulus lupulus*) in Ontario and Quebec named according to the nearest towns that were sampled by shaking bines for flea beetles (Chrysomelidae: Alticini) and other arthropods in 2022 and 2023.

TABLE 1. Site information for flea beetle (Chrysomelidae: Alticini) collections in nine commercial hopyard (*Humulus lupulus*) sites in Canada in 2022 and 2023. Five samples were collected in one or more rows of the cultivar ‘Cascade’ at each site.

Province	Site	GPS coordinates	Hopyard area (ha)	Sample dates		Sample locations	
				2022	2023	Rows	Length (m)
Ontario	Aylmer	42.6825, -80.9353	3.7	8 Jun, 7 Jul, 9 Aug	14 Jun, 19 Jul, 14 Aug	1	600
	Tavistock	43.3140, -80.8738	2.6	8 Jun, 7 Jul, 9 Aug	14 Jun, 19 Jul, 18 Aug	2	120
	Alton	43.8205, -80.0601	0.7	17 Jun, 8 Jul, 9 Aug	16 Jun, 20 Jul, 22 Aug	5	50
	Coldwater	44.6519, -79.5765	3.1	10 Jun, 8 Jul, 9 Aug	16 Jun, 20 Jul, 22 Aug	5	75
	Williamstown	45.1890, -74.5935	2.8	16 Jun, 13 Jul, 12 Aug	20 Jun, 25 Jul, 16 Aug	2	140
Quebec	L'Isle-Aux-Allumettes	45.8677, -77.0763	6.5	13 Jun, 13 Jul, 12 Aug	21 Jun, 25 Jul, 17 Aug	1	300
	Terrebonne	45.7431, -73.7064	9.1	13 Jun, 12 Jul, 12 Aug	20 Jun, 24 Jul, 16 Aug	1	430
	Saint-Édouard-de-Lotbinière	46.5852, -71.8525	7.6	14 Jun, 11 Jul, 11 Aug	20 Jun, 23 Jul, 15 Aug	1	220
	Saint-Bernard	46.5204, -71.1220	14.8	14 Jun, 11 Jul, 11 Aug	19 Jun 24 Jul, 16 Aug	1	250

Results

By August 2023, *P. attenuata* was found at all nine hopyards, although just one beetle was found at the Tavistock hopyard (Table 2). In Ontario, *P. attenuata* was not found at the two most southwestern locations, Aylmer and Tavistock, until July and August 2023, respectively. At the Alton site, one beetle was found in each of the June and July 2022 samples, but a total of 64 beetles was found by August 2023. Both the Coldwater and Williamstown hopyards yielded few beetles throughout 2022 and in June and July 2023, but numbers were higher in August 2023. In Quebec, we captured beetles at all sites on each sampling date in both years, except at L'Isle-aux-Allumettes in July 2022. Beetle numbers were 3–4 times higher in August 2023 than 2022 at the Saint-Édouard-de-Lobtinière and Saint Bernard yards, but 16 times higher during the same period at the Terrebonne hopyard. A total of 28 beetles were captured in June 2022 at the Terrebonne hopyard, and by August 2023, 1,882 beetles were captured. The L'Isle-aux-Allumettes hopyard, the most westerly in Quebec, had fewer beetles than the other Quebec sites but had slightly more than Ontario sites.

In 2023, we also captured 16 specimens of seven other flea beetle species (Table 3). The majority were captured at two of the Quebec hopyards. We found one specimen of *Psylliodes punctulata* Melsheimer, the native hop flea beetle, at the L'Isle-aux-Allumettes site.

Discussion

The invasive hop flea beetle *P. attenuata* appears to be well-established and possibly spreading throughout Quebec and Ontario. At all sites, there were more *P. attenuata* in 2023 than 2022, and by August 2023 all Quebec hopyards yielded more *P. attenuata* than the Ontario hopyards. Establishment and spread of *P. attenuata* in hops are likely due to factors including plant propagative sources, alternate host plant usage, the insect's dispersal capability, and hopyard management practices. Damage to leaves and cones was readily apparent at three of the four Quebec hopyards in August 2023, and research is needed for developing an integrated management strategy.



FIGURE 3. White plastic funnel with 1 × 1 m top opening with a clear plastic collecting jar at the bottom for ‘shake’ sampling arthropods from hop (*Humulus lupulus*) bines in Ontario and Quebec in 2022 and 2023.

TABLE 2. Mean $\pm$ SEM number of *Psylliodes attenuata* adults per sample (three bins shaken for 15 sec each) in nine commercial hopyard (*Humulus lupulus*) sites in Ontario and Quebec, Canada in 2022 and 2023. There were five samples per site from one or two rows of the cultivar ‘Cascade’.

Province Site		Number of <i>P. attenuata</i>						Total
		2022			2023			
		June	July	August	June	July	August	
Ontario	Aylmer	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.6	16.6 ± 4.6	86
	Tavistock	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	1
	Alton	0.2 ± 0.2	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	12.8 ± 2.4	66
	Coldwater	0.4 ± 0.2	0.0 ± 0.0	1.2 ± 0.7	0.0 ± 0.0	0.4 ± 0.2	17.2 ± 4.8	96
	Williamstown	ns ¹	0.6 ± 0.2	1.8 ± 0.9	1.8 ± 1.1	0.0 ± 0.0	20.8 ± 6.1	125
Quebec	L'Isle-Aux-Allumettes	1.0 ± 0.3	0.0 ± 0.0	ns ¹	3.0 ± 1.5	13.6 ± 6.3	26.8 ± 9.9	222
	Terrebonne	5.6 ± 1.4	0.8 ± 0.5	24.0 ± 5.7	6.2 ± 2.7	115.2 ± 27.0	376.4 ± 59.4	2641
	Saint-Édouard-de-Lotbinière	8.6 ± 1.3	2.0 ± 0.7	53.8 ± 11.8	12.4 ± 4.2	20.6 ± 3.9	142.4 ± 19.5	1199
	Saint-Bernard	18.0 ± 3.6	1.2 ± 0.2	80.8 ± 7.7	27.2 ± 9.9	0.8 ± 0.8	282.0 ± 33.5	2050

¹ns = not sampled

TABLE 3. List of flea beetle (Chrysomelidae: Alticini) species (other than *Psylliodes attenuata*) and total number captured at commercial hopyard sites in Canada in 2023.

Species	Status	No. captured	Sites and dates
<i>Chaetocnema concinna</i> (Marshall, 1802)	Non-native	3	Saint-Édouard-de-Lotbinière, 23 Jul; Tavistock, 18 Aug
<i>Chaetocnema confinis</i> Crotch, 1873	Native	2	Williamstown, 16 Aug
<i>Dibolia borealis</i> Chevrolat, 1834	Native	1	Coldwater, 22 Aug
<i>Neorepidodera ferruginea</i> (Scopoli, 1763)	Non-native	3	L'Isle-aux-Allumettes, 25 Jul; Williamstown, 16 Aug
<i>Psylliodes punctulata</i> Melsheimer, 1847	Native	1	L'Isle-aux-Allumettes, 25 Jul
<i>Phyllotreta striolata</i> (Fabricius, 1803)	Native	3	Saint-Édouard-de-Lotbinière, 15 Aug; L'Isle-aux-Allumettes, 25 Jul
<i>Systema frontalis</i> (Fabricius, 1801)	Native	3	Saint-Édouard-de-Lotbinière, 23 Jul; L'Isle-aux-Allumettes, 17 Aug

Infested planting material (usually plug transplants or rhizomes) may have been the source of populations in both provinces, as larvae develop feeding on and inside roots in spring and early summer (Edde 2002; Rheinheimer and Hassler 2018). Most of the Ontario growers sourced the majority of their original planting material (2013–2017) from two nurseries in the Niagara region of Ontario. Interestingly, the majority of the planting material at the Tavistock site, where we found just one *P. attenuata*, was sourced from another nursery in central Ontario. The Tavistock grower sourced a small number of a particular cultivar from one of the Niagara nurseries but removed them within a year of planting due to poor growth. The Niagara region nurseries and the central Ontario nursery are all permanently closed, and thus we have not been able to determine the origin of their planting material. *Psylliodes attenuata* is univoltine, meaning it may take many years or even a decade for a population to increase to detectable levels depending on juvenile and adult overwintering survival rates (Douglas *et al.* 2021). High populations in three of the Quebec hopyards in both years suggests that *P. attenuata* may have been established there longer than in Ontario. However, populations fluctuate, and thus growth is affected by climate, biological interactions, and control practices for other pests. Additionally, the highly-infested Quebec hopyards were 3–5 times larger in area than the largest Ontario

hopyard, meaning that there would have been an increased likelihood of receiving a flea beetle-infested plant.

Local spread of *P. attenuata* may also occur and could be aided by host plants in the landscape. Industrial hemp, *Cannabis sativa* L. (Rosales: Cannabaceae), is a known host (Bakro *et al.* 2018; Guo *et al.* 2022) but also minor in crop area, with 1300 and 780 ha grown in Ontario and Quebec, respectively, in 2020 (PMC 2021). All planting material at the Alton and L'Isle-aux-Allumettes hopyards was sourced from hops nurseries in the US states of Michigan, Washington, or Oregon between 2010 and 2022, where *P. attenuata* has not been observed (Erin Lizotte, personal communication) or formally reported. The grower of the Alton hopyard is aware of a field planted with hemp in recent years about 2.5 km away. Other potential landscape hosts include wild (*H. lupulus* ssp. *lupuloides*), home garden, and feral hops (*H. lupulus* ssp. *lupulus*) that occur in eastern and central North America, including the Canadian Maritime provinces (Hampton *et al.* 2001; Somalraju *et al.* 2024). As of more than 40 years ago, both hops subspecies appeared to be more widely distributed in the Ottawa River and St. Lawrence River Valleys and eastern Ontario than in southern Ontario (Small 1978). Stinging nettle, *Urtica dioica* L. (Rosales: Urticaceae), has been recognized as an occasional food plant of adult *P. attenuata* in Europe, and it is common in Canada (Rheinheimer and Hassler 2018; ARS 1961). Plants in the genera *Articum* L. (Asterales: Asteraceae), *Chenopodium* L. (Caryophyllales: Amaranthaceae), *Linum* L. (Malpighiales: Linaceae), *Beta* L. Caryophyllales: Amaranthaceae, *Solanum* L. (Solanales: Solanaceae), and *Phaseolus* L. (Fabales: Fabaceae) have also been recorded as adult feeding hosts (Nadein 2010), although no feeding was recorded on certain weed species (*Chenopodium album* L., *Amaranthus retroflexus* L. (Caryophyllales: Amaranthaceae), *Galinsoga parviflora* Cavanilles (Asterales: Asteraceae) (Rak Cizej and Milevoj 2007).

We sampled only the cultivar 'Cascade' at all hopyards, as it is commonly grown in Ontario, Quebec and the USA (NASS 2023). However, all hopyards contain multiple cultivars, and cultivars may vary in their susceptibility or attractiveness to *P. attenuata*. Using a feeding preference index, Rak Cizej and Milevoj (2007) showed differences in laboratory consumption of leaves from cultivars grown in Slovenia, but 'Cascade' was not included in their study. Generally, leaves from most commercial cultivars were preferred compared with leaves from wild hops (Rak Cizej and Milevoj 2007). Colour, trichome type and density or plant volatile profiles may affect *P. attenuata* responses to different cultivars and should be evaluated in future experiments. In mid-August 2024, we observed, in one hopyard, that *P. attenuata* feeding damage in late-maturing cultivars where the cones had not yet fully formed was greater than in earlier-developing cultivars, like 'Cascade', where the cones were nearly mature and harvestable. Identifying cultivars that are more susceptible or attractive to *P. attenuata* should help focus management efforts within hopyards.

Our sampling suggests that the life cycle of *P. attenuata* in Ontario and Quebec is the same as in other countries (Dimitriev 1935; McPartland *et al.* 2000; Rak Cizej and Žolnir 2003). Mid-June sampling results likely represent the tail-end of the spring activity period, meaning peak spring populations at the sampled hopyards could be higher than we estimated. Also, the number of spring-active beetles would be concentrated on smaller above-ground hop bine biomass available in spring compared to the summer. Adult captures in mid-July were expected to be lower than in June or August due to mortality of overwintered beetles and that the soon-to-emerge generation remained in the larval or pupal stage (Rak Cizej and

Žolnir 2003). However, in 2023 at three of the four Quebec sites, numbers were already higher in July than in June (Table 2.), indicating that the summer emergence of new adults was already occurring. In 2023, we sampled Quebec sites July 23–25, which was 12 days later than in 2022, and seasonal temperature differences may have also affected *P. attenuata* emergence timing. Insecticide application may have also reduced *P. attenuata* populations at some hopyards, as imidacloprid (Admire® Pro) is registered in hops and sometimes sprayed for hop aphid, *Phorodon humuli* (Schrank) (Hemiptera: Aphididae) or Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabaeidae).

Of the other flea beetle species captured in hops, none were abundant, and all are common and mobile in the landscape and likely to rest on many kinds of plants. Only one species, *P. punctulata*, the native ‘hop flea beetle’, is considered a pest. However, it is polyphagous and may prefer to feed on other crops or plants, such as canola or other Brassicaceae (Cárcamo *et al.* 2008). *Chaetocnema concinna* (Marsham) and *C. confinis* Crotch (Coleoptera: Chrysomelidae) are also polyphagous with many weedy hosts, although Cannabaceae is listed as a host plant family for the former (Majka and LeSage 2010). *Neocrepidodera ferruginea* (Scopoli) (Coleoptera: Chrysomelidae) is a recently discovered invasive flea beetle mainly from weedy hosts but could be a threat to certain crops (LeSage and Savard 2012). *Systema frontalis* (F.) is highly polyphagous, but hops is not a known host, while *Phyllotreta striolata* (F.) (Coleoptera: Chrysomelidae) and *Dibolia borealis* Chevrolat (Coleoptera: Chrysomelidae) have narrow host ranges and were likely captured because of particular weeds in or near hopyards.

As *P. attenuata* is expected to be able to survive and establish throughout southern Canada and most of the USA (Douglas *et al.* 2024), continued monitoring of its distribution and spread, not only in hops but also in *Cannabis* crops, will be important. Determining *P. attenuata* presence in commercial hemp fields will help resolve whether occurrence in hopyards is due primarily to planting of infested material or also due to local spread from another host plant. Genetic diversity at regional and local scales may be useful for assessing population structure and potential dispersal routes (Guo *et al.* 2020). Best practices for applications of cyantraniliprole (Exirel®) should be determined as well as the efficacy of alternatives, such as biostimulants, repellents, or biological control agents (McPartland *et al.* 2000; Rak Cizej and Poličnik 2022). Microbial symbionts have been determined in Chinese populations of *P. attenuata* and could also be developed for biological control (Guo *et al.* 2022). Overall, *P. attenuata* is a serious threat to hop production in North America and will require effective management to prevent crop losses. Monitoring and control in hop nurseries and minimizing or abandoning hops rhizome sharing among growers will be particularly important for preventing further dispersal of *P. attenuata*.

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