SELECTION AND IMPORTATION OF EUROPEAN PARASITOIDS FOR THE BIOLOGICAL CONTROL OF THE LILY LEAF BEETLE IN NORTH AMERICA, AND PROSPECTS FOR CONTROL IN EUROPE

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INTRODUCTION

The lily leaf beetle, *Lilioceris lilii* Scopoli, occurs throughout Eurasia, from Siberia to Morocco and from the United Kingdom to China. It was first found in North America near Montreal in 1945 (LeSage, 1992) and was officially reported in Boston, Massachusetts, in 1992 (Livingston, 1996). The beetle now occurs in Quebec, Ontario, Nova Scotia, Manitoba, and several New England States, and–based on its Eurasian geographic distribution–it seems capable of spreading throughout the North American continent. Over the past few years, it has become an important pest of native and cultivated lilies and fritillaria in North America (Gold *et al*., 2001). In Europe, the beetle is well known, but rarely attains outbreak densities, except in Holland and Great Britain, where severe damage is observed in parks and gardens (Cox, 2001; C. Conijn and A. Salisbury, personal communication).

Adults overwinter in the litter and start to feed when the first lily leaves are found. Eggs are laid on the underside of leaves, from April on. The four larval instars, covered by a thick fecal shield, feed on leaves for two to three weeks. The mature larva then builds a cocoon in the soil, in which it pupates. New adults emerge in summer and feed for a few weeks before entering the overwintering sites. There is usually only one generation per year, but adults can lay eggs from April through August (Fox-Wilson, 1942; Livingston, 1996).

In 1996, a biological control program was initiated at the University of Rhode Island (URI). In 1998, a joint program was set up between URI and the CABI Bioscience Switzerland Centre. This paper summarizes the biological control program carried out at URI and CABI until 2001.

SURVEYS FOR PARASITOIDS IN EUROPE

Until the beginning of this study, very little was known from the literature about natural enemies of the lily leaf beetle. Nothing was reported from North America. Lataste (1932) mentioned a gregarious larval parasitoid in France. Other members of the subfamily Criocerinae are known to be heavily parasitized by egg and larval parasitoids (Cox, 1994) and some, such as the cereal leaf beetle (*Oulema melanopus* [L.]) and two asparagus beetles (*Crioceris asparagi* [L.]) and *C. duodecimpunctata* (L.), have already been the targets of successful biological control programs (Hendrickson *et al.,* 1991; Barbosa *et al.,* 1993).

Surveys were started in France in 1996 (Gold *et al.,* 2001) and were conducted throughout Europe, on cultivated lilies, during the seasonal period of occurrence of the beetle. In Switzerland and Germany, more intensive collections were carried out, throughout the year and in various habitats, i.e., in gardens, in commercial lily fields, and on the wild lily, *Lilium martagon* L. (Haye, 2000). Over 1,000 eggs, 30,000 larvae, and 1,000 adults were collected and reared in the laboratory for parasitism. Seven parasitoids and hyperparasitoids were obtained from surveys in Europe, one from eggs and six from larvae (Haye, 2000, Gold *et al.,* 2001).

BIOLOGY, ECOLOGY, AND DISTRIBUTION OF EUROPEAN PARASITOIDS

Anaphes sp. (Hym.: Mymaridae) was reared from lily leaf beetle eggs, but collected exclusively from forested areas. It is a gregarious species with up to seven individuals emerging per host egg. *Anaphes* sp. is an undescribed, multivoltine species which overwinters in an unknown host species. It is not suitable for classical biological control because it is not specific and needs alternate hosts to complete its development.

Tetrastichus setifer Thomson (Hym.: Eulophidae) is a gregarious parasitoid that attacks all four larval stages and kills its hosts in their cocoons in the soil. It is strictly univoltine and overwinters in the larval stage in the host cocoon. Up to 21 adults emerge in spring from each *L. lilii* host larva. The emergence is protracted, with individuals from the same brood emerging over several weeks. It was the most widespread species encountered, occurring in all regions investigated, from Bulgaria to the United Kingdom and from northern Germany to Italy.

Diaparsis jucunda Holmgren (Hym.: Ichneumonidae) is a solitary, univoltine, larval parasitoid, attacking all larval stages and killing the prepupa in the host cocoon, and then overwintering as a larva. It is the dominant parasitoid in central and southern Europe (e.g., Switzerland, Austria, and Italy), especially on wild lilies. In contrast, it is nearly absent from western and northern Europe.

Lemophagus errabundus Gravenhorst (Hym.: Ichneumonidae) is also a solitary, univoltine, larval parasitoid killing the beetle in the pre-pupal stage. It overwinters as a teneral adult in the host cocoon. It replaces *D. jucunda* as a dominant parasitoid in western and northern Europe (United Kingdom, The Netherlands, western France, and northern Germany), but it is rare elsewhere.

Lemophagus pulcher (Szepligeti) is similar to the previous species, except that it is partly bivoltine. About 30-40% of the individuals emerge for a second generation, both in laboratory and outdoor rearing. It is a very widespread species, occurring in nearly all regions investigated (except the United Kingdom), but dominates only in Bulgaria. Both Lemophagus spp. are parasitized by an ichneumonid hyperparasitoid, *Mesochorus lilioceriphilus* Schwenke.

Meigenia sp. (Dipt.: Tachinidae) was occasionally reared from lily leaf beetle larvae collected in Germany, France, Switzerland, and Bulgaria. The specimens from France were identified as *Meigenia simplex* Tschorsnig and Herting.

Parasitism rates were usually very high. In Switzerland in 1999, total parasitism in the last instar averaged about 60% in cultivated lily fields, 75% in gardens, and 90% on the wild lily *L. martagon*. At natural sites, the parasitoid guild was strongly dominated by *D. jucunda*, which accounted for over 90% of the parasitoids reared. The same species also dominated in gardens and commercial fields in the first part of the season, but was later replaced by *T. setifer* and *L. pulcher*, the former due to its protracted emergence period, and the latter because of a partial second generation (Haye, 2000).

HOST SPECIFICITY

Host specificity of the four main larval parasitoids was assessed using two methods. First, data were gathered from the literature and our own collections on the parasitoid complexes of closely related Criocerinae species in Europe. Second, laboratory screening tests were run on potential non-target species (Gold, Haye and Kenis, unpub.).

None of the four main larval parasitoids had been recorded from any other host in Europe before this study, with the exception of *L. errabundus*, reported from *Lilioceris merdigera* (L.) in France (Elliott and Morley, 1911). The well studied cereal leaf beetle (*O. melanopus)* and the aspara-

gus beetles (*C. asparagi* and *C. duodecimpunctata*) are three Criocerinae with similar biologies to that of the lily leaf beetle that also have very similar parasitoid complexes. These complexes, however, are made up of different species in the genera *Tetrastichus*, *Diaparsis,* and *Lemophagus* (Dysart *et al*., 1973; Hendrickson *et al*., 1991). Two other species of *Lilioceris* occur in central Europe: *L. merdigera*, a common species feeding on other Liliaceae of the genera *Polygonatum*, *Convallaria*, and *Allium*; and the rare *Lilioceris tibialis* (Villa) found on *Lilium* spp. at high altitudes in the Alps. Since almost nothing was known of the parasitoids of these two species, collections were made in regions where the three species occurred sympatrically, and their respective parasitoid complexes were compared. Studies showed that all three beetles were attacked by the same four parasitoids, but proportions varied dramatically. Parasitism in wild populations of *L. lilii* was strongly dominated by *D. jucunda*, which was rare on *L. tibialis* and nearly absent from *L. merdigera*. This latter species was mainly parasitized by *L. pulcher,* whereas parasitism in *L. tibialis* was dominated by *T. setifer*, with the two species of *Lemophagus* being occasionally abundant.

No-choice screening tests were run with the four parasitoids under study on nine other Chrysomelidae (including the two *Lilioceris* spp., four other Criocerinae, two Chrysomelinae, and one Gallerucinae) and three species of Coccinellidae. The four parasitoids attacked and developed in *L. merdigera* and *L. tibialis* but showed no interest in the other species offered to them. In contrast, *L. pulcher* parasitized successfully two other criocerine species, *C. asparagi* and *Lema trilineata* Olivier.

CONCLUSIONS–CLASSICAL BIOLOGICAL CONTROL PROGRAM

Parasitism of the lily leaf beetle is very high in Europe, and damage is usually much lower than in North America, suggesting potential for biological control. Four larval parasitoids can be locally, or temporally, abundant. Three of them seem specific at the genus level. Since no species in the genus *Lilioceris* are native to North America, nor are there any other North American species of Criocerinae that feed on the genera *Lilium* or *Fritillaria,* these three parasitoid species are all suitable for introduction in North America. A combination of at least two species is probably desirable because each of them seems to have different ecological or climatic preferences. Furthermore, the three parasitoids cover different periods in the season, *D. jucunda* and *L. errabundus* occurring earlier than *T. setifer*, which emerges later but remains longer in the field and parasitizes late-occurring larvae in summer.

Over 3,000 females of *T. setifer* were released in the summer of 2001 in Massachusetts. Investigations are presently being completed to allow the selection of an additional species for introduction.

POTENTIAL FOR OTHER BIOLOGICAL CONTROL STRATEGIES

Other biological control strategies for lily leaf beetle are presently being considered, in particular for countries in Europe that suffer from lily leaf beetle damage, such as the United Kingdom and The Netherlands. Plowing and removal of bulbs before winter has a detrimental effect on the survival of parasitoids, which overwinter in host cocoons at the bottom of the stems. Covering the soil with mulch in autumn instead of removing bulbs would help conserve parasitoids in gardens. Augmentative biological control might also be considered, using the egg parasitoid *Anaphes* sp., in particular in commercial lily fields. *Anaphes* sp. is usually present only in forests, most likely because its alternate hosts are forest species. However, since this parasitoid is multivoltine and has a very short life cycle, it could be released in commercial fields at the beginning of the season and maintain itself until late summer. For this to be possible, however, proper rearing and production techniques would have to be developed.

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