Establishment of Parasitoids of the Lily Leaf Beetle 
(Coleoptera: Chrysomelidae) in North America

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Subject Editor: James Nechols
Received 15 September 2016; Editorial decision 30 January 2017

Abstract
Three larval parasitoids were imported from Europe to control the lily leaf beetle, Lilioceris lilii Scopoli (Coleoptera: Chrysomelidae), an accidentally introduced herbivore of native and cultivated lilies in North America. Tetraastichus setifer Thomson (Hymenoptera: Eulophidae) was introduced in Massachusetts in 1999, and was found to be established there in 2002. Subsequent releases of T. setifer were made and two additional parasitoids, Lemophagus errabundus Szepligeti (Hymenoptera: Ichneumonidae) and Diaparsis jucunda (Holmgren) (Hymenoptera: Ichneumonidae), were introduced. The establishment and distribution of the three parasitoids was evaluated through 2016. Tetraastichus setifer is now established in Massachusetts, Rhode Island, New Hampshire, Maine, Connecticut, and Ontario, Canada. Lemophagus errabundus is established in Massachusetts and Rhode Island, and D. jucunda is established in Massachusetts, Rhode Island, Connecticut, and Maine. All three parasitoids have spread at least 10 km from release sites. The establishment of T. setifer is associated with a substantial reduction of L. lilii. In time it is likely that the parasitoids will spread throughout the North American range of L. lilii. This process can be accelerated to protect ornamental and native lilies by collecting and redistributing parasitoids to new infestations of L. lilii.

Key words: lily leaf beetle, Lilioceris lilii, Tetraastichus setifer, Lemophagus errabundus, Diaparsis jucunda

The lily leaf beetle, Lilioceris lilii Scopoli, was first reported in North America near Montreal, Canada, in 1943 (LeSage 1992). In 1992, the beetle showed up in several disjunct sites, including Cambridge, MA, apparently as a result of plant movement within North America and from Europe (Dieni et al. 2016). By 2000, the population spread throughout the northern New England states. (Fig 1). In the United States, populations now occur in all New England states, and through much of the Northeast, with localized populations in the upper Midwest and Washington State. In Canada, the beetle is widely distributed in the Maritime Provinces, Newfoundland, Quebec, and Ontario and is also established in Manitoba, Saskatchewan, and Alberta (Fig. 1). The beetle’s arrival in Manitoba, Canada, was attributed to plant movement (LeSage and Elliott 2003). The populations in Alberta, Canada (Cappuccino et al. 2013), Washington, and the Midwest were likely established in the same manner. Lilioceris lilii is present in Europe and Asia as far north as Siberia and to Morocco in the south (Slate 1953, Labeyrie 1963), and in China (Lu and Casagrande 1998, Yu et al. 2001). Based on the wide geographic and climatic range of the beetle’s native distribution, it is likely to establish across much of North America (Kenis et al. 2002).

Since its introduction into North America, L. lilii has become a serious pest of both native and cultivated lilies in the family Liliaceae (Livingston 1996, LeSage and Elliott 2003, Bouchard et al. 2008). Adult and larval feeding cause extensive defoliation of lily leaves, buds, and flowers (Ernst 2005). Infested lilies may survive for a few seasons, but without their aesthetic value, ornamental lilies are often removed because of this pest (LeSage 1992, Stocker 2002).

There are 26 native Lilium species in Canada and the United States; two are federally listed as endangered and 13 are listed as threatened or endangered in at least one state (USDA Plants Database 2017). The lily leaf beetle is univoltine, overwinters as an adult, and after initiating feeding in the spring, lays rows of eggs on the undersides of leaves. The larvae carry a fecal shield, which is believed to provide some defense against predators (Jolivet and Verma 2002, Keefover-Ring 2013) but is also used by parasitoids to locate their host (Schaffner and Müller 2003). Larvae complete four instars before pupating in the soil or leaf litter (Haye and Kenis 2004).

Lilioceris Reiter is a large genus with the greatest concentration of species found in China (Yu et al. 2001). Five species are reported in Europe (Schmitt 2013). Based on a study of the dynamics of the
known range of *L. lilii*, Orlova-Bienkowskaja (2013) suggests that the beetle could be native to Asia and was introduced into Europe about 400 years ago with ornamental lilies. From its discovery in North America in 1943 until 2011, *L. lilii* was the only species in its genus known in North America. However, in 2011, *Lilioceris cheni* Gressitt & Kimoto was introduced into Florida as a weed biological control agent for air potato, *Dioscorea bulbifera* L. (Center et al. 2013).

Three insects from the same subfamily as *L. lilii* (Criocerinae) were introduced into North America prior to *L. lilii*. The cereal leaf beetle, *Oulema melanopus* (L.), the common asparagus beetle, *Crioceris asparagi* (L.), and the spotted asparagus beetle, *C. duodecimpunctata* (L.), have been largely controlled by a complex of European parasitoids (Haynes and Gage 1981, Hendrickson et al. 1991, Evans et al. 2006, Poll et al. 1998), indicating good potential for successful biological control of *L. lilii*.

Prior to 1996, there was very little literature about parasitoids of *L. lilii*. Examination of North American populations revealed no native parasitoids and no predation (Livingston 1996). Early trials with the cereal leaf beetle egg parasitoid *Anaphes flavipes* (Forst.) showed that it could reproduce on *L. lilii* in Petri dishes but would not attack it in larger cages and did not establish in field plots (Livingston 1996). Lataste (1932) referred to an unidentified gregarious larval parasitoid in France, and *Lemophagus errabundus* (Gravenhorst) (Hymenoptera: Ichneumonidae) was reported from *Lilioceris merdigera* (L.) in France (Elliott and Morley 1911). These reports led to exploration in France and nearby European countries (Gold et al. 2001), resulting in the discovery of seven European parasitoids: one egg parasitoid, *Anaphes sp.* (Hymenoptera: Mymaridae), and six larval parasitoids: *Meigenia simplex* Tschorsnig & Herting (Diptera: Tachinidae), *Meigenia uncinata Mesnil* (Diptera: Tachinidae), *Tetristichus setifer* Thomson (Hymenoptera: Eulophidae), *Lemophagus errabundus*, *Lemophagus pulcher* (Szepigeti) (Hymenoptera: Ichneumonidae), and *Diaparsis jucunda* Holmgren (Hymenoptera: Ichneumonidae) (Gold et al. 2001, Kenis et al. 2002, Haye and Kenis 2004). In Europe, parasitism is common in lilies growing in gardens, and populations found on native lilies are particularly heavily parasitized (Gold et al. 2001, Haye and Kenis 2004). The discovery of these parasitoids led to European research on parasitoid distribution and biology (Kenis et al. 2002, Haye and Kenis 2004) and a series of experiments to reveal host specificity, including parasitism of sympatric field populations of other native *Lilioceris* species (*L. tibialis* and *L. merdigera*), host range testing with these congeneric species in Europe, laboratory tests of chemical ecology, and host range testing in quarantine, as summarized by Casagrande and Kenis (2004).

The dipteran larval parasitoids were rejected as potential biological control agents for *L. lilii* because they attack many other chrysomelid species, and the egg parasitoid was rejected because it needed unknown alternate hosts for overwintering (Haye and Kenis 2004). The remaining four parasitoid species were sent to the University of Rhode Island (URI) quarantine facility for host-specificity testing. *Lemophagus pulcher* was rejected as a biological control agent because, as initially indicated by European studies with sympatric populations of *L. lilii*, *L. merdigera*, and *L. tibialis* (Haye and Kenis 2004) as well as chemical ecology investigations (Schaffner and Müller 2001), this species lacks adequate host specificity. In quarantine, Gold (2003) found that *L. pulcher* attacked the North American native three-lined potato beetle, *Lema daturophila* Kogan & Goeden and the asparagus beetle *Crioceris asparagi* (L.). The three remaining parasitoids, *T. setifer*, *L. errabundus*, and *D. jucunda*, were found to be specific to the genus *Lilioceris* and all

![Fig. 1. Confirmed records for *L. lilii* in North America. (Lily Leaf Beetle Tracker 2016).](image-url)
were approved by USDA APHIS PPQ for field release (Casagrande and Kenis 2004).

_Tetrastichus setifer_ is a gregarious larval parasitoid described in 1978 (Graham 1991). This 3–4 mm univoltine parasitoid overwinters as mature larvae in host cocoons in the soil (Graham 1991). It is the most widespread parasitoid of _L. lilii_ in Europe, found from Bulgaria to the United Kingdom and Northern Germany to Italy (Kenis et al. 2002, Haye and Kenis 2004). This parasitoid is distributed in a broad range of climatic conditions in Europe from the maritime regions of northern Germany to the colder high altitudes of the Alps, descending into Italy. Based upon this distribution, we expect _T. setifer_ to survive in most of the current North American distribution of the lily leaf beetle.

*Lemophagus errabundus_, a 6–8 mm solitary, univoltine larval parasitoid, kills _L. lilii_ in the prepupal stage and overwinters as a teneral adult in the host cocoon (Haye and Kenis 2004). It is more prevalent in northern Germany, the Netherlands, western France, and Sweden, with parasitism rates reaching over 70% among late instars in these areas with ocean-moderated climates (Kenis et al. 2002, Haye and Kenis 2004, Rämert et al. 2009). It is also found in England (Salisbury 2003). Based upon this European distribution, we considered _L. errabundus_ to be climatically suited for establishment in coastal southern New England.

_Diaparsis jucunda_ was reported by Horstmann (1971) from Sweden, Finland, Denmark, Germany, and the Czech Republic. This solitary univoltine larval parasitoid, measuring 6–8 mm, attacks all instars of _L. lilii_. It is very common in native lilies (_Lilium martagon_ L.) in Switzerland (Kenis et al. 2002, Haye and Kenis 2004), and is the dominant parasitoid of _L. lilii_ in the colder, mountain areas of central and southern Europe. In Switzerland, parasitism averages 34% on cultivated lilies and 65% on wild lilies, with peaks over 90% in the last instar (Kenis et al. 2002, Scarborough 2002, Haye and Kenis 2004). Based upon the European distribution, _D. jucunda_ appears most adapted to the inland sites of New England and other cold areas of North America.

Surveys by Haye and Kenis (2004) revealed that throughout Western Europe a complex of parasitoids attacks _L. lilii_. Different parasitoids predominate in different regions, but more than one species is important at virtually all sites. We released all three parasitoids in New England, attempting to match our releases to each species’ climatic range in Europe (Haye and Kenis 2004). This document summarizes parasitoid releases, recoveries, establishment, and distribution from 1999 to 2016, and provides recommendations for facilitating establishment of lily leaf beetle parasitoids.

### Materials and Methods

#### Parasitoid Handling

Beginning in 1998, _T. setifer, L. errabundus_, and _L. pulcher_ were field-collected from many sites in Europe, predominantly in Northern Germany and Switzerland (Tewksbury 2014). _Lilioceris lili_ larvae of all stages were collected on cultivated lilies and wild _L. martagon_. Larvae were held in the laboratory at CABI, Delémont, Switzerland, at room temperature and fed lily leaves until pupation in vermiculite and emergence of adult _L. lilii_. The remaining parasitized pupae were held at 4°C in a growth chamber for a minimum of 2 mo before shipment to the University of Rhode Island in chilled insulated boxes. At the URI Insect Quarantine Laboratory, parasitoids were stored at 4°C and then moved to 25°C as needed for adult emergence. Emerged adult parasitoids were kept in 1.8-liter plastic jars in growth chambers under fluorescent lights with a photoperiod of 16:8 (L: D) h and a day: night temperature cycle of 20°C:15°C. Jars contained cotton wicks with honey water to provide water and food for the adult parasitoids, which were held for 3–4 d to allow mating. Prior to release, adult parasitoids were examined individually in the URI Insect Quarantine Laboratory to confirm identity, then packaged in vials and moved to the field plots in coolers.

#### Initial Parasitoid Releases

Following USDA and state approvals for _T. setifer_ release, primary release plots were established from 1999 through 2002. Initially plots measured 6 by 6 m and were planted with ~800 mixed, organically grown Asiatic and Oriental lily bulbs. These large plots (release sites 1–5 in Fig. 4) allowed for destructive sampling and use of

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**Fig. 2.** _Lilioceris lili_ larvae per stem at the Wellesley, MA, _T. setifer_ release site and Belmont, MA, control site and percent parasitism of fourth instars by _T. setifer_ in the release plot (right axis).
emergence cages to determine overwinter survival. However, the large plots were expensive to establish and maintain and were determined unnecessary for parasitoid establishment. Beginning in 2003, small release plots measuring 2 by 2 m were planted with 100 Asiatic lily bulbs. In 1998 and 1999, plots were covered with a 5 cm layer of cedar bark mulch. The first release plots were established in Massachusetts before the beetle spread to other states. Through 2003, *T. setifer* was released in five primary release sites, three plots in Massachusetts, and two in Rhode Island. (release sites 1–5 in Fig. 4). These primary release plots for *T. setifer* (and other parasitoids) were kept discrete: only one parasitoid species was released per plot and all release plots were at least 2 km distant.

Following USDA and state approval to release *L. errabundus* and *D. jucunda*, we established one primary release plot for *L. errabundus* in Rhode Island (release site 1 in Fig. 5). We also established two primary release sites for *D. jucunda* in Rhode Island (release sites 1–2 in Fig. 6). Male and female adult parasitoids were released on foliage infested with *L. lilii* in all plots. In addition to release plots, a control plot was established in 2000 in Belmont, MA, ~3 km distant from the nearest *T. setifer* release site (Gold 2003, Tewksbury 2014). All plots were monitored weekly from late May through early July using haphazard sampling to choose 40 lily stems in the larger plots and 20 stems in the smaller plots, and counting adults, eggs, and larval instars of *L. lilii* on each stem. We removed 20 fourth stage larvae (when available) for dissection to determine parasitism. When there was no evidence of establishment in individual plots, additional parasitoids were released as detailed in Tewksbury (2014). Between 1999 and 2006, we made 44 releases of *T. setifer* (11,503 adults), 28 releases of *L. errabundus* (817 adults), and 46 releases of *D. jucunda* (1,643 adults) into these plots. Details on release locations, dates, sources and numbers of parasitoids released are provided in Tewksbury (2014).

Parasitoid Redistribution

After documenting establishment of all three parasitoids in our release plots, *T. setifer* adults were released in 27 secondary release sites (primarily gardens) including three in Rhode Island, one in New Hampshire, four in Maine, two in Massachusetts, 16 in Connecticut (Fig. 4), and one in Ontario, Canada (Tewksbury 2014). In 2010, we shipped 88 *T. setifer* adults to Dr. N. Cappuccino who, having received a Canadian permit, released them into a (2 by 2 m) plot near Ottawa, Canada. We similarly distributed *L. errabundus* to one site in Middleboro, MA, and *D. jucunda* to two sites in New Hampshire, one in Maine and one additional site in Rhode Island (Figs. 5 and 6). Adult releases generally ranged from 50–150 for *T. setifer*, and 20–50 for the ichneumonids (as detailed in Tewksbury 2014). Adult parasitoids for these secondary releases were primarily from a laboratory colony generated by field-collecting larvae from sites where each parasitoid is established. Parasitized larvae were collected, reared until adult *L. lilii* emerged from cocoons made by unparasitized larvae, and the remaining parasitized cocoons were overwintered to allow for emergence and releases the following year.

Parasitoid Spread

In addition to sampling the release plots, we collected larvae from gardens in communities near release sites, dissecting them to determine parasitism. This technique was successful for Rhode Island release sites, but at more distant locations we found it difficult to locate gardens with lilies and secure permission for sampling them, so beginning in 2007, we enlisted the assistance of residents in sampling for parasitoids of *L. lilii*. These gardeners, contacted through Master Gardener training, local newspapers, and our web site, collected larvae and sent them to us for dissection. From 2007 to 2013, we received over 2,000 larvae from 240 home gardens in six states.
Fig 4. Tetrastichus setifer release and recovery sites in New England. Service Layer Credits: Esri, HERE, DeLorme, MapmyIndia, copyright Open Street Map Contributors, and the GIS user community.
Fig. 5. *Lemaphagus errabundus* release and recovery sites in New England. Service Layer Credits: Esri, HERE, DeLorme, MapmyIndia, copyright Open Street Map Contributors, and the GIS user community.
Fig. 6. *Diaparasis jucunda* release and recovery sites in New England. Service Layer Credits: Esri, HERE, DeLorme, MapmyIndia, copyright Open Street Map Contributors, and the GIS user community.
Results

*Tetrastichus setifer* Establishment

As documented in Gold (2003), the 1999 and 2000 releases of *T. setifer* in the Wellesley, MA, plot (Fig. 4, site 1) did not result in successful overwintering populations. Following a release of 100 adults, parasitism in 2000 peaked at 6%, with four parasitized larvae per 40 stems (~80 parasitized larvae in the plot). An initial release of 584 *T. setifer* in Cumberland, Rhode Island (Fig. 4, site 2), in 2001 resulted in a peak parasitism of 63.4%, with 28 parasitized larvae per 40 stems (~560/plt). However, as in Wellesley, there was no successful overwintering survival of the parasitoids until the following season when mulch was removed from the plot. Following mulch removal and release of additional adult parasitoids (810 in Wellesley and 1660 in Cumberland), Gold (2003) found successful winter survival of *T. setifer* in both the Wellesley and Cumberland plots. The mulch was never removed from a Waltham, MA, release plot (Fig. 4, site 2) and despite releases of 2,141 *T. setifer* adults into this plot from 2000–2002, *T. setifer* was never found to successfully overwinter in this plot (Tewksbury 2014). Parasitism of *L. lilii* was detected in the Wellesley plot through 2008 following the last release of *T. setifer* in 2001. During this period, beetle populations declined (Fig. 2) relative to the 3-km-distant control plot where no parasitoids were found until 2011, when both *T. setifer* and *D. jucunda* were recovered.

Similar results were observed in the *T. setifer* release plot in Cumberland, RI, where parasitoids were permanently established in 2002 (Fig. 3). In the release plot near Ottawa, Canada, *T. setifer* was recovered in 2011—the year after release (Cappuccino et al. 2013). Parasitism rates were 71.4% in 2013, 84.6% in 2014, and 87.5% in 2015.

Following establishment in Wellesley and Cumberland, *T. setifer* was recovered at varying distances from release sites (Fig. 4) as reported in detail in Tewksbury (2014).

*LEMOPHAGUS ERRABUNDUS* Establishment

Following the release of 129 adult *L. errabundus* in a 2 by 2 m Plainville, MA, plot in 2003, evidence of establishment was found in 2005 in a home garden 1.2 km from the release site. The parasitoid was subsequently found in a home garden 2.9 km from the release site in 2006 (Fig. 5). One home garden recovery site (4 km from the Plainville release site) experienced steadily increasing parasitism, from a peak of 9% in 2009, to 30% in 2010, 78% in 2011, and 94% in 2012. In 2013 there were no *L. lilii* larvae in this garden.

At the Kingston, RI, site, 353 parasitoids were released in 16 separate releases over 5 yr. We never recovered overwintered parasitoids from this plot (perhaps because of a pesticide legacy of this former apple orchard), but it appears that these releases resulted in local establishment of *L. errabundus*, as the parasitoid was recovered in six sites in Southern Rhode Island (Fig 5). The release site on Cape Cod (Fig. 5) was lost due to the owners’ decision to remove their lilies.

*DIAPARIS JUCUNDA* Establishment

Overwintered parasitoids were recovered for the first time in a home garden 4.8 km from the Cumberland, RI, release site in 2007, 4 yr after the first release at this site. Additionally, in 2007, *D. jucunda* was recovered from four home gardens near Orono, ME, one year after release in a nearby garden. The establishment and spread of *D. jucunda* from the first release in 2001, including recoveries until 2014, is shown with all release sites and all recovery sites in Fig. 6. In the last 3 yr of monitoring (2012–2014), there were as many recoveries of *D. jucunda* as in all previous years.

Parasitoid Spread

The spread of *T. setifer* is graphed in Fig. 7a using the date of first recovery for each of the recovery sites in Fig. 4. Most points in this figure result from submitted homeowner samples. These records may represent the first parasitoid arrival in an area, the first sample a homeowner sent to us, or even the first time a homeowner planted lilies. They merely indicate that the parasitoid was present in that garden at that time. Hence, the maximum values in Fig. 7a are probably most representative of the potential rate of parasitoid spread.

The highest points in this figure show that the maximum rate of spread is under 2 km per yr. This is consistent with Ontario releases where the maximum rate as of 2016 is 1.15 km per yr (Cappuccino, unpublished). The spread of *L. errabundus* is graphed in Fig. 7b using the date of first recovery for each of the recovery sites in Fig. 5. These homeowner samples have the same constraints as the *T. setifer* results and demonstrate the same dispersal potential: <2 km per yr. The spread of *D. jucunda* (Fig. 7c) indicates that this parasitoid can move as much as 4–5 km per year.

Discussion

Since its introduction into North America in 1943, *L. lilii* has experienced a familiar pattern of long-range redistribution with potted plants or bulbs and then a localized spread throughout each newly colonized area. Kenis et al. (2002) predicted that the beetle’s distribution would eventually encompass suitable habitats throughout all of North America, and this prediction may be accurate if *L. lilii* continues to expand its distribution. If this is the case, then the successful application of a classical biological control program early in the invasion of this introduced species could be an important tool in slowing the spread and reducing the severity of the invasion as it reaches new areas. It is also likely that a complex of parasitoids will be important for managing this pest in different climatic zones.

*Tetrastichus setifer*, the first parasitoid released in North America, appears to have the best chance of establishing throughout the North American range of *L. lilii*. European surveys show it to exist in a wide range of climatic conditions (Haye and Kenis 2004). In Sweden, *T. setifer* and *L. errabundus* are the most abundant *L. lilii* parasitoids (Rämmert et al. 2009). In the United Kingdom, *T. setifer* is found throughout the range of its host (Salisbury 2008). In North America, *T. setifer* has established in every state and province where released. It has spread at least 32 km from a release site and is associated with reductions in both *L. lilii* populations and damage to lilies as shown in the control study and anecdotally in many gardener’s reports (Tewksbury 2014).

*Lemophagus errabundus* is also established and spreading in North America. Unfortunately, loss of release and control plots on Cape Cod (Tewksbury 2014) has hampered our assessment of this parasitoid, but it is well-established and spreading at roughly the same rate as *T. setifer* in Rhode Island. Since this parasitoid is most prevalent in Europe in areas with ocean-moderated climates (Haye and Kenis 2004), we only made releases in Rhode Island and Cape Cod. Hence, we are unsure if it is capable of establishing in colder climates. It is possible that in North America *L. errabundus* may have a greater impact on *L. lilii* than it does in Europe, because it was introduced without its hyperparasitoid, *Mesochorus lilicerciphilus* Schwenke, which is very common in the United Kingdom, Sweden, and most of Europe (Haye and Kenis 2004, Salisbury 2008, Rämmert et al. 2009).

*Diaparsis jucunda* is the dominant parasitoid found in native lilies in mountainous sites in Switzerland and in colder areas of central
and southern Europe (Haye and Kenis 2004). For this reason we primarily released *D. jucunda* in more northern or inland sites of New England. In more southern releases of *D. jucunda*, we did not detect parasitism until 4 yr after release, but in our northern Maine releases we found successfully overwintered parasitoids the year following release. *Diaparsis jucunda* is now established in Massachusetts, Rhode Island, Connecticut, New Hampshire, and Maine.

It is clear that all three parasitoids are established but they are expanding their distributions fairly slowly, which may in part be due to the patchy distribution of lilies. Most home gardeners have small numbers of lilies, and the distance between gardens might exceed the dispersal abilities of the wasps. Native lilies have a similar patchy distribution. This distribution is similar to that in Europe where the parasitoids are widely distributed in gardens. Thus, in

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**Fig. 7.** Spread of *T. setifer*, *L. errabundus*, and *D. jucunda*: distance from closest release site (km) plotted against year of first recovery after initial parasitoid release.
time it is likely that the parasitoids we have released will spread throughout the range of *L. lilii* in North America, but how long might this take? The parasitoids have become well-established in the area between southern Rhode Island and Boston and show good potential for providing control of *L. lilii*. However, this area is a tiny portion of the current distribution of *L. lilii* and this pest is spreading rapidly. This raises the question of how rapidly the parasitoids can spread on their own and to what extent their spread will need to be supplemented by additional releases. Distance from release sites given in Fig. 7 indicates potential spread for each new positive recovery. The results for *T. setifer* and *L. errabundus* are quite similar, with a maximum on the order of 1.5 km per year. The results for *D. jucunda* are much more variable, possibly because of the greater N–S gradient of release sites, but also more encouraging because they show a potential for spread on the order of 4–5 km per year.

To date, rearing and release of agents has been done through URI at a fairly small scale. As the beetle spreads into more states and provinces, there may be interest in a larger program of collecting and redistributing, or rearing of all three parasitoids. The cereal leaf beetle biological control program of the 1970s provides precedent for distribution of the three cereal leaf beetle parasitoids (*T. julis*, *D. temporalis*, and *L. curtus*), close relatives of our three agents. This program used large field plots to produce cereal leaf beetle larvae and county agents were brought in for field days to successfully redistribute parasitized larvae throughout the state (Haynes and Gage 1981). This program also benefited from a USDA parasitoid rearing laboratory in Niles, MI, which distributed parasitoids throughout the infested states (Haynes and Gage 1981). The cereal leaf beetle was considered a major threat to US agriculture and the biological control program was a well-funded priority of the USDA. With limited funding for lily leaf beetle, no major parasitoid redistribution programs have been initiated. The cost and shortage of organic lily bulbs is an important issue: at $0.50 US per bulb it costs about $11.00 per square meter just for the bulbs to establish a rearing plot. We have worked our procedures for laboratory rearing, but it is also quite expensive.

As the parasitoids further increase their distribution and abundance, it is possible that their rate of spread will increase, beyond the rate of 1.5 to 5 km/yr observed to date. Releases made at 16 sites spread throughout Connecticut in the past two seasons should add considerably to our knowledge of parasitoid spread and also to the optimal numbers of parasitoids to release per site. To date, we have focused on parasitoid establishment and likely released more agents at a time than necessary. For instance, the release of only 88 *T. setifer* adults resulted in establishment in Ontario (Cappuccino et al. 2013) as did the 29 adults released in Waterbury, CT, in 2012. Based upon these results, it seems that releases of 50 female *T. setifer* into a plot of 20–50 infested lilies is adequate for establishment. In contrast, many releases of large numbers of the ichneumonid parasitoids did not result in establishment. Pre-emergence mortality of *D. jucunda* increases with parasitism rate, both in the field and in the laboratory; i.e., when parasitoid females are abundant and oviposited frequently in the same host larva, this larva dies without allowing parasitoid development (M.K. and N.C., unpublished data). Thus, the releases of large numbers of parasitoid females at small, isolated spots likely resulted in high mortality. Releases of 10–20 mated females in plots of at least 20 infested lilies now seems to be the best strategy for establishing *L. pulcher* and *D. jucunda*.

The popular practice of mulching lilies in the garden may inhibit parasitoid establishment. Unlike lily leaf beetle adults which can fly to suitable overwintering habitats, all three parasitoids overwinter as immature larvae or pupae within their host cocoon, directly under host plants. Parasitized larvae that fall on mulch may not go deep enough to be sufficiently protected from cold, dessication, and predation. Gold (2003) suggested that our initial establishment efforts with *T. setifer* benefited from the removal of mulch from the plot. This may also be one explanation for the continued prevalence of persistent *L. lilii* populations in many home gardens in Cumberland, RI, after 10 yr of *T. setifer* establishment. All three parasitoids we have released are also present in Sweden, but *L. lilii* still causes significant damage to lilies. It has been suggested that cultivation practices, use of mulch, and the practice of fall digging and spring replanting of bulbs may negatively impact parasitoid success in Sweden (Kamert et al. 2009, Kroon 2009). Experiments on the impact of mulching on parasitoid populations would be useful in developing management recommendations to enhance biological control. Insecticides provide another complication in biological control of *L. lilii*. Following a colony loss due to systemically treated bulbs, we have used organically produced lily bulbs in our rearing program for over a decade. Gardeners who wish to encourage parasitoid establishment should consider this as well as it is difficult to determine whether new bulbs have been treated.

Establishment may be easier to achieve on wild lilies, which are also infested by the beetle (Bouchard et al., 2008). In Europe, parasitism by the same three parasitoids is much higher on wild lilies than on cultivated lilies (Haye and Kenis 2004). Consequently, wild lilies usually experience lower damage and outbreaks of shorter duration that cultivated lilies. The establishment of the three parasitoids in North America may eventually be more beneficial for wild lilies than for cultivated lilies because parasitism may lower the damage by the beetle to a level that is harmless for the reproductive capacities of wild lilies but still unacceptable for ornamental growers. It will be important to study the impact of *L. lilii* on wild lily populations. Many lily species are listed as rare, vulnerable, threatened, or endangered by various US states (USDA Plants Database 2017) and populations may not survive heavy and permanent defoliations by *L. lilii*. Furthermore, since the only US federally listed endangered lily species (*Lilium occidentale* Purdy) and sub species (*Lilium parudatum* Kellogg subsp. *pitkinense* [Beane & Vollmer] M.W. Skinner) occur in Western USA, it is important to consider introducing the parasitoids into Washington State, where the beetle is already established, before it reaches the few spots where the endangered taxa occur.

We have established in North America the three host-specific parasitoids that are most commonly found attacking lily leaf beetle populations in Europe. Based upon research conducted to date, we believe they have potential to manage this pest in North America and we encourage further work on parasitoid redistribution and subsequent management. As the parasitoids spread throughout North America, there will also be an opportunity to compare the distribution of these three species to the distributions found in Europe. Documentation of this program will provide additional knowledge about the use of multiple parasitoids for management of an introduced insect.

**Acknowledgments**

Foundational work for this study was conducted by Sayles Livingston, Marion Gold, Heather Faubert, and many students at URI, with GIS assistance from Max Ragozzino and Kevin Lamothe, as well as Urs Schaffner, Tim Haye, Claire Scarborough, and Caroline Müller at CABl and Chelsey Blackman at Carlton University, Ottawa, ON. We acknowledge financial support from the North American Lily Society, White Flower Farm, New York, the Port of New York Authority, White Flower Farm, New York, the Port of New England, White Flower Farm, New Hampshire, the Port of Long Island, White Flower Farm, New York, and the USDA. We thank Jack Huth for his generous assistance with field work, and spreadsheets and GIS data and analysis.

**References**


Hampshire Plant Growers Association, USDA-NE Region Integrated Pest Management Grant Program, and USDA National Institute of Food and Agriculture, Hatch project 5452, 1/5/17.

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