CHAPTER 15

Successful Biological Control of the Lily Leaf Beetle, *Lilioceris lilii*

Richard A. Casagrande[1]*, Lisa Tewksbury[1], and Naomi Cappuccino[2]

[1] University of Rhode Island, Kingston, RI *casagrande@uri.edu, lisat@uri.edu
[2] Carleton University, Ottawa, Canada naomicappuccino@cunet.carleton.ca

NON-TECHNICAL SUMMARY

The lily leaf beetle, *Lilioceris lilii* (Coleoptera: Chrysomelidae: Criocerinae), native to Eurasia, was discovered in Canada in 1943 and found in the United States in 1992. It has since spread widely throughout northeastern United States and eastern Canada, with satellite populations in several western states and provinces. Throughout its invaded range, it causes widespread damage to cultivated and native lilies. Protecting natural populations of native lilies from defoliation by this pest is impractical, and many gardeners stopped growing lilies in infested areas. Consideration of a biological control program against this pest was based on past successes in North America against several of the pest's close relatives in the same subfamily; the cereal leaf beetle, *Oulema melanopus*, and two asparagus beetles, *Crioceris asparagi* and *C. duodecimpunctata* (all Coleoptera: Chrysomelidae: Criocerinae).

Initial exploration in Europe in 1996 found several parasitoids of lily leaf beetle, and beginning in 1998, CABI of Delémont, Switzerland, was contracted for European research on this pest. CABI scientists identified seven parasitoids of *L. lilii*; four were selected for further evaluation of their chemical ecology and host specificity, including parasitism of closely related species. Additional host range testing in quarantine at the University of Rhode Island showed that three species had adequate host specificity for release in North America. With USDA and Canadian approval, *Tetrastichus setifer* (Hymenoptera: Eulophidae) was released in Massachusetts in 1999 and in Ontario in 2010. Based upon European parasitoid distributions, *Lemophagus errabundus* (Hymenoptera: Ichneumonidae) was released in coastal areas of the northeastern United States, and *Diaparsis jucunda* (Hymenoptera: Ichneumonidae) was released at inland sites. Between 1999 and 2006, we made 44 releases of *T. setifer*, 28 releases of *L. errabundus*, and 46 releases of *D. jucunda* adults in New England. Later, we made releases in New York and Washington State, as well as 25 releases of *T. setifer* in Canada, including Ontario, Quebec, Alberta, and Manitoba.

By 2016, *T. setifer* was established at release sites in New England, Ontario, and Alberta. *Lemophagus errabundus* established in Massachusetts and Rhode Island, and *D. jucunda* did so in Massachusetts, Rhode Island, Connecticut, and Maine. All three parasitoids had spread at least 10 km (6.2 mi) from release sites

Casagrande, R. A., L. Tewksbury, and N. Cappuccino. 2022. Successful biological control of the lily leaf beetle, *Lilioceris lilii*, pp. 161–171. *In:* Van Driesche, R. G., R. L. Winston, T. M. Perring, and V. M. Lopez (eds.). *Contributions of Classical Biological Control to the U.S. Food Security, Forestry, and Biodiversity.* FHAAST-2019-05. USDA Forest Service, Morgantown, West Virginia, USA. https://bugwoodcloud.org/resource/files/23194.pdf

and caused substantial reduction in *L. lilii* numbers (Tewksbury et al., 2017). An updated survey of lily growers in 2021 showed considerable decline in damage caused by the beetle in eastern Massachusetts and Rhode Island, as well as the cities of Ottawa and Montreal and their surrounding suburbs.

HISTORY OF INVASION AND NATURE OF PROBLEM

The Species Invasion

Lily leaf beetle, *Lilioceris lilii* (Coleoptera: Chrysomelidae: Criocerinae), occurs throughout Europe, North Africa, and parts of Asia, from Siberia to Morocco (Slate, 1953; Labeyrie, 1963), and in China (Lu and Casagrande, 1998). It was first reported in North America near Montreal, Canada in 1943 (LeSage, 1992), and in successive years, the beetle spread slowly from that area. However, in 1992 the beetle was detected in many distant sites, including Cambridge, Massachusetts, apparently imported with bulbs from Europe, and it was then moved along with plants within North America (Dieni et al., 2016). By 2016 the beetle was present throughout all of New England and much of the northeastern United States, with localized populations in the midwestern United States and Washington State. In Canada by 2016, it was widely distributed in the Maritime Provinces, Newfoundland, Quebec and Ontario, and also found in Manitoba, Saskatchewan, and Alberta (Tewksbury et al., 2017). The beetle's natural spread by flight has been assisted by movement of infested lilies within Canada and the United States (Lesage and Elliott, 2003; Cappuccino et al., 2013; Tewksbury et al., 2017). Current distribution records (iNaturalist, 2021) show that the beetle is well-established in southeastern Pennsylvania, and it has populations near Washington, D.C. and in parts of eastern Tennessee.

Nature of the Problem

Lily leaf beetle overwinters as an adult, and in spring it feeds and then lays its eggs on the undersides of leaves (**Fig. 1**). The larvae cover themselves with their fecal material, which apparently protects them from predators (Jolivet and Verma, 2002; Keefover-Ring, 2013). However, these fecal shields are used by parasitoids to locate beetles and identify them as hosts (Schaffner and Müller, 2001). Larvae complete four instars and then pupate in the soil (Haye and Kenis, 2004). Adults emerge in late summer and feed for a few weeks before moving to overwintering sites. There is one generation per year. *Lilioceris lilii* is a serious pest of both native and cultivated lilies in North America (LeSage and Elliott, 2003). Adults and larvae both feed on lily leaves, buds, and flowers (Ernst, 2005), often completely defoliating plants. After a few years of defoliation, plants cease flowering and many die. Perhaps more commonly, gardeners who are unwilling to tolerate defoliated lilies covered with fecal-coated larvae (**Fig. 2**) simply remove the plants (LeSage, 1992; Stocker, 2002). Despite availability of several new cultivars, lily sales have declined by more than 50% concurrent with the spread of the beetle throughout the United States (White Flower Farm, pers. comm.).

Figure 1. Lily leaf beetle (*Lilioceris lilii*) laying eggs. (Andrea Brauner, Agriculture and Agri-Food Canada)

Lily leaf beetle's threat to native plants stems from its host-range expansion onto native lilies and related species. The beetle has been reported from Canada lily (*Lilium canadense*) (Bouchard et al., 2008), Michigan lily (*Lilium michiganense*) (Blackman et al., 2016), Turk's cap lily (*Lilium superbum*) (Livingston, 1996), and

Figure 2. Lily leaf beetle (*Lilioceris lilii)* larva with fecal material. (Andrea Brauner, Agriculture and Agri-Food Canada)

rose twisted stalk (*Streptopus lanceolatus*) (Blackman et al., 2016). Infestations on wood lily (*Lilium philadelphicum*) have not been reported (Bouchard et al., 2008; N. Cappuccino, pers. obs.); however, the species is an excellent laboratory host for lily leaf beetle (Ernst et al., 2007; Bouchard et al., 2008). No estimates of the impact of the beetle on plant fitness have been published, although mean defoliation levels as high as 65% have been reported for *L. canadense* (Bouchard et al., 2008). The conservation status of native lilies is tenuous for many species. Of the 24 native lily species in North America, four are federally listed as threatened or endangered (USDA Plants Database, 2021; ECOS Environmental Conservation System, 2021), and many other species are listed as rare, threatened, or endangered by individual states. Modeling of habitat suitability predicts that the beetle will be able to spread throughout most of North America, and its distribution will eventually overlap with that of most endangered, threatened, rare, or sensitive species in *Calochortus, Fritillaria, Lilium, Medeola*, and *Streptopus* (Freeman et al., 2020).

WHY CONTROL THIS INVASIVE SPECIES?

The lily leaf beetle is susceptible to many insecticides but out of concern for pollinators, gardeners and natural area managers are reluctant to use insecticides on flowers. It was at the request of Master Gardeners from the Boston, Massachusetts area that we began investigating biological control of *L. lilii*, based on our experience with the closely related cereal leaf beetle, *Oulema melanopus* (Casagrande et al., 1977). The cereal leaf beetle, the common asparagus beetle, *Crioceris asparagi*, and the spotted asparagus beetle, *C. duodecimpunctata* (all Coleoptera: Chrysomelidae: Criocerinae), invaded North America from Europe. All became serious pests, but all three species were largely controlled by releases of their European parasitoids (Haynes and Gage, 1981; Hendrickson et al., 1991; Evans et al., 2006; Poll et al., 1998; see also Chapter 10 on cereal leaf beetle in this volume).

THE ECOLOGY OF THE PROBLEM

In classical biological control of insects, it is customary to look to the center of origin of the pest and its host plants for insights. Lilies are in the genus *Lilium*, which apparently originated in the Himalayas, with species diversifying about 12 million years ago as they spread throughout Eurasia and into North America (Patterson and Givnish, 2002). At present, about 55 of the roughly 100 species in this genus exist in China, which has the greatest diversity of wild *Lilium* in the world (Rong et al., 2011).

Lily leaf beetle is in the genus *Lilioceris*, which contains 142 species, mostly concentrated in China (Yu et al., 2001). Five species are reported in Europe (Schmitt, 2013), but none are native to North America. *Lilioceris lilii* is the most widespread species of its genus in Europe (Casagrande and Kenis, 2010), and its spread from Asia may have been assisted by moving ornamental lilies into Europe about 400 years ago (Orlova-Bienkowskaja, 2013). Based on this information, it would be reasonable to expect to find natural enemies of the lily leaf beetle in China. However, we are not aware of any such records. In Europe, despite its widespread distribution, the lily leaf beetle is not generally known as a serious pest of native lilies or the

commonly grown ornamental varieties (Salisbury, 2003). This led to the expectation that, like the cereal leaf beetle and two asparagus beetles, this pest might have been introduced into North America without the natural enemies that regulated densities in Europe. If so, like those species, lily leaf beetle would be a good candidate for biological control. Livingston (1996) found no native parasitoids and no predation among *L. lilii* populations near Boston, Massachusetts. A literature review revealed very few studies of this pest in Europe. Lataste (1932) mentioned an unidentified gregarious parasitoid of *L. lilii* in France, and Fox-Wilson (1942) referred to a larval parasitoid in England. Given the widespread distribution of *L. lilii* in Europe, the scarcity of studies there on its natural enemies suggests that it is relatively unimportant as a pest.

PROJECT HISTORY THROUGH AGENT ESTABLISHMENT

The first step of the biological control project (foreign exploration) started in 1996/1997 with surveys in France that revealed lily leaf beetle was often present, but it occurred in low numbers in home gardens and small commercial lily fields. We found two parasitoids—*Tetrastichus setifer* (Hymenoptera: Eulophidae) and *Lemophagus errabundus* (Hymenoptera: Ichneumonidae)—attacking lily leaf beetle during this survey (Gold et al., 2001). Based on these discoveries, we enlisted for assistance an international biocontrol institution, CABI, through its station in Delémont Switzerland, to undertake further agent discovery, agent evaluation, and rearing.

Surveys run by CABI researchers found a generally high rate of parasitism in *L. lilii*, ranging from 25 to 78%, with regional and seasonal variation in parasitoid complexes (Haye and Kenis, 2004). CABI entomologists also found five additional parasitoids of *L. lilii*. Two tachinid flies were eliminated from consideration in this program because they were also known from other hosts. Similarly, an egg parasitoid was determined to have inadequate host specificity because it overwinters in an alternate host species (Haye and Kenis, 2004). The remaining four species were deemed worthy of consideration for lily leaf beetle biological control in North America, and in initial studies Haye and Kenis (2004) evaluated their biology and distribution, as briefly summarized below.

(1) *Tetrastichus setifer* was found to be widely distributed in Europe, from the United Kingdom to Bulgaria and from northern Germany through Italy. Adult parasitoids paralyze host larvae for several minutes while they insert their eggs (**Fig. 3**). An average of seven parasitoid larvae develop per host larva, and they overwinter in the host cocoon in the soil. In spring, adults emerge over several weeks and attack all four larval stages of *L. lilii*. There is one parasitoid generation per year.

(2) *Diaparsis jucunda* (Hymenoptera: Ichneumonidae) was the dominant parasitoid found in Switzerland, Austria, and Italy, but it was rare in the coastal regions of Western Europe and northern Germany. Like the other ichneumonid parasitoids under consideration, it overwinters as a young teneral adult inside the host's pupal case. It has one generation per year.

(3) *Lemophagus errabundus* (Hymenoptera: Ichneumonidae) was the dominant parasitoid found in the United Kingdom,

Figure 3. *Tetrastichus setifer* ovipositing in lily leaf beetle (*Lilioceris lilii*) larva. (Andrea Brauner, Agriculture and Agri-Food Canada)

the Netherlands, western France and northern Germany, but it was rare at greater distances from the coast. It is a solitary parasitoid, producing one larva per host with one generation per year.

(4) *Lemophagus pulcher* (Hymenoptera: Ichneumonidae) was found widely across Europe (except in the United Kingdom), but it was the dominant species only in Bulgaria. It has one full generation and a partial second each year. It is commonly attacked by the hyperparasitoid *Mesochorus lilioceriphilus* (Hymenoptera: Ichneumonidae), which also occasionally attacks *L. errabundus*.

These four parasitoids were evaluated in Europe through laboratory host range testing and studies of field parasitism of other species of *Lilioceris* from the same areas (Scarborough, 2002), as well as through investigation of the species' chemical ecology (Schaffner and Kenis, 1999; Schaffner and Müller, 2001; Schaffner, 2002). Afterwards, further host range testing was continued in quarantine in the United States by Gold (2003) who evaluated these parasitoids against three species of Criocerinae found in North America (*O. melanopus*, *C. asparagi*, and *Lema trilineata*), as well as non-Criocerinae species of chrysomelids (e.g., *Plagiodera versicolora, Leptinotarsa decemilineata, Galerucella calmariensis,* and *G. pusilla*). One coccinellid, the Mexican bean beetle, *Epilachna varivestis*, was also tested.

These three research approaches (field studies of parasitism of related host species, chemical ecology, and laboratory screening) produced generally similar results that together gave a clear picture of these parasitoids' host specificity (Casagrande and Kenis, 2010). *Diaparsis jucunda* is the most specialized of the group, showing a clear preference for *L. lilii* over *L. merdigera* and *L. tibialis* in the field. It is attracted to lily foliage that has been damaged by *L. lilii* and is stimulated to oviposit by fecal shields from *L. lilii* larvae. Furthermore, in quarantine trials, it never attacked any other species, while in the same tests it consistently parasitized *L. lilii*.

At the other extreme, *L. pulcher* was the least specialized of the group. In natural field populations, it was more commonly found parasitizing *L. tibialis* and *L. merdigera* than nearby *L. lilii*. Chemical screening in the laboratory showed it to be attracted to *L. lilii* larvae, their fecal material, and lily leaves damaged by these larvae, but it also showed attraction and oviposition responses to extracts from the North American species *L. trilineata*. Finally, in quarantine, *L. pulcher* attacked *L. trilineata* as readily as *L. lilii*, and it also attacked *C. asparagi*. This species is clearly the least specific of the four species investigated, and based on these tests, it is not presently being considered for release in North America.

The other two parasitoids showed intermediate results in these evaluations. Neither species was very common in sympatric populations of congeneric species, but *T. setifer* was more common in *L. tibialis* than in *L. lilii*. Neither species responded to an olfactory bioassay, but *T. setifer* was more attracted to fecal material from *L. lilii* than from *L. merdigera*. Quarantine studies showed *L. errabundus* to attack nothing but *L. lilii*, and *T. setifer* attacked only a single *L. trilineata* (of 150 exposed). Thus, *L. errabundus* and *T. setifer* have host preferences within the genus *Lilioceris*, but they are unlikely to attack insects outside of that genus. Therefore, they were determined safe to release in North America (Casagrande and Kenis, 2010) because there were no other *Lilioceris* species in North America at that time. This changed when *Lilioceris cheni* was established in Florida in 2012 as a biological control agent of air potato, *Dioscorea bulbifera* (Overholt et al., 2016). Fortunately, collaboration between the lily leaf beetle and air potato biocontrol projects (Lake et al., 2020) demonstrated little potential for parasitoids of *L. lilii* to interfere with air potato biological control.

Following USDA and state approvals based on data described above, *T. setifer* release was approved and began in 1999. Initial releases were made for three years in Wellesley and Waltham in Massachusetts, and Cumberland in Rhode Island into relatively large plots (6 x 6 m [~20 x 20 ft] with approximately 800 lilies) to allow destructive sampling. Within-season sampling showed parasitism of *L. lilii* larvae as high as 63% within these plots. However, there was no overwintering survival in any plot for two seasons until a 5 cm (2 in) layer of cedar bark mulch was removed from two plots. Following mulch removal and continued parasitoid releases, parasitoids became permanently established in the Wellesley and Cumberland plots,

but never established at Waltham, which remained mulched. We have not mulched lily plots used for releases since then. No additional parasitoids were released in the Wellesley plot where larval parasitism was found to increase annually. *Lilioceris lilii* populations decreased to near zero in this plot by 2008, while remaining relatively constant in a control plot 3 km (1.9 mi) away (Gold, 2003; Tewksbury et al., 2017). Based upon this success and similar results in Cumberland, additional releases of *T. setifer* were made at 27 sites (mostly home gardens) through 2016, including three in Rhode Island, one in New Hampshire, four in Maine, two in Massachusetts, 16 in Connecticut, and one in Ontario, Canada (where 88 *T. setifer* adults were released into a 2 x 2 m (6.5 x 6.5 ft) plot in Ottawa in 2010 [Tewksbury, 2014]). By 2016, *T. setifer* was found to be established in every state where it was released and to be spreading roughly 1.5 km (0.9 mi) per year, with associated reductions in both *L. lilii* populations and damage to lilies (Tewksbury et al., 2017). Similar results, but with somewhat slower dispersal, were observed in Ottawa, Ontario, where *T. setifer* had dispersed 3.5 km (2.2 mi) in six years following the initial release and was parasitizing up to 100% of beetle larvae at sites where it was present (Blackman, 2017). After 2016, *T. setifer* was released at eight sites in New York (2017–2018) and one site in Vermont. In northwestern Washington State, *T. setifer* was released at four sites (2018–2019). In addition, in Canada, *T. setifer* was released at 25 sites, in Ontario, Quebec, Alberta, and Manitoba.

After obtaining USDA release permits and state approvals, *L. errabundus* and *D. jucunda* releases were begun in 2003. *Lemophagus errabundus* releases were concentrated in coastal areas, with initial release sites in Middleboro and Plainville, Massachusetts, and Kingston, Rhode Island. By 2005, it was confirmed to have established in a garden 1.2 km (0.75 mi) from the release site in Plainville, and subsequently at six sites in southern Rhode Island. As with *T. setifer*, increasing parasitism by *L. errabundus* was associated with reduction in *L. lilii* populations, and the parasitoid was found to have spread approximately 1.5 km (0.9 mi)/year (Tewksbury et al., 2017). There were two releases of *L. errabundus* in New York from 2017 through 2018.

Starting in 2003, *D. jucunda* was released in Cumberland and Kingston, Rhode Island, two sites in New Hampshire, and one in Maine. It was first recovered in a garden 5 km (3.1 mi) from the Cumberland release site four years after release. In Orono, Maine, it was confirmed to have established one year after its release. This parasitoid has spread 4–5 km (2.5–3.1 mi)/year away from release sites (Tewksbury et al., 2017). There were two releases of *D. jucunda* in New York from 2017 through 2018 and four in Washington State in 2018/2019.

HOW WELL DID BIOLOGICAL CONTROL WORK?

In the spring of 2021, we used an online survey to determine the status of the lily leaf beetle and its parasitoids in North America. We asked participants what year they had first noticed the lily leaf beetle in their gardens, what year they had experienced the worst damage caused by the beetle, and how they would describe the observed trend in damage levels (increasing, decreasing, remaining at a high level, or remaining at a low level) over the past year and over the past five years. We also asked them to tell us what methods they had used to control the beetle. A total of 649 individuals responded to the survey. Most people (55%) who responded to the question about control methods replied that they hand-picked lily leaf beetles from their plants. Nearly 10% reported giving up growing lilies and removing the defoliated plants from their gardens.

Respondents from Massachusetts and Rhode Island, where the first U.S. releases took place, commonly reported that lily beetle damage in their gardens had declined over the last five years (green dots in **Fig. 4**) or had remained at low levels (yellow in **Fig. 4**). A few people from previously infested parts of Massachusetts reported having never seen a lily leaf beetle in recent years. Gardeners from the adjacent states of Connecticut and New York were more likely to report increasing damage from lily leaf beetle (**Fig. 4**). Parasitoids were first released in Connecticut in 2016 and New York in 2017. As parasitoids only move 2–4 miles per year, many years are required for parasitoids to spread long distances from release sites.

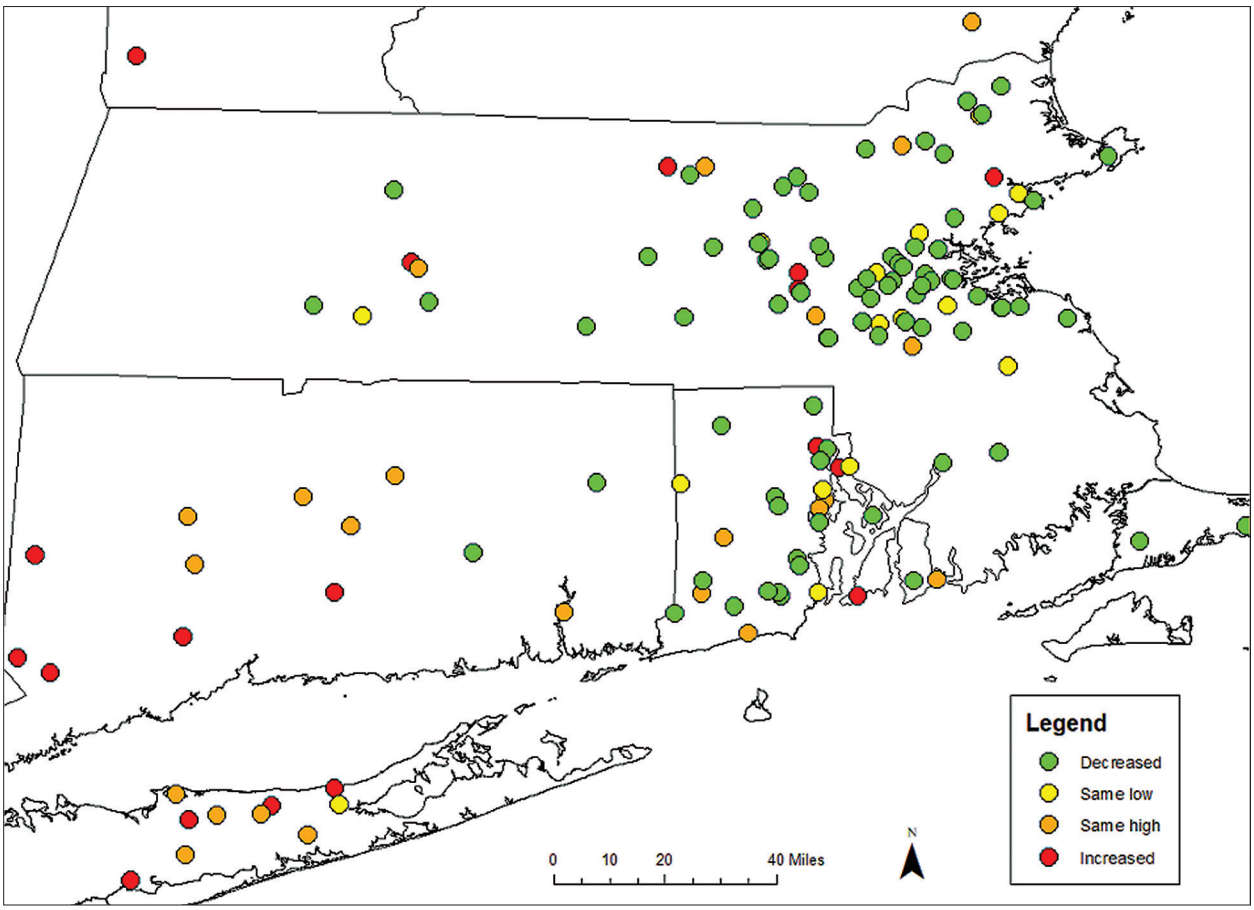

Figure 4. Survey results for southern New England, showing reduced lily leaf beetle (*Lilioceris lilii*) numbers in Massachusetts and Rhode Island, locations where parasitoids were first released. (Map: Alana Russell, University of Rhode Island)

Similarly, respondents from Ottawa and Montreal, where releases were made in 2010 and 2013, respectively, commonly reported declining or low levels of damage (**Fig. 5**). No lily leaf beetles or damaged plants were observed at the Ottawa release sites and several adjacent sites in July 2021. Beetle populations were generally found to decline wherever parasitoids had been released, including release sites in western Canadian provinces where growers reported declining beetle populations around release sites near Winnipeg, Manitoba and from Calgary to Edmonton, Alberta.

In addition to carrying out the online survey, for further evaluation we collected larvae from nine sites in Massachusetts or Rhode Island and dissected them for parasitism. Seven of those sites (77.8%) had larvae that were parasitized by either *L. errabundus*, *D. jucunda*, or both (**Table 1**). Parasitism, when present, ranged from 28–100%. None of the sites we sampled had serious leaf damage, and in general, effort was required to find larvae, except for those Massachusetts sites that were far from parasitoid releases.

Given results of earlier sampling efforts (Tewksbury et al., 2017), we were not surprised to find low populations of *L. lilii*. However, we did expect to find *T. setifer*, which was known to be widely established throughout the sampled area. The absence of this parasitoid from our results may indicate that we sampled too early for *T. setifer*. Haye and Kenis (2004) found that the ichneumonds (*D. jucunda* and *L. errabundus*) emerged before *T. setifer* in Europe, and Gold (2003) found that established populations of *T. setifer* were most abundant around mid-June near Boston, Massachusetts. Most of our samples in 2021 (**Table 1**) were taken before mid-June. Parasitoid dispersal rates may also have affected our results. Tewksbury et

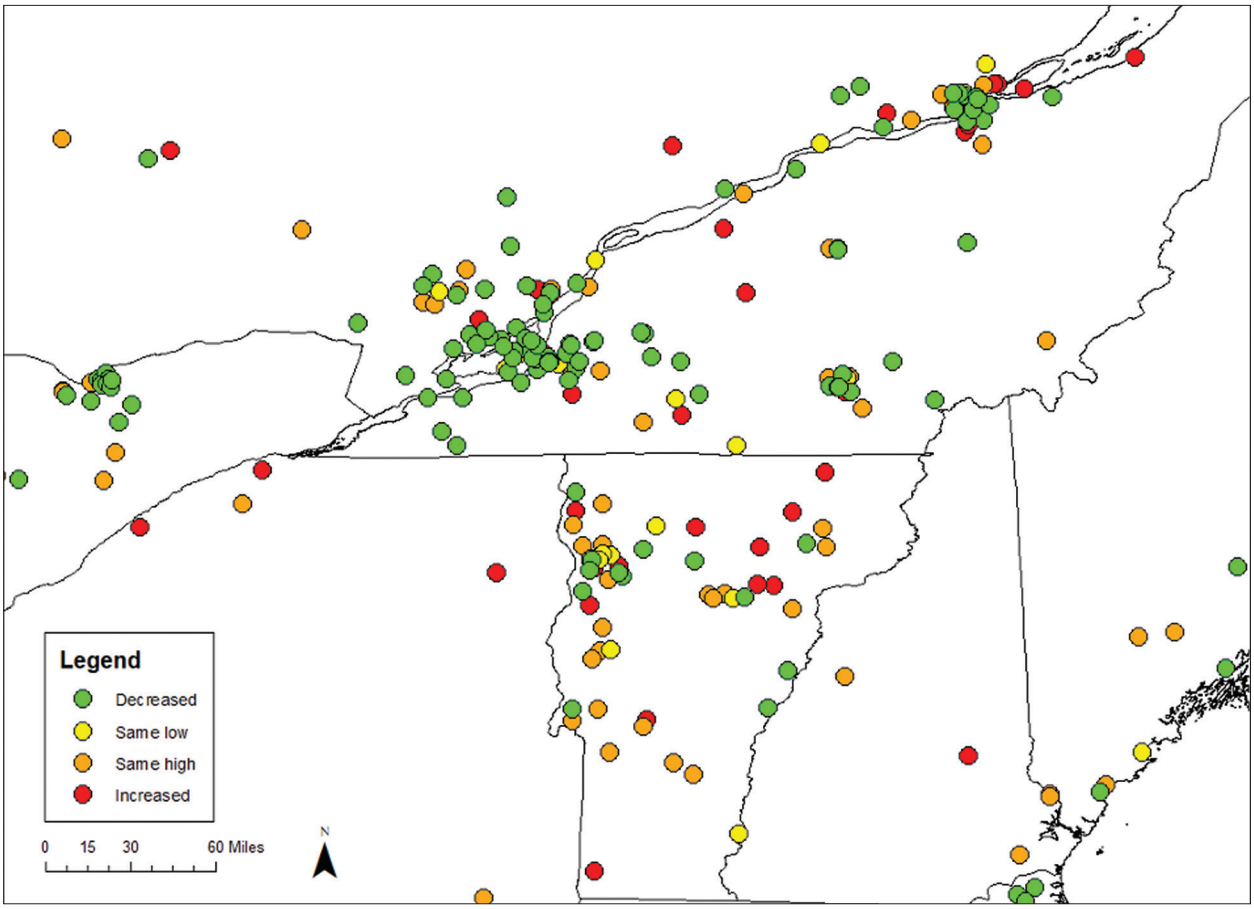

Figure 5. Clusters of decreasing lily leaf beetle (*Lilioceris lilii*) populations near Ottawa, Montreal, Quebec City, and Burlington, Vermont, all sites where parasitoids were released. (Map: Alana Russell, University of Rhode Island)

Table 1. Levels of parasitism in lily leaf beetle (*Lilioceris lilii*) larvae at sites sampled for introduced parasitoids in spring of 2021. Abbreviations: TS – *Tetrastichus setifer*, DJ – *Diaparsis jucunda*, LE – *Lemophagus errabundus*, RI – Rhode Island, USA, MA – Massachusetts, USA.

Site	Date	# Larvae Dissected	# Parasitized by TS	# Parasitized by DJ	# Parasitized by LE	% Parasitism
URI Kingston, RI	June 1–12	20	0	6	3	45
Wakefield, RI	June 10	19	0	0	15	79
Charlestown, RI	June 11	3	0	1	0	33
Charlestown, RI	June 12–30	14	0	0	0	0
Richmond, RI	June 23	16	0	0	0	0
Cumberland, RI	June 2	2	0	2	0	100
Cumberland, RI	June 2	18	0	0	5	28
Lancaster, MA	June 5	112	0	58	0	52
Holliston, MA	June 5	23	0	20	0	87

al. (2017) found *D. jucunda* to disperse more rapidly than the other parasitoids, and it may have been the first parasitoid species to reach the sites in Holliston and Lancaster, Massachusetts. It is also possible that *D. jucunda* and *L. errabundus* have displaced *T. setifer*. Haye and Kenis (2004) found that although *T. setifer* is widespread in Europe, it only dominates in northern Germany and Sweden. Scarborough (2002) found that *T. setifer* was best suited to parasitize small larvae—a disadvantage for a parasitoid emerging relatively late in the season. Further, Gold (2003) found that when *T. setifer* oviposited into a larva previously attacked by either of the ichneumonids *D. jucunda* or *L. errabundus*, the ichneumon prevailed. Although our limited sampling season may have caused us to miss *T. setifer*, it does show that both *D. jucunda* and *L. errabundus* are widely distributed and likely contributing significantly to the regional decline of *L. lilii* populations and damage.

Declines of lily leaf beetle in Ottawa, where we had previously collected *T. setifer* (Blackman, 2017), were also likely due to the activity of *T. setifer*. We do not have dissection results to document establishment of *T. setifer* at the other 25 sites where *T. setifer* was released in Ontario, Quebec, Alberta, and Manitoba, but Tewksbury et al. (2017) showed that *T. setifer* was established at most sites where it had been released. *Lilioceris lilii* populations have declined near Canadian sites where this parasitoid was released, while beetle populations have increased elsewhere in the United States and Canada.

BENEFITS OF BIOLOGICAL CONTROL OF LILY LEAF BEETLE

Control of the lily leaf beetle has been of obvious benefit to gardeners. Several survey respondents from Massachusetts, Rhode Island, Ottawa, and Montreal included a note of gratitude that they can once again grow lilies without the constant vigilance that was previously necessary to hand remove beetle life stages before defoliation became severe. In recent years, as the lily leaf beetle has become rare in much of southern New England, lilies are once again becoming common in residential landscapes. In recognition of the success of this biological control program, the North American Lily Society in June 2021 presented R. Casagrande with their E.H. Wilson award that is "given to an individual who has made an outstanding contribution to the genus *Lilium*."

Although releases have been made in populations of native lilies, including *L. canadense* in Granby, Quebec, and *L. michiganense* in Burlington, Ontario, follow-up sampling has not been done to determine if the parasitoids established and prevented damage. The protection of populations of native lilies, especially species of conservation concern, is arguably the most important benefit stemming from our biocontrol efforts. Overall, the biological control program for the lily leaf beetle has already been quite successful in the parts of eastern North America where the beetle and its parasitoids have been established longest. The established parasitoid species will continue to spread on their own, filling in many of the gaps between release sites. Additional releases will be needed in the western states and provinces as it would be difficult (or take decades) for the parasitoids to spread naturally against the prevailing winds. To date, *T. setifer* looks very successful in Canada, and *D. jucunda* and *L. errabundus* may be considered for future releases.

REFERENCES

Blackman, C. K. 2017. North American host range expansion, of an introduced pest, the lily leaf beetle, *Lilioceris lilii* (Scopoli) (Coleoptera: Chrysomelidae) and potential to attain enemy free space from its parasitoid *Tetrastichus setifer*. M.S. Thesis. Carleton University.

Blackman, C. K., N. Cappuccino, and P. G. Mason. 2016. First record of *Lilioceris lilii* (Scopoli) (Coleoptera: Chrysomelidae) on *Lilium michiganense* Farwell and confirmation of its association with *Streptopus lanceolatus* (Aiton) Reveal (Liliaceae). *The Coleopterists Bulletin* 70(3): 482–484.

Bouchard, A. M., J. N. McNeil, and J. Brodeur. 2008. Invasion of American native lily populations by an alien beetle. *Biological Invasions* 10: 1365–1372.

Cappuccino, N., T. Haye, L. Tewksbury, and R. Casagrande. 2013. *Lilioceris lilii* (Scopoli), lily leaf beetle (Coleoptera: Chrysomelidae), pp. 208. *In:* Mason, P. and D. R. Gillespie (eds.). *Biological Control Programmes in Canada, 2001–2012.* CAB International, Wallingford, U.K.

Casagrande, R. A., W. G. Ruesink, and D. L. Haynes. 1977. The behavior and survival of adult cereal leaf beetles. *Annals of the Entomological Society of America* 70: 19–30.

Casagrande, R. A. and M. Kenis. 2010. Evaluation of lily leaf beetle parasitoids for North American introduction, pp. 110–124. *In:* Van Driesche, R. and R. Reardon (eds.). *Assessing Host Ranges for Parasitoids and Predators Used for Classical Biological Control: A Guide to Best Practice.* FHTET-04-03. USDA Forest Service, Morgantown, West Virginia, USA.

Dieni, A., J. Brodeur, and J. Turgeon. 2016. Reconstructing the invasion history of the lily leaf beetle, *Lilioceris lilii*, in North America. *Biological Invasions* 18: 31–44.

ECOS Environmental Conservation System. 2021. USFWS. Ecos.fws.gov/ecp. [Accessed 15 December 2021].

Ernst, C. 2005. The lily leaf beetle (*Lilioceris lilii*): an unwelcome invader. *The Lily Yearbook of the North American Lily Society* 58: 29–34.

Ernst, C., N. Cappuccino, and J. T. Arnason. 2007. Potential novel hosts for the lily leaf beetle *Lilioceris lilii* Scopoli (Coleoptera: Chrysomelidae) in eastern North America. *Ecological Entomology* 32: 45–52.

Evans, E.W., J. B. Karren, and C. E. Israelsen. 2006. Interactions over time between cereal leaf beetle (Coleoptera: Chrysomelidae) and larval parasitoid *Tetrastichus julis* (Hymenoptera: Eulophidae) in Utah. *Journal of Economic Entomology* 99(6): 1967–1973.

Fox-Wilson, G. 1942. The lily beetle, *Crioceris lilii*. *Journal of the Royal Horticultural Society* 67: 165–168.

Freeman, M. C. Looney, M. J. Orlova-Bienkowskaja, and D. W. Crowder. 2020. Predicting the invasion potential of the lily leaf beetle, *Lilioceris lilii* Scopoli (Coleoptera: Chrysomelidae), in North America. *Insects* 11(9): 560. https://www.mdpi.com/2075-4450/11/9/560

Gold, M. S., R. A. Casagrande, L. Tewksbury, M. Kenis, and S. B. Livingston. 2001. European parasitoids of the lily leaf beetle, *Lilioceris lilii* Scopoli (Coleoptera: Chrysomelidae). *The Canadian Entomologist* 133: 671–674.

Gold, M.S. 2003. Biological control of the lily leaf beetle, *Lilioceris lilii* in North America. PhD. Dissertation. University of Rhode Island.

Haye, T. and M. Kenis. 2004. Biology of *Lilioceris* spp. (Coleoptera: Chrysomelidae) and their parasitoids in Europe. *Biological Control* 29: 399–408.

Haynes, D. L. and S. H. Gage. 1981. The cereal leaf beetle in North America. *Annual Review of Entomology* 4: 423–434.

Hendrickson, R. M., F. Gruber, G. Mailloux, and J. J. Drea. 1991. Parasite colonizations against *Crioceris asparagi* (L.) and *C. duodecimpunctata* (L.) (Coleoptera: Chrysomelidae) in North America from 1983 to 1988. *Proceedings of the Entomological Society of Washington* 93: 67–69.

iNaturalist.org. 2021. https://www.inaturalist.org. [Accessed 15 December 2021].

Jolivet, P. and K. K. Verma. 2002. *Biology of Leaf Beetles.* Intercept Ltd., Andover, Hampshire, U.K.

Keefover-Ring, K. 2013. Making scents of defense: do fecal shields and herbivore-caused volatiles match host plant chemical profiles? *Chemoecology* 23: 1–11.

Labeyrie, V. 1963. Phytophagoidea Chrysomelidae Sous-Famille De Criocerinae, pp. 192–198. *In:* Balachowsky, A. (ed.). *Entomologie Appliquee a L'Agriculture.* Masson et Cie Editeurs, Paris.

Lake, E. C., L. Tewksbury, M. C. Smith, F. A. Dray, Jr, A. D. Russell, P. T. Madeira, M. B. Rayamajhi, and R. A. Casagrande. 2020. Potential for negative interactions between successful arthropod and weed biological control programs: A case study with *Lilioceris* species. *Biological Control* 144: 104218. https://doi.org/10.1016/j.biocontrol.2020.104218

Lataste, F. 1932. Addition à ma note du 10 mars 1931 sur le criocère du lis. *Bulletin de la Société zoologique de France T. LVI* 56(2): 192–198.

LeSage, L. 1992. The lily beetle, *Lilioceris*, lilii (Scopoli), in Canada (Coleoptera: Chrysomelidae). *La Revue Canadienne des Insectes Nuisibles aux Cultures* 70: 88–96.

LeSage, L. and B. Elliott. 2003. Major range extension of the lily leaf beetle (Coleoptera: Chrysomelidae), a pest of wild and cultivated lily. *The Canadian Entomologist* 135: 587–588.

Livingston, S. B. 1996. Biology, control, and host range of *Lilioceris lilii*: a new ornamental pest in the USA. M.S. Thesis, University of Rhode Island.

Lu, W. and R.A. Casagrande. 1998. Notes on the distribution and host range of *Lilioceris* in China (Coleoptera: Chrysomelidae). *Chrysomela* 35: 7–8.

Orlova-Bienkowskaja, M. 2013. Dynamics of the range of lily leaf beetle (*Lilioceris lilii*, Chrysomelidae, Coleoptera) indicates its invasion from Asia to Europe in the 16th–17th century. *Russian Journal of Biological Invasions* 4(2): 93–104.

Overholt, M.A, M. Rayamajhi, E. Rohrig, S. Hight, F.A. Dray, E. Lake, M. Smith, K. Hibbard, G.P. Ghattarai, K. Bowers, R. Poffenberger, M. Clark, B. Curry, B. Stange, E. Calise, T. Wasylik, C. Martinez, and J. Leidi. 2016. Release and distribution of *Lilioceris* cheni (Coleoptera: Chrysomelidae), a biological control agent of air potato (*Dioscorea bulbifera*: Dioscroeaceae), in Florida. *Biocontrol Science and Technology* 26(8): 1087–1099.

Patterson, T. B. and T. J. Givnish. 2002. Phylogeny, concerted convergence, and phylogenetic niche conservatism in the core Liliales: Insights from rbcL and ndhF sequences data. *Evolution* 56: 233–252.

Poll, J. T. K., J. Alphen, and G. van Driessen. 1998. Biological control of the asparagus beetle *Crioceris asparagi* using *Tetrastichus asparagi. Proceedings of the Section Experimental and Applied Entomology of the Netherlands Entomological Society* 9: 129–130.

Rong, L., Lei, J., and C. Wang. 2011. Collection and evaluation of the genus *Lilium* resources in Northeast China. *Genetic Resources and Crop Evolution* 58: 115–123. https://doi.org/10.1007/s10722-010-9584-2

Salisbury, A. 2003. Two parasitoids of the lily beetle *Lilioceris lilii* (Scopoli) (Coleoptera: Chrysomelidae) in Britain, including the first record of *Lemophagus errabundus* Gravenhorst (Hymenoptera; Ichneumonidae). *British Journal of Entomology and Natural History* 16: 103–104.

Schaffner, U. 2002. Report on the chemo-ecological investigations of the host-selection behavior of the parasitoids of the lily leaf beetle. Internal CABI Bioscience Report. Delémont, Switzerland.

Scarborough, C. 2002. An investigation of the parasitoids of the lily leaf beetle, *Lilioceris lilii* (Scopoli) (Coleoptera: Chrysomelidae): A case study for biological control in North America. M.S. Thesis. University of London and the Diploma of Imperial College.

Schaffner, U. and M. Kenis. 1999. Host-selection behavior by natural enemies of the lily leaf beetle, *Lilioceris lilii* (Scopoli) (Coleoptera: Chrysomelidae). Internal CABI Bioscience Report. Delémont, Switzerland.

Schaffner, U. and C. Müller. 2001. Exploitation of the fecal shield of the lily leaf beetle, *Lilioceris lilii* (Coleoptera: Chrysomelidae), by the specialist parasitoid *Lemophagus pulcher* (Hymenoptera: Ichneumonidae). *Journal of Insect Behavior* 14(6): 739–757.

Schmitt, M. 2013. Fauna Europaea: *Lilioceris* Reitter, 1912. *Fauna Europaea version 2.6*, http://www.fauna-eu.org. Museum fur Naturkunde, Berlin.

Slate, G. L. 1953. Insects and other pests of lilies. *The Lily Yearbook of the North American Lily Society* 6: 21.

Stocker, C. 2002. Lilies losing battle against a new pest from Europe. Boston Globe 7/18/2002.

Tewksbury, L. 2014. Introduction and establishment of three parasitoids of the lily leaf beetle, *Lilioceris lilii* (Coleoptera: Chrysomelidae), in North America. PhD Dissertation. University of Rhode Island, Kingson, Rhode Island, USA.

Tewksbury, L., R. A. Casagrande, N. Cappuccino, M. Kenis. 2017. Establishment of parasitoids of the lily leaf beetle (Coleoptera: Chrysomelidae) in North America. *Environmental Entomology* 46(2): 226–236.

USDA Plants Database. 2021. https://plants.usda.gov [Accessed December 15, 2021].

Yu, P., W. Lu, and R. Casagrande. 2001. *Lilioceris lilii* (Scopoli) occurs in China (Coleoptera: Chrysomelidae). *Coleopterists Bulletin* 55(1): 65–66.