CONSERVATION OF LEAFROLLER PARASITOIDS THROUGH PROVISION OF ALTERNATE HOSTS IN NEAR-ORCHARD HABITATS

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INTRODUCTION

Leafrollers are common pests of pome fruits throughout the world. In the northwest United States, damage from leafrollers has been exacerbated by increased resistance to some pesticides and reduced mortality of leafrollers in orchards switching from pesticide-based control of codling moth (*Cydia pomonella* [L.] Lepidoptera: Tortricidae) to the use of mating disruption (Knight, 1995; Gut and Brunner, 1998). The leafrollers *Choristoneura rosaceana* (Harris) and *Pandemis pyrusana* Kearfott (Lepidoptera: Tortricidae) are consistent pests in orchards in the northwestern United States, causing up to 25% damaged fruit in some situations. Both of these leafrollers are bivoltine species with late spring and summer flight peaks. They both overwinter as second and third instars and are native to North America (Beers *et al*., 1993; Brunner and Beers, 1996). These leafrollers are both attacked by many of the same species of parasitoids. The parasitoids commonly recovered from these leafrollers in Washington orchards include two eulophids (*Colpoclypeus florus* Walker and *Sympiesis* sp.), two tachinids (*Nemorilla pyste* Walker and *Nilea erecta* Coquillet), and several braconids (*Apanteles* sp., *Macrocentrus* sp., and *Oncophanes americanus* Weed). Parasitism of leafrollers in some locations of central Washington can be high, with rates in the summer generation sometimes exceeding 95% (Brunner, 1996). The dominant parasitoid in most instances in which parasitism exceeds 60% has been *C. florus*, a gregarious ectoparasitoid of leafrollers from Europe that has recently established in Washington, possibly as a result of releases in Canada (Brunner, 1996). Despite high levels of parasitism of leafrollers in the summer generation, in most areas economic control has not occurred because parasitism in the spring generation is usually quite low. Both *C. rosaceana* and *P. pyrusana* are suitable hosts for *C. florus* for relatively short periods during the late spring (late April to the end of May) and again in summer (July). About six *C. florus* generations per year are possible, based on laboratory studies. However, there are no suitable hosts in orchards between generations of these two leafrollers in June and again for an extended period in the fall. In particular, the extended host-free period in the fall may pose a problem for *C. florus* because this species diapauses as large larvae on suitable hosts and suitable hosts are not available near many orchards at this time.

Parasitism of leafrollers in central Washington orchards may be integrally linked to nonorchard habitats containing alternate hosts. The eulophids *C. florus* and *Sympiesis* sp. and the braconid *O. americanus* all overwinter on leafroller species that do not occur in orchards. The tachinids attacking these leafrollers, *N. pyste* and *N. erecta*, may overwinter outside of orchards (they do not overwinter on pest leafrollers in orchards), but where they overwinter and on what hosts is uncertain. All of these parasitoids attack medium-to-large hosts. Because all of these parasitoids depend on alternate hosts, particularly for overwintering, their effectiveness in orchards may be limited by the local availability of alternate hosts. Provision of alternate hosts in near-orchard habitats might increase subsequent parasitism and control of leafroller pests in orchards. Unfortunately, the alternate hosts that support overwintering were unknown in Washington for all of these parasitoids as of 1996.

Colpoclypeus florus has been studied in Europe for several decades, yet in much of Europe its overwintering hosts remain unidentified (Evenhuis, 1974; Gruys, 1982; Evenhuis and Vlug, 1983; Gruys and Vaal, 1984) or only hypothesized (Blommers *et al*., 1988). Diapausing *C. florus* have been collected in Italy attacking *Argyrotaenia pulchellana* Thunberg (Lepidoptera: Tortricidae) (Dalla Montà and Gambaro, 1973). Surveys were conducted in Washington beginning in 1996 to identify the overwintering hosts for *C. florus* in Washington. Three overwintering hosts for *C. florus* have since been identified that occur in the riparian areas of eastern Washington. The most important alternate host in Washington appeats to be *Ancylis comptana* (Froelich) (Lepidoptera: Tortricidae), the strawberry leafroller, which feeds on a wild rose, *Rosa Woodsii* Lindl. (Rosaceae), that is common in the riparian areas of eastern Washington. *Ancylis comptana* is of European origin and has previously been reported as a host for *C. florus* in Italy (Gambaro, 1971; Dalla Montà and Gambaro, 1973) and may serve as an overwintering host there. In Washington, *A. comptana* is bivoltine and becomes suitable for parasitism by *C. florus* during a short period in late June and then again in late September and October as larvae of *A. comptana* enter diapause. Both periods of suitability by *A. comptana* occur during periods when there are no suitable hosts for *C. florus* within orchards. Therefore, *A. comptana* could act as an important alternate host both for bridging the period between orchard leafroller generations within the season as well as providing a critical overwintering host for *C. florus*.

In 1999, we began to study the relationship of parasitism of leafrollers in orchards to the availability of nonorchard habitats containing alternate hosts, particularly roses infested by *A. comptana*. Our studies have included examination of the effects of locally high densities of *A. comptana* on parasitism in nearby orchards, patterns of leafroller parasitism in large areas of mixed orchard types (>200 ha) relative to nearby riparian areas, and manipulations of near-orchard habitats in an attempt to increase parasitism of leafrollers in orchards by *C. florus*.

MATERIALS AND METHODS

Parasitism was evaluated using third instar *P. pyrusana* as sentinel larvae placed on potted apple trees (cv. "Red Delicious"). The apple trees were one to three years in age and were maintained in drip-irrigated 19-liter pots at the Yakima Area Research Laboratory (Wapato, Washington, U.S.A.). The trees were placed into field sites when parasitism was to be determined. Sentinels were placed on the foliage, and trees were left in the field for two to three weeks. After exposure, all larvae were collected and reared in the laboratory to determine parasitism rates.

Rose Patches

The role of rose patches infested by high densities of *A. comptana* on parasitism of leafrollers in nearby orchards was examined at two locations. Sentinel larvae were used to monitor parasitism along two transects at each location. Groups of four to six potted trees were placed at three to six sites along each transect and each tree was infested with 10 sentinel larvae. Sites along these transects were infested six times each year at 3- to 4-week intervals. One rose patch was adjacent to the Washington State University orchards at Columbia View about 10 km north of Wenatchee, Washington. The second site was Ahtanum ridge about 3 km south of Yakima, Washington. The rose patch at Columbia View was about 30 × 40 m and about 70 to 100 m from the nearest orchard with a large windbreak at the edge of the orchards. The roses at Ahtanum consisted of several 5 × 15 m patches with each about 5 m from the orchard edges. The Columbia View site was evaluated in 1999 and 2000, and the Ahtanum site was evaluated in 2001.

Landscape Patterns

Two large areas were selected to examine landscape patterns of leafroller parasitism in an area of mixed orchard production. The landscape in these areas was dominated by apple and pear orchards but also included cherry, apricot, and peach orchards. The Parker orchard area encompassed 234 ha and Wapato about 425 ha. There was about 2 km separating the two areas. Both areas were bordered on the southwest by an interstate highway, the Yakima River, and associated riparian habitats. To the north and east, the areas were bordered by seasonal grassland (primarily cheatgrass, *Bromus tectorum* L., Poaceae). *Ancylis comptana* has been found in the riparian habitats near these areas but in barely detectable numbers (10 individuals collected from 1998 to 2000). Therefore the background density of suitable overwintering hosts for parasitoids (especially *C. florus*) in this region appears to have been low. Numerous sites were selected (60 – 130 depending on the year and the date) for the deployment of sentinel larvae in apple, pear, and cherry blocks within both areas. Groups of four to six potted trees were placed at each site, and 10 (1999) or 20 (2000) sentinel larvae were placed on the foliage of each tree. Potted trees were placed into orchards and infested three times each year. Sentinel larvae were deployed when the larvae of the overwintering generation would be suitable (May), when the summer larvae would be suitable (July), and again in the fall (September) to determine the fall distribution of parasitoids. Only the Parker area was sampled during the fall of 1999.

Manipulations

At each of the two areas used for the large-scale landscape studies (Parker and Wapato), two locations were selected for habitat manipulation through the addition of a patch containing roses and strawberries. Each patch was then infested with *A. comptana,* the alternate host for *C. florus*, to allow local overwintering by *C. florus* and potentially an increase in parasitism of orchard leafrollers the following spring. No *C. florus* had been previously been recovered at any of the four locations chosen for manipulation during the periods when leafrollers would normally be suitable (May and July1999 or spring 2000). However, *C. florus* was commonly observed near these sites during the fall of 1999 when natural hosts were not available. The four sites were 412 to 1,975 m (mean=1,455 m) from the nearest riparian habitats possibly containing alternate hosts. At each of these locations a 5 × 15 m garden plot was established with each 5 × 5 m end section planted with locally collected roses (*Rosa woodsii* Lindl.) and the center 5 × 5 m section planted with strawberries (cv. Quinault). Each of these gardens was infested with a combination of laboratory-reared and field-collected *A. comptana* larvae during July and August 2000. New transects were established to evaluate parasitism of leafrollers relative to distance from these new habitats containing suitable alternate hosts. A small subset of the sites used in the landscape study in 1999 and 2000 were sampled again in 2001 to allow control comparisons of post-manipulation data with the data from previous years. These sites were sampled during spring 2001 until most orchards near the plots were sprayed with organophosphate insecticides to control an outbreak of codling moth.

RESULTS

Rose Patches

Populations of *A. comptana* on nearby wild roses provided an overwintering host for *C. florus* at both the Columbia View and Ahtanum sites. However, there were significant differences between the sites in the pattern of parasitism by *C. florus* in nearby orchards. At the Columbia View site, low parasitism (under 20%) by *C. florus* was observed on orchard leafrollers in the spring generation. However, parasitism rates were much higher on the summer leafroller generation in the Columbia View orchards. Parasitism near the Columbia View rose-patch increased from less than 20% in spring to more than 90% in summer soon after *C. florus* began emerging from *A. comptana* in early July, in both 1999 and 2000. We infer that *A. comptana* acted as a bridge between orchard leafroller generations at the Columbia View site. Also, the occurrence of parasitism of leafrollers in orchard blocks more distant from the rose patch was delayed in comparison with the closer orchard blocks. At the Ahtanum site, parasitism by *C. florus* in nearby orchards was over 90% during the early spring and remained high (but variable) throughout the season. In spring, parasitism was higher in the orchard sites close to the rose patch and declined slightly at the more distant sites. In late spring and summer, parasitism was uniformly high (over 50%) and unrelated to distance from the rose patch.

Landscape Patterns

Parasitism was low in both the Parker (1.0%) and the Wapato (6.6%) areas during the first leafroller generation in 1999. Tachinids (primarily *N. erecta*) dominated the parasitoids recovered, especially at Wapato. Spatial distribution of parasitism was unrelated to proximity to riparian areas in the spring, but *C. florus* was recovered from only one area in Wapato near riparian habitats. During the summer generation, parasitism increased at both sites. This increase was substantial at in the Parker area (from 1.0 to 34.5%), but was marginal in the Wapato area (from 6.6% to 11.5%). Overall parasitism in the summer was dominated by tachinids in the Wapato area and showed no apparent relationship to riparian areas. There was an increase in parasitism of leafrollers by *C. florus* and *O. americanus* in riparian areas and orchards near riparian areas in the Parker area. In the fall, parasitism of sentinel leafrollers in orchards of both areas approached 100%. In fall, *C. florus* and *O. americanus* had distributed themselves throughout the Parker area despite the absence of naturally occurring hosts in suitable life stages for parasitism. This dispersal into areas lacking suitable hosts included those orchard blocks most distant from riparian areas, which was surprising given that no parasitism by *C. florus* or *O. americanus* was detected in these locations in spring or summer.

In 2000, spatial and species patterns of parasitism were similar to those observed in 1999. Parasitism was relatively low in the spring (23.4% at Parker and 24.1% at Wapato) and was dominated by tachinids at Wapato and an *Apanteles* sp. at Parker. Parasitism by both species was spatially independent of riparian areas. During the summer, parasitism increased to 34.3% at Parker and to 41.5% at Wapato, with tachinids making up the majority again. There was also a slight increase in leafroller parasitism in orchards near riparian areas by *C. florus* and *O. americanus*. Unlike 1999 and previous years, parasitism by *C. florus* increased only slightly in the summer (0.8% at Parker and 2% at Wapato). Parasitism in one block within the Parker area had been followed almost continuously since 1996 and the parasitism by *C. florus* in the summer of 2000 was lower than it had been in any year since 1996. As in 1999, in September, *C. florus* was found parasitizing sentinel hosts throughout the Parker and Wapato areas with high parasitism by tachinids as well (96.3% total parasitism at Parker and 97.5% at Wapato). Again, C. *florus* was common in the fall in areas distant from riparian sites that may harbor alternative hosts. The parasitoid species reared from the sentinel larvae shifted significantly from tachinids strongly dominating in the summer at both sites to *C. florus* dominating at Parker and appearing codominant with tachinids at Wapato in the fall.

Manipulations

During the summer of 2000, populations of *A. comptana* were established at three of the four garden plots. At one of the garden sites in the Wapato area, the strawberries and roses did poorly due to a water shortage and we were unable to establish *A. comptana*. At the three sites where *A. comptana* successfully established, the density of overwintering larvae varied from 2 to 47 larvae / m^2 in February 2001 (based on six 0.25 m^2 absolute samples). Parasitism of these diapausing *A. comptana* larvae by diapausing *C. florus* ranged from 10 to 33%. The following spring (2001), parasitism of leafrollers placed in or adjacent to these gardens by *C. florus* ranged from 40 to 100% at locations where parasitism had not been observed the previous spring. At the garden site where *A. comptana* was not established, there was no increase in parasitism by *C. florus* in the spring of 2001.

DISCUSSION

Orchards near naturally occurring rose patches containing high densities of *A. comptana* exhibited high levels of parasitism of sentinel *P. pyrusana* by *C. florus*. At Ahtanum parasitism was high in spring, and at both Columbia View and Ahtanum parasitism was high in the summer leafroller generation. Topography may partially explain these differences. At Columbia View, the closest orchards trees were about 100 m from the rose patch and the orchard was bordered by a windbreak and was about 30 m uphill of the rose patch. At Ahtanum, the orchards were about 5 to 10 m from the nearest roses, which were on a hillside and only about 10 m above the orchards. Both distance and the windbreak at Columbia View may have inhibited colonization of the orchards by *C. florus* in spring, when temperatures were cool and dispersal may be more difficult. At both sites, parasitism was lower on sentinel larvae distant from the rose patch than on larvae deployed closer to the roses. Both the relationship of parasitism with distance from rose patches and low parasitism in many orchards without nearby rose patches support the importance of rose patches as habitats for alternate hosts habitats.

In the landscape areas studied in 1999 and 2000, tachinids were the dominant parasitoids, but there was no geographic association between tachinid parasitism and riparian areas. Parasitism rates by *C. florus* and *O. americanus* were low during spring in 1999 and 2000 and increased near riparian areas in the summer, although only slightly in 2000. Patterns of parasitism at the landscape scale in an area where *A. comptana* was rare suggested that some parasitoids moved into orchards from riparian areas near orchards in the second generation (or possibly in the first generation in numbers too low to detect) and reproduced there. But these parasitoids (including *C. florus*) did not dramatically increase in density until the summer when *C. florus* may complete two generations during the summer leafroller generation. The tachinids, with much broader host ranges than the hymenopteran parasitoids recovered, parasitized more leafrollers in most areas during spring and summer. Even though some *C. florus* moved into orchards in spring and summer, they–or their offspring–did not reach orchards distant from riparian habitats in either pest leafroller generation. Not until fall, after the second pest leafroller generation was complete (and when no suitable hosts were naturally available), did *C. florus* move to sites distant from riparian areas. We interpret this as *C. florus* searching far and wide for overwintering hosts. But parasitoids present in orchards after the summer leafroller generation lack suitable hosts and must either perish or return to distant, riparian habitats to produce diapausing offspring.

Parasitism by *C. florus* was not observed the spring in either 1999 or 2000 on sentinel hosts near the future locations of our gardens. But parasitism by *C. florus* was high within and near rose and strawberry gardens in spring 2001, although parasitism declined rapidly with distance. Parasitism by *C. florus* was also enhanced in the summer generation near the gardens in 2001. This result provides clear evidence that the landscape mosaic can be manipulated to enhance parasitism, even in the spring generation.

Colpoclypeus florus has often been cited as the most important parasitoid of leafrollers in Europe (Evenhuis, 1974; Evenhuis and Vlug, 1983; Gruys, 1982; Gruys and Vaal, 1984; Dijkstra, 1986). But the lack of alternate hosts has been hypothesized to limit its efficacy and prevent successful biological control of pest leafrollers in orchards (Gruys, 1982; Evenhuis and Vlug, 1983; Gruys and Vaal, 1984). While searches for alternate hosts had been unsuccessful (Evenhuis, 1983), *C. florus* was observed every year, although they are always rare in the spring. This suggests that alternate hosts were present but might have been rare or distant and only a small portion of the *C. florus* population was able to overwinter and emerge the following spring to rebuild their numbers and show high parasitism on orchard leafrollers. One challenge in manipulating near-orchard habitats in the northwestern United States is to establish high enough populations of alternate hosts to support significant emergence and parasitism by *C. florus* in spring. A second challenge is to find a balance that will prevent

C. florus from decimating the alternate host population on which this approach depends. We are hopeful that *A. comptana* may even be a more abundant overwintering host for *C. florus* in North America than in Europe because other specialist parasitoids that attack it in Europe are absent here.

We have discovered an important alternate host (*A. comptana*) in Washington and demonstrated that the availability of natural populations of this host can affect rates of parasitism of pest leafrollers in nearby orchards. Subsequently, during studies at the landscape level of variation in parasitism of leafrollers, orchards were identified where *C. florus* could not effectively attack leafrollers because of the lack of locally available alternate hosts. At these sites, we initiated attempts to manipulate near-orchard habitats by planting mixed gardens of roses and strawberries and infesting these gardens with the leafroller *A. comptana*, an alternate host for the parasitoid *C. florus*. This small-scale habitat manipulation was successful in significantly increasing local parasitism by *C. florus* during the spring and summer when this species would normally not be present at these sites. This successful manipulation of overwintering *C. florus* is highly encouraging and suggests that practical manipulation of near-orchard habitats for leafroller control in orchards is possible. Enlargement of these near-orchard rose and strawberry plantings may provide for significant control of leafrollers in coming years. The science of understanding landscape-level phenomena manipulating alternate habitats and hosts to enhance biological control in tree fruits in North America is still in its infancy (Bugg and Pickett, 1998; Coll, 1998). We believe that continued efforts are likely to reduce pesticide use and increase suppression of these orchard pests.

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