BIOLOGICAL CONTROL OF *LYGUS* SPP.: A COMPONENT OF AREAWIDE MANAGEMENT

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ABSTRACT

Lygus spp. are attacked by a variety of predators, parasitoids, and pathogens in the United States, but the overall impact of this natural enemy complex on Lygus populations is not well known. Although nymphal and adult parasitism have been characterized in a number of studies, egg parasitism and the impact of predation are still not well delineated. Several studies indicate that some native predators and parasitoids can inflict high mortality on Lygus populations; however, efficacy of these natural enemies appears to vary among the bugs' host plants, with crop systems experiencing some of the poorest biological control. The fungal pathogen *Beauveria bassiana* (Balsamo) may have potential for managing early-season populations of *Lygus* spp. in crop systems, but its role at present is quite limited. More information is needed on the role of native natural enemies in the population dynamics of *Lygus* spp., in both crop and natural systems. This information may help us develop programs using native natural enemies, through either releases or conservation, to target and suppress Lygus populations over large areas and before they enter crop systems. In addition to native natural enemies, there are opportunities for enhancing biological control of *Lygus* spp. through importation of exotic natural enemies. Although neither the tarnished plant bug (TPB) (*Lygus lineolaris* (Palisot de Beauvois)) nor the western tarnished plant bug (WTPB) (*Lygus hesperus* Knight) occur in Europe, there are several promising parasitoids of congeneric mirids in Europe which exhibit good host specificity, and appear to be good candidates for importation. Several species of European parasitoids have been introduced into the United States, one of which (*Peristenus digoneutis* Loan) is now established in 7 states of the northeastern U.S., but has failed to establish below 40°N latitude. Continuing efforts should be directed toward importing exotic, effective natural enemies that can provide permanent population suppression, as well as the development of habitats that are conducive to survival and reproduction of Lygus natural enemies, whether resident or introduced. These approaches provide opportunities to extend suppression of Lygus populations well beyond the crop system.

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INTRODUCTION

Lygus spp. comprise a serious pest problem for a number of crops throughout the Nearctic region (Hedlund and Graham 1987). Management of *Lygus* spp. is often problematic because of the high mobility, broad host range, cryptic damage, and poorly understood population dynamics of these species. In cotton, for example, control decisions for *Lygus* spp. are complicated by often inadequate sampling procedures, difficulty in assigning damage to the appropriate pest, and difficulty in defining treatment thresholds (see Layton 1995 for review of thresholds across the Cotton Belt).

Control options for *Lygus* spp. are quite limited at present, with chemical measures being the dominant approach. Nevertheless, insecticides used against *Lygus* spp. are typically broad spectrum materials that can seriously disrupt beneficial species in cropping systems. These disruptions can trigger other pest problems, leading to increased use of insecticides during the remainder of the season, increasing grower costs and environmental risks. In addition, the growing prevalence of insecticide resistance in *Lygus* spp. seriously threatens the utility and efficacy of chemical controls (Snodgrass 1996). The value of biological control for *Lygus* spp. is not well defined at present, and as a result biological control has little to offer growers at its present level of sophistication. In the future, however, natural enemies may offer additional management options that are effective.

This paper addresses the current status of biological control of *Lygus* spp. in the southern United States. For the purposes of this paper, only two *Lygus* spp. will be considered specifically: the western tarnished plant bug (WTPB) (*Lygus hesperus* Knight) and the tarnished plant bug (TPB) (*Lygus lineolaris* (Palisot de Beauvois)), with an emphasis on TPB. These two species comprise the majority of the pest *Lygus* spp. present in the U.S. WTPB dominates in the western United States. TPB, in contrast, is found throughout the United States and Canada, although it is generally more of a problem in the eastern half of the Nearctic region than in the western half. Both species are native to the Nearctic region and occur in many habitats (Schwartz and Foottit 1998), attacking a broad range of host plants including numerous crops (e.g., Fye 1982, Young 1986). The natural enemy complex appears to be comparable or shared for both *Lygus* species; thus, in this paper there will be little attempt to distinguish between natural enemies of the two species.

NATURAL ENEMIES OF *LYGUS* SPP.

Lygus spp. are attacked by a variety of natural enemies, including predators, parasitoids, and pathogens (Coulson 1987, Schuster 1987, King et al. 1996). They are susceptible to natural enemies at all life stages, from egg to adult, although levels of mortality vary considerably among life stages. The natural enemies of *Lygus* spp. are briefly discussed below, with a more complete listing in Table 1.

Parasitoids of *Lygus* spp. belong to the insect orders Hymenoptera and Diptera. The most common parasitoids are hymenopteran species (Table 1). Eggs are reportedly attacked by at least four species of parasitoids: *Anaphes iole* Girault, *Polynema pratensiphagum* Walley, and *Erythmelus miridiphagus* Dozier of the hymenopteran family Mymaridae; and *Telenomus* sp. of the hymenopteran family Scelionidae. Of these species, *A. iole* has a Nearctic distribution, and is widespread in the United States. Parasitism by *P. pratensiphagum* and *Telenomus* sp. has only been reported in Canada (Krombein et al. 1979, Sohati et al. 1989, 1992, Al-Ghamdi et al. 1993, 1995). Parasitism of *Lygus* eggs by *E. miridiphagus* has been reported from disparate locations in the Nearctic region (Sohati et al. 1989).

TABLE 1. Natural Enemies of *Lygus* spp. in North America

Species	Stage Attacked[a]	Origin[b]	References
	Parasitoids		
Hymenoptera: Mymaridae			
Anaphes iole	E(E)	Native	Clancy & Pierce 1966 Stoner & Surber 1969
Polynema pratensiphagum	E(E)	Native	Krombein et al. 1979
Erythmelus miridiphagus	E(E)	Native	Sohati et al. 1992 Al-Ghamdi et al. 1995
Hymenoptera: Scelionidae			
Telenomus sp.	E(E)	Native	Sohati and Stewart 1989 Sohati et al. 1992 Al-Ghamdi et al. 1995
Hymenoptera: Braconidae			
Leiophron uniformis	N	Native	Clancy & Pierce 1966 Debolt 1981
Leiophron schusteri	N	Exotic	King et al. 1996
Peristenus pallipes	N(N,A)	Native	Lim & Stewart 1976a, b
Peristenus pseudopallipes	N(N,A)	Native	Lim & Stewart 1976a, b
Peristenus howardi	N	Native	Day et al. 1999
Peristenus stygicus	N	Exotic	Hedlund & Coutinot 1983
Peristenus digoneutis	N	Exotic	Day et al. 1990 Day 1996
Peristenus rubricollis	N	Exotic	Jackson et al .1995
Peristenus nigricarpus	N	Exotic	Jackson et al. 1995
Diptera: Tachinidae			
Phasia (=Alophorella) aeneoventris	N/A	Native	Arnaud 1978
Phasia (=Alophorella) fumoea	N/A	Native	Arnaud 1978
Phasia (=Alophorella) pulversa	N/A	Native	Arnaud 1978
Phasia robertsonii	A	Native	Day 1995

TABLE 1. Cont.

Species	Stage Attacked[a]	Origin[b]	References
	Predators		
Heteroptera			
Nabis alternatus	N, E/A?	Native	Perkins & Watson 1972 Hagler et al. 1992
Nabis americoferus	N	Native	Leigh & Gonzalez 1976
Nabis roseipennis	N	Native	Nadgauda & Pitre 1986
Geocoris punctipes	E,N, A?	Native	Dunbar & Bacon 1972 Hagler et al. 1992
Geocoris bullatus	E,N	Native	Chow et al. 1983
Geocoris pallens	E,N	Native	Leigh & Gonzalez 1976
Podisus maculiventris	N	Native	Young 1989a
Orius tristicolor	E?	Native	Hagler et al. 1992
Zelus cervicalis	N	Native	Young 1989a
Zelus renardii	E/A?	Native	Hagler et al. 1992
Sinea confusa	E/A?	Native	Hagler et al. 1992
Sinea diadema	N	Native	Young 1989a
Acari			
Lasioerythraeus johnstoni	N	Native	Young & Welbourn 1987
Arachnida			
Phidippus audax	A	Native	Young 1989c
Metaphidippus galathea	A	Native	Young 1989a
Phidippus clarus	A	Native	Young 1989a
Thiodina puerpera	A	Native	Young 1989a
Misumenops spp.	N/A	Native	Young 1989b
Oxyopes salticus	A	Native	Lockley & Young 1987
Pisaurina mira	A	Native	Young 1989d

Table 1. Cont.

Species	Stage Attacked[a]	Origin[b]	References
	Pathogens		
Beauveria bassiana	N,A	Native	Steinkraus & Tugwell 1997
Entomophthora sp.	?	Native	Garman 1890 (in Crosby and Leonard 1914)
Mermithid sp.	A	Native	Scales 1973

[a] Stage attacked: E: egg; N: nymph; A: adult; a letter followed by another, parenthetical letter in parentheses indicates that the bug is attacked by the parasitoid in one stage (nonparenthetical) and subsequently emerges from the parenthetical stage(s).
[b] Native: organism native to the Nearctic region; Exotic: imported from outside of the Nearctic region into the Nearctic.

The parasitoid *A. iole* is the most commonly encountered parasitoid of Lygus eggs in the United States. Most studies of *A. iole* have been conducted in the western U.S., but it is reported to occur in the eastern portion of the U.S., as well (Scales 1973; Schuster 1987). *Anaphes iole* attacks at least several species of mirids, and is capable of parasitizing eggs of *Nabis* spp. (Clancy and Pierce 1966; Stoner and Surber 1969), although this is probably quite rare in the field (Jackson and Graham 1983). *Lygus* spp. insert their eggs into plant tissue, as is the case for a number of other heteropterans, including *Nabis* spp. For example, in cotton most egg deposition by *Lygus* spp. occurs in the upper third of the plants, at the juncture of the stem and the petiole (Graham et al. 1986). Eggs are located by *A. iole* apparently in response to cues left behind by the ovipositing female Lygus bug in the scar where the egg is inserted (Conti et al. 1997). The parasitoid emerges after 2-3 weeks of development at field temperatures (average of 32.8°C; Jackson 1987). Parasitism is most successful in young eggs (1-4 days old), but parasitoids can still develop in eggs parasitized shortly before hatch, although with less success (Stoner and Surber 1969). *Anaphes iole* has been found attacking *Lygus* spp. eggs in a variety of crop systems, but its efficacy appears to vary with the plant species in which the host eggs are located (Graham et al. 1986). In some systems, parasitism by *A. iole* is quite high (Clancy and Pierce 1966). For example, in alfalfa, parasitism rates have been reported to range from 0 to 53% (Graham et al. 1986). In Arizona, parasitism rates by *A. iole* on Lygus eggs in cotton tended to be lower than those observed in wild host plants (Graham et al. 1986). Considerable effort has been expended in developing rearing methods for *A. iole* so that inundative releases could be undertaken (e.g., Jones and Jackson 1990), and there may be opportunities for releasing this parasitoid for managing *Lygus* spp. (see below; Norton and Welter 1996).

Evaluation of parasitism of nymphal and adult *Lygus* spp. is often difficult because of typical high mortality among bugs transferred to the laboratory (Hedlund and Coutinot 1983, Bilewicz-Pawinska and Varis 1985). This problem can be circumvented by dissecting the bugs shortly after capture, but then precise identification of the immature parasitoids is often impossible. A recently-developed method, using parasitoid DNA, may provide greater opportunities to appropriately attribute parasitism to proper parasitoid species (Tilmon et al.

1997). Despite the difficulties of assessment, the braconid wasp *Leiophron uniformis* (Gahan) has been reared from *Lygus* spp. nymphs and adults (Graham et al.1986), and occurs throughout the United States. Although multivoltine, *L. uniformis* typically parasitizes *Lygus* spp. at low levels throughout the season [e.g., maximum of 19% of adults and 11% of nymphs in alfalfa in California (Clancy and Pierce 1966)]. This parasitoid appears to be more effective against and prefer other mirids over *Lygus* spp. (Day and Saunders 1990). Besides *L. uniformis*, an exotic *Leiophron* sp. was imported into the United States from Kenya in 1985, but no establishment has been recorded (King et al. 1996).

The most commonly reared native parasitoids of nymphal and adult *Lygus* spp. in the United States are braconids of the genus *Peristenus*. *Peristenus pallipes* (Curtis) and *Peristenus pseudopallipes* (Loan) are univoltine, native braconid wasps that attack nymphs of *Lygus* spp. and emerge from either the late nymphal or adult stages (Lim and Stewart 1976b). *Peristenus pallipes* appears to be most prevalent from Texas eastward (although it has an Holarctic distribution), while *P. pseudopallipes* has a northeastern Nearctic distribution, primarily in Canada. The two species are distinguishable exclusively by their respective phenologies -- *P. pallipes* is active in late spring and early summer, whereas *P. pseudopallipes* is active from mid to late summer (Loan 1974) -- raising some questions regarding the validity of the species' separation. In alfalfa, parasitism of bugs by *P. pallipes* varies considerably (e.g., Clancy and Pierce 1966), but rarely exceeds 40%, and is usually considerably lower. Host plant also influences the effectiveness of *P. pallipes*. Streams et al. (1968) reported that parasitism of TPB nymphs in Connecticut ranged from 0% on evening primrose (*Oenothera biennis* L.) to over 40% on fleabane (*Erigeron* spp.). Similarly, parasitism by *P. pallipes* was variable on non-crop plants in Mississippi and Arkansas (Scales 1973). Efficacy of *P. pallipes* is likely limited by the univoltine life history of the parasitoid – with only a single generation each year, the parasitoid is unable to respond numerically to seasonal intergenerational growth of Lygus populations.

A new species, *Peristenus howardi* Shaw, was recently discovered parasitizing WTPB nymphs in Idaho seed alfalfa (Day et al. 1999). Parasitism rates ranged from 5 to 81%, considerably more than those observed in New Jersey alfalfa (Day et al. 1990). This native wasp is thelytokous and completes three generations annually. Some individuals from each generation enter diapause. Subsequent studies demonstrated that *P. howardi* readily parasitized laboratory colonies of TPB. Further research is warranted to determine the impact that *P. howardi* might have on Lygus bugs, particularly TPB in the southeastern U.S., where *Peristenus* species imported from Europe have not established (see below).

Other species of *Peristenus* have been imported, primarily from Europe, for biological control of *Lygus* spp. (see Table 1, exotic species). These parasitoids were collected on European species of *Lygus* (chiefly *Lygus rugulipennis* Poppius), as TPB and WTPB do not occur in the Palearctic region. To date, the success of these importations has been rather limited (Coulson 1987; Jackson et al. 1995), but there are some encouraging signs that further work in this area is warranted. One introduced species, *Peristenus digoneutis* Loan, has established in the northeastern U.S., and has spread to and established in 7 states thus far (Day 1996; Day et al. 1998).

Native flies of the tachinid genus *Phasia*, have been reared from *Lygus* spp. (Table 1). All reported species (see listing in Arnaud 1978) are currently believed to be a single species, *Phasia robertsonii* (Townsend) (W. H. Day, pers. comm.). Parasitism by tachinid flies, however, accounts for very little mortality in Lygus bug populations (Clancy and Pierce 1966; Day 1995), and likely contributes little to suppression of bug populations.

Predation of *Lygus* spp. has not been well studied (King et al. 1996), chiefly because of the difficulties typically encountered when studying arthropod predation (Jervis and Kidd

1996). A variety of generalist predators have been reported to feed on *Lygus* spp. adults, nymphs, and/or eggs in the laboratory or field (Table 2); however, the true impact of predators on *Lygus* spp. populations are unknown. In field cage studies, Leigh and Gonzalez (1976) found that the natural predator complex reduced nymphal populations of WTPB 53-76% relative to controls from which predators had been eliminated with insecticides. They observed that 99% of the predators present in the cages were *Geocoris pallens* (Say). In small-cage tests, *Nabis americoferus* Carayon and *G. pallens* reduced populations of WTPB 71.3% and 92.9%, respectively, while larvae of *Chrysoperla carnea* (Stephens) had no significant effect on the bug's populations (Leigh and Gonzalez 1976). Several heteropteran predators, including *Geocoris* spp., *Nabis* spp., reduviids, and predatory pentatomids have been noted to feed on Lygus bugs in the laboratory (Knowlton 1949; Clancy and Pierce 1966; Perkins and Watson 1972; Propp 1982; Chow et al. 1983; Young 1989a; Arnoldi et al. 1991). Heteropteran predators, such as *Geocoris* spp., share some phylogenetic similarities with *Lygus* spp., and this may present challenges in targeting chemical controls at Lygus bugs. In many cases, insecticides that are toxic to *Lygus* spp. will likewise be toxic to other heteropteran species. Toxicity of pesticides to both *Lygus* spp. and *Geocoris* spp. has been observed, and "shared toxicity" probably exists for other heteropterans as well.

Other predators also have been associated with Lygus bug mortality. Spiders have been noted as Lygus bug predators in the field and laboratory (Young 1989a; 1989b; 1989c; 1989d). The role of spiders is often underestimated in cotton (as well as other systems), or is overlooked because of the presumed catholic diet of spiders. Nevertheless, spiders can be very important predators of a number of insect pests in and outside of crop systems (e.g., Nyffeler et al. 1987; Sterling et al. 1992). Young (1989b) obtained indirect evidence (a strong inverse relationship) for an adverse impact of the crab spider *Misumenops* sp. on TPB on the composite *Aster pilosus* (Wildenow). Ants also may be important predators of *Lygus* spp., particularly preying on the nymphal stages (JRR, pers. observation). The red imported fire ant *(Solenopsis invicta* Buren) is a formidable predator of numerous insect pests of cotton in the eastern half of the U. S. Cotton Belt, and may be capable of destroying Lygus bugs in numerous habitats. Some vertebrate predation of Lygus bugs has been reported. Crosby and Leonard (1914) reported that birds occasionally fed on TPB.

In addition to the predators and parasitic wasps and flies discussed above, a parasitic mite, *Lasioerythraeus johnstoni* Welbourn & Young, was recorded on nymphal and adult TPB (Young and Welbourn 1987), although its impact on Lygus populations is unknown. Rates of infestation reported by Young and Welbourn (1987) varied from 0 to 36% for TPB. The mite is capable of destroying at least early-instar nymphs.

There are few records of pathogens of Lygus bugs in the United States (Table 1). Crosby and Leonard (1914) cited Garman (1890) regarding a fungal entomopathogen, which was identified as an *Empusa* sp. (now *Entomophthora* sp.), attacking Lygus bugs. Scales (1973) reported finding a mermithid nematode in an adult TPB. The fungus *Beauveria bassiana* (Balsamo) also has been isolated from TPB (Steinkraus 1996, Steinkraus & Tugwell 1997). Commercial formulations utilizing spores of *B. bassiana* as the active ingredient have been tested against *Lygus* spp., and have yielded mixed results. Snodgrass and Elzen (1994) found that Naturalis-L (Fermone Corp., Phoenix, AZ) had little effect on adult bugs, but nymphal populations were reduced 53.8% relative to untreated controls. They suggested that this material might be useful for early-season control, but would be inadequate for managing mid-season populations. Steinkraus (1996) and Brown et al. (1997) found that the efficacy of Mycotrol WP (Mycotech, Butte, MT), a *B. bassiana* formulation, was greatly enhanced by the addition of moderate rate of the insecticide imidacloprid – the resulting mortality was

significantly greater than that of either material alone. Integration of microbial materials with reduced rates of insecticides may hold considerable promise for managing Lygus bugs.

CHALLENGES AND POSSIBILITIES FOR BIOLOGICAL CONTROL OF *LYGUS* SPP.

The life histories of *Lygus* spp. present some serious challenges to control efforts. The extensive host ranges (see Young 1986 for review of host range for TPB), multivoltinism, and high mobility of Lygus bugs make it possible for these bugs to exploit a wide range of habitats and host plants throughout the season. Widespread chemical applications would be questionably effective, costly, and potentially harmful over the range of habitats necessary to effect a substantial impact on the bug's populations. However, reliance on actively searching natural enemies, whether released or resident, that track and respond to the location and density of pest populations, may be advantageous for controlling such a pest, complementing farm- or field-scale control efforts. Successful suppression of *Lygus* spp. by natural enemies would need to start early in the season in off-crop habitats, and would need to occur across a majority of locations for an impact to be detected in cropping systems.

Day (1996) suggested that the native parasitoids of *Lygus* spp. are perhaps less effective in crop systems than in natural systems because the crop plants in question are themselves exotic to the United States. This suggestion assumes that the crop plants lack sufficient evolutionary history with the bugs and their native parasitoids to allow the parasitoids to use the necessary plant-related cues to find the host bugs. Although evidence to support such a hypothesis is presently lacking, the difference in parasitoid efficacy between crop plants and non-crop plants is striking and relevant to biological control in crop systems. Biological control of *Lygus* spp. beyond the target field, extending over large areas and into non-crop systems, will probably provide the best opportunity for using natural enemies for suppressing *Lygus* spp. populations (see Schuster 1987). Careful planning will be necessary. For example, area-wide releases of natural enemies would likely be most cost-effective early in the season, when pest populations are low, and the number of habitats available for colonization is limited (see Knipling 1992 for discussion). In addition, off-site natural habitats are seldom treated with insecticides, making them ideal systems in which natural enemies can function effectively.

Within crop systems, a combination of microbial agents and insecticides may provide a useful early-season tool for managing Lygus populations. This approach could reduce the adverse impact of insecticides on beneficial species, and could help minimize the risk of flaring secondary pests, particularly if selective insecticides are used. However, considerably more work is needed with the microbial agents to make sure they can be used effectively with consistency and to ensure their safety to arthropod natural enemies in the crop. Ultimately, it would appear that a suite of approaches will be necessary to manage *Lygus* spp., and at least some of these approaches will need to range well beyond individual grower fields if they are to be effective at the population level. Use of predators and parasitoids (native or introduced) may be the ideal method for locating and suppressing Lygus bugs in diverse habitats, in effect using "search and destroy" tools, while pathogenic agents may prove to be valuable management tools within target fields via augmentative releases. For both uses, the appropriate natural enemies will need to be carefully selected and properly utilized.

NEEDS FOR BIOLOGICAL CONTROL OF *LYGUS* SPP.

Understanding and Utilizing the Activity of Resident Natural Enemies. It is important that the native natural enemy complex attacking *Lygus* spp. be identified and quantified. There are numerous hints that predators and parasitoids can inflict considerable mortality on Lygus populations, but more specific information is necessary. Recent tools, such as the DNA method noted above (for identifying immature parasitoids) and immunotechniques (Hagler et al. 1991, 1992), provide opportunities to identify and quantify predator and parasitoid activity. Large-scale studies of parasitism and predation in multiple habitats and over time to are needed to begin understanding the metapopulation dynamics of Lygus bugs in relation to their natural enemies. Information collected in such studies will allow us to devise total crop management programs that conserve important natural enemies. It also will help us to determine where weak links exist – time periods or habitats where *Lygus* spp. can build up populations with little or no pressure from natural enemies. Identifying these weak links will allow us to target those habitats or time periods with appropriate chemical, biological, or cultural controls to suppress bug populations.

Knowledge of specific requirements for natural enemies (e.g., food, overwintering sites, mating sites, alternate hosts) can be utilized in designing specific systems that yield a net reduction in Lygus bugs. The literature has numerous examples of differential parasitism or predation on various plant species or genera (Streams et al. 1968; Scales 1973; Shahjahan and Streams 1973; Lim and Stewart 1976a; 1976b; Graham et al. 1986; Craig and Loan 1987; Young 1989b; Snodgrass and Fayad 1991), with the highest rates of parasitism typically occurring on *Erigeron* and *Aster* spp. Plants of these genera are also preferred hosts for TPB (Fleischer and Gaylor 1987). It might be possible to utilize plants from these genera to attract Lygus bugs into plantings where they are more susceptible to mortality, and thereby reduce pest populations. The challenge will be to balance the effect of the host plants in such a manner that the net result of Lygus bug reproduction and mortality is a reduction in Lygus population size. In addition, such habitat management may create a more favorable environment (i.e., untreated with numerous potential hosts) into which exotic species might be released, thereby enhancing the likelihood of establishment.

Augmentative Release Technology. Because biological control agents often have the ability to actively search out targets, and have limited environmental impact, the use of released natural enemies, particularly early in the season, may hold considerable promise for managing populations of *Lygus* spp. in and outside of crop systems (e.g., Knipling 1992). To be successful, the appropriate natural enemy(-ies) must be identified and cost-effective, and rearing methodology must be devised to maintain quality; appropriate release habitats, methodology, and timing also must be identified (Obrycki et al. 1997). Releases could be made on an area-wide basis into a variety of natural habitats that serve as reservoirs for Lygus bugs, but are untreated with insecticides (Debolt 1987). For example, data from studies of *A. iole* suggest that this parasitoid can destroy a large number of Lygus eggs in non-crop systems (Clancy and Pierce 1966; Graham et al. 1986), indicating that this parasitoid might be a useful organism for release programs. Indeed, it has shown promise in release programs in other crops (Norton and Welter 1996). Releases may offer some outstanding opportunities to attack *Lygus* spp. on a population, if not metapopulation scale, particularly if these releases can be undertaken early in the season when Lygus populations are low. Success of inoculative releases may be improved by utilizing appropriate plantings in and around fields to foster the natural enemies of Lygus bugs.

Importation of Natural Enemies. Numerous efforts have been made to introduce exotic natural enemies into the United States against *Lygus* spp. (Coulson 1987, Jackson et

al. 1995). Thus far, only the parasitoid *Peristenus digoneutis* has successfully established, as noted above. Nevertheless, establishment of an effective natural enemy may contribute sufficient mortality to that already occurring to provide adequate Lygus population suppression. Establishment of an effective natural enemy also would provide long-term suppression without additional inputs (e.g., augmentative releases), accruing additional savings as the years pass. Continued efforts are warranted in this area.

It is important to note that TPB and WTPB are both of Nearctic distribution – they do not occur in the Palearctic region. Thus, all of the parasitoids of *Lygus* spp. imported into the Nearctic region from Europe originated in congeners of our native pests. This may present some challenges for importation efforts. First, the parasitoid must be able to move from its native target *Lygus* spp. and attack the "new" host species in North America. This "new association" may or may not be successful. Second, by virtue of the introduced parasitoid's need to attack a novel host species in its "new" environment, the risk of adverse impacts on nontarget Miridae (or other heteropterans), should any of these parasitoids successfully establish, may be relatively high. This second issue is quite important, as the Miridae is a large and diverse family (e.g., Wheeler and Henry 1992), and includes many members that are predominantly predators, such as those of the subfamily Deraeocorinae. As such, it will be critical to evaluate the risk to nontarget species prior to release of imported natural enemies targeting *Lygus* spp. in an effort to minimize adverse effects (Kuhlmann et al. 1998). As part of the risk evaluation, it will be vital to delineate the possible host range of these parasitoids as clearly as possible and to monitor nontarget effects after release, should the parasitoids be deemed safe for release. With the growing emphasis on environmental conservation, there is an intensifying interest in the environmental safety of biological control releases (e.g., Food and Agriculture Organization -- United Nations 1997). This interest has contributed to a closer scrutiny of importation biological control efforts, and careful study of the parasitoids would certainly be justified in the case of these exotic parasitoids of *Lygus* spp. Nevertheless, there appear to be some promising possibilities for biological control using imported natural enemies.

CONCLUSION

Biological control has not played a prominent role in management of *Lygus* spp. However, the availability of a large and diverse native natural enemy complex, and the possibility of acquiring appropriate exotic natural enemies, suggests that biological control agents could make an important contribution to *Lygus* spp. suppression. Further studies are needed to: (1) determine the relative importance of the various natural enemy species in suppressing *Lygus* spp., (2) effectively integrate native natural enemies into IPM programs, and (3) to locate and introduce effective and appropriate exotic natural enemies.

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LITERATURE CITED

Al-Ghamdi, K. M., R. K. Stewart, and G. Boivin. 1993. Note on overwintering of *Polynema pratensiphagum* (Walley) (Hymenoptera: Mymaridae) in southwestern Quebec. Can. Entomol. 125:407-408.

Al-Ghamdi, K. M., R. K. Stewart, and G. Boivin. 1995. Synchrony between populations of the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Hemiptera: Miridae), and its egg parasitoids in southwestern Quebec. Can. Entomol. 127:457-472.

Arnaud, P. H., Jr. 1978. A host-parasite catalog of North American Tachinidae (Diptera). USDA-SEA Misc. Publ. No. 1319.

Arnoldi, D., R. L. Stewart, and G. Boivin. 1991. Field survey and laboratory evaluation of the predator complex of *Lygus lineolaris* and *Lygocoris communis* (Hemiptera: Miridae) in apple orchards. J. Econ. Entomol. 84:830-836.

Bilewicz-Pawinska, T., and A. L. Varis. 1985. Structure of mirid communities (Heteroptera) and the parasitism of the main bug populations on wheat in the eastern parts of North and Central Europe. Ann. Entomol. Fenn. 51:19-23.

Brown J. Z., D. C. Steinkraus, N. P. Tugwell, and T. G. Teague. 1997. The effects and persistence of the fungus *Beauveria bassiana* (Mycotrol) and imidacloprid (Provado) on tarnished plant bug mortality and feeding. Proc. Beltwide Cotton Conf., pp. 1302-1305. National Cotton Council, Memphis, TN.

Chow, T., G. E. Long, and G. Tamaki. 1983. Effects of temperature and hunger on the functional response of *Geocoris bullatus* (Say) (Hemiptera: Lygaeidae) to *Lygus* spp. (Hemiptera: Miridae) density. Environ. Entomol. 12:1332-1338.

Clancy, D. W., and H. D. Pierce. 1966. Natural enemies of some Lygus bugs. J. Econ. Entomol. 59:853-858.

Conti, E, W. A. Jones, F. Bin, and S. B. Vinson. 1997. Oviposition behavior of *Anaphes iole*, an egg parasitoid of *Lygus hesperus* (Hymenoptera: Mymaridae; Heteroptera: Miridae). Ann. Entomol. Soc. Am. 90:91-101.

Coulson, J. R. 1987. Studies on the biological control of plant bugs (Heteroptera: Miridae): An introduction and history, 1961-1983, pp. 1-12. In: R.C. Hedlund & H.M. Graham (eds.), Economic Importance and Biological Control of *Lygus* and *Adelphocoris* in North America. USDA-ARS-64.

Craig, C. H., and C. C. Loan. 1987. Biological control efforts on Miridae in Canada, pp. 48-53 In: R.C. Hedlund and H.M. Graham (eds.), Economic importance and biological control of *Lygus* and *Adelphocoris* in North America. USDA-ARS, ARS-64. 95 pp.

Crosby, C. R., and M. D. Leonard. 1914. The tarnished plant bug. Cornell Univ. Agric. Exp. Sta. Bull. 346

Day, W. H. 1995. Biological observations on *Phasia robertsonii* (Townsend) (Diptera: Tachinidae), a native parasite of adult plant bugs (Hemiptera: Miridae) feeding on alfalfa and grasses. J. New York Entomol. Soc. 103:100-106.

Day, W. H. 1996. Evaluation of biological control of the tarnished plant bug (Hemiptera: Miridae) in alfalfa by the introduced parasite *Peristenus digoneutis* (Hymenoptrea: Braconidae). Environ. Entomol. 25:512-518.

Day, W. H., and L. B. Saunders. 1990. Abundance of the garden fleahopper (Hemiptera: Miridae) on alfalfa and parasitism by *Leiophron uniformis* (Gahan) (Hymenoptera: Braconidae). J. Econ. Entomol. 83:101-106.

Day, W. H., R. C. Hedlund, L. B. Saunders, and D. Coutinot. 1990. Establishment of *Peristenus digoneutis* (Hymenoptera: Braconidae), a parasite of the tarnished plant bug (Hemiptera: Miridae) in the United States. Environ. Entomol. 19:1528-1533.

Day, W. H., J. M. Tropp, A. T. Eaton, R. F. Romig, R. G. Van Driesche, and R. Chianese. 1998. Geographic distributions of *Peristenus conradi* and *P. digoneutis* (Hymenoptera: Braconidae), parasites of the alfalfa plant bug and the tarnished plant bug (Hemiptera: Miridae) in the Northeastern United States. J. New York Entomol. Soc. 106:69-75.

Day, W. H., C. R. Baird, and S. R. Shaw. 1999. New, native species of *Peristenus* (Hymenoptera: Braconidae) parasitizing *Lygus hesperus* (Hemiptera: Miridae) in Idaho: biology, importance, and description. Ann. Entomol. Soc. Am. 92:370-375.

Debolt, J. W. 1981. Laboratory biology and rearing of *Leiophron uniformis* (Gahan) (Hymenoptera: Braconidae), a parasite of *Lygus* spp. (Hemiptera: Miridae). Ann. Entomol. Soc. Am. 74:334-337.

Debolt, J. W. 1987. Augmentation: rearing, release, and evaluation of plant bug parasites, pp. 82-87. In: R. C. Hedlund and H. M. Graham (eds.), Economic Importance and Biological Control of *Lygus* and *Adelphocoris* in North America. USDA-ARS-64.

Dunbar, D. M., and O.G. Bacon. 1972. Feeding, development, and reproduction of *Geocoris punctipes* (Heteroptera: Lygaeidae) on eight diets. Ann. Entomol. Soc. Am. 65:892-895.

Fleischer, S. J., and M. J. Gaylor. 1987. Seasonal abundance of *Lygus lineolaris* (Heteroptera: Miridae) and selected predators in early season uncultivated hosts: Implications for managing movement into cotton. Environ. Entomol. 16:379-389.

Food and Agriculture Organization, United Nations. 1997. Code of conduct for the import and release of exotic biological control agents. Biocontrol News and Information 18:119N-124N.

Fye, R. E. 1982. Weed hosts of the Lygus (Heteroptera: Miridae) bug complex in central Washington. J. Econ. Entomol. 75:724-727.

Graham, H. M., C. G. Jackson, and J. W. Debolt. 1986. *Lygus* spp. (Hemiptera: Miridae) and their parasites in agricultural areas of southern Arizona. Environ. Entomol. 15:132-142.

Hagler, J. R., A. C. Cohen, F. J. Enriquez, and D. Bradley-Dunlop. 1991. An egg-specific monoclonal antibody to *Lygus hesperus*. Biol. Control 1:75-80.

Hagler, J. R., A. C. Cohen, D. Bradley-Dunlop, and F. J. Enriquez. 1992. Field evaluation of predation on *Lygus hesperus* eggs using a specific and stage-specific monoclonal antibody. Environ. Entomol. 21:896-900.

Hedlund, R. C., and D. Coutinot. 1983. Parasitism of *Lygus* spp. and *Adelphocoris* spp. in central France. In: Proc. Interntl. Conf. Integrated Plant Prot. (4-9 July 1983) 4:92-94 (published by Plant Protection Section of the Hungarian Society of Agricultural Science).

Hedlund, R. C., and H. M. Graham. 1987. Economic importance and biological control of *Lygus* and *Adelphocoris* in North America. U.S. Dept. of Agric., ARS-64.

Jackson, C. G. 1987. Biology of *Anaphes ovijentatus* (Hymenoptera: Mymaridae) and it host, *Lygus hesperus* (Hemiptera: Miridae), at low and high temperatures. Ann. Entomol. Soc. Am. 80:367-372.

Jackson, C. G., and H. M. Graham. 1983. Parasitism of four species of *Lygus* (Hemiptera: Miridae) by *Anaphes ovijentatus* (Hymenoptera: Mymaridae) and an evaluation of other possible hosts. Ann. Entomol. Soc. Am. 76:772-775.

Jackson, C. G., J. W. Debolt, and J. J. Ellington. 1995. Lygus bugs, pp. 87-90. In: J. R. Nechols, L. A. Andres, J. W. Beardsley, R. D. Goeden, and C. G. Jackson (eds.), Biological Control in the Western United States: Accomplishments and Benefits of Regional Research Projects W-84, 1964-1989. Univ. of California – DANR Publ. 3361.

Jervis, M., and N. A. C. Kidd. 1996. Insect natural enemies: Practical approaches to their study and evaluation. Chapman and Hall, London.

Jones, W. A., and C. G. Jackson. 1990. Mass production of *Anaphes iole* for augmentation against *Lygus hesperus:* effects of food on fecundity and longevity. Southwest. Entomol. 15:463-468.

King, E. G., R. J. Coleman, J. A. Morales-Ramos, K. R. Summy, M. R. Bell, and G. L. Snodgrass. 1996. Biological control. In: E. G. King, J. R. Phillips, and R. J. Coleman (eds.). Cotton Insects and Mites: Characterization and Management, pp. 511-538. The Cotton Foundation, Memphis TN.

Knipling, E. F. 1992. Principles of insect parasitism analyzed from new perspectives: practical implications for regulating insect populations by biological means. USDA Agric. Handbk. No. 693.

Knowlton, G. F. 1949. Predacious Hemiptera feeding observations. J. Kansas Entomol. Soc. 22:37-39.

Krombein, K. V., P. D. Hurd, Jr., D. R. Smith, and B. D. Burks. 1979. Catalog of the Hymenoptera in America North of Mexico. Smithsonian Instit. Press, Wash. DC. 3 Volumes.

Kuhlmann, U., P. G. Mason, and D. J. Greathead. 1998. Assessment of potential risks for introducing European *Peristenus* species as biological control agents of native *Lygus* species in North America: A cooperative approach. Biocontrol News and Information 19: 83N-90N.

Layton, M. B. 1995. Tarnished plant bug: Biology, thresholds, sampling, and status of resistance, Proc. Beltwide Cotton Conf., pp. 131-134. National Cotton Council, Memphis, TN.

Leigh, T. F., and D. Gonzalez. 1976. Field cage evaluation for predators for control of *Lygus hesperus* Knight on cotton. Environ. Entomol. 5:948-952.

Lim, K. P., and R. K. Stewart. 1976a. Parasitism of the tarnished plant bug, *Lygus lineolaris* (Hemiptera: Miridae), by *Peristenus pallipes* and *P. pseudopallipes* (Hymenoptera: Braconidae). Can. Entomol. 108:601-608.

Lim, K. P., and R. K. Stewart. 1976b. Laboratory studies on *Peristenus pallipes* and *P. pseudopallipes* (Hymenoptera: Braconidae), parasitoids of the tarnished plant bug, *Lygus lineolaris* (Hemiptera: Miridae). Can. Entomol. 108:815-821.

Loan, C. C. 1974. The North American species of *Leiophron* Nees, 1818 and *Peristenus* Foerster, 1862 (Hymenoptera: Braconidae, Euphorinae) including the description of 31 new species. Le Naturaliste Canadien 101:821-860.

Lockley, T. C. and O. P. Young. 1987. Prey of the striped lynx spider, *Oxyopes salticus* (Araneae, Oxyopidae), on cotton in the Delta area of Mississippi. J. Arachnol. 14:395-397.

Nadgauda, D., and H. N. Pitre. 1986. Effects of temperature on feeding, development, fecundity, and longevity of *Nabis roseipennis* (Hemiptera: Nabidae) fed tobacco budworm (Lepidoptera: Noctuidae) larvae and tarnished plant bug (Hemiptera: Miridae) nymphs. Environ. Entomol. 15:536-539.

Norton, A. P., and S. C. Welter. 1996. Augmentation of the egg parasitoid *Anaphes iole* (Hymenoptera: Mymaridae) for *Lygus hesperus* (Heteroptera: Miridae) management in strawberries. Environ. Entomol. 5:1406-1414.

Nyffeler, M., D. A. Dean, and W. L. Sterling. 1987. Feeding ecology of the orb-weaving spider *Argiope aurantia* [Araneae: Araneidae] in a cotton agroecosystem. Entomophaga 32:367-375.

Obrycki, J. J., L. C. Lewis, and D. B. Orr. 1997. Augmentative releases of entomophagous species in annual cropping systems. Biol. Control 10:30-36.

Perkins, P. V., and T. F. Watson. 1972. *Nabis alternatus* as a predator of *Lygus hesperus*. Ann. Entomol. Soc. Am. 65:625-629.

Propp, G. D. 1982. Functional response of *Nabis americoferus* to two of its prey, *Spodoptera exigua* and *Lygus hesperus*. Environ. Entomol. 11:670-674.

Scales, A. L. 1973. Parasites of the tarnished plant bug in the Mississippi Delta. Environ. Entomol. 2:304-306.

Schuster, M. F. 1987. Biological control of plant bugs in cotton, pp. 13-19. In: R. C. Hedlund and H. M. Graham (eds.) Economic Importance and Biological Control of *Lygus* and *Adelphocoris* in North America. USDA-ARS-64.

Schwartz, M. D., and R. G. Foottit. 1998. Revision of the Nearctic Species of the Genus *Lygus* Hahn, with a Review of the Palearctic Species (Heteroptera: Miridae). Memoirs on Entomology, International, vol. 10. Associated Publishers, Gainesville, FL.

Shahjahan, M., and F. A. Streams. 1973. Plant effects on host-finding by *Leiophron pseudopallipes* (Hymenoptera: Braconidae), a parasitoid of the tarnished plant bug. Environ. Entomol. 2:921-925.

Snodgrass, G. L. 1996. Insecticide resistance in field populations of the tarnished plant bug (Heteroptera: Miridae) in cotton in the Mississippi Delta. J. Econ. Entomol. 89:783-790.

Snodgrass, G. L., and G. W. Elzen. 1994. Efficacy of Naturalis-L for adults and nymphs of the tarnished plant bug in cotton. Proc. Beltwide Cotton Conf., pp. 1103-1104. National Council, Memphis TN.

Snodgrass, G. L., and Y. H. Fayad. 1991. Euphorine (Hymenoptera: Braconidae) parasitism of the tarnished plant bug (Heteroptera: Miridae) in areas of Washington County, Mississippi disturbed and undisturbed by agricultural production. J. Entomol. Sci. 26:350-356.

Sohati, P. H., G. Boivin, and R. K. Stewart. 1992. Parasitism of *Lygus lineolaris* eggs on *Coronilla varia*, *Solanum tuberosum*, and three host weeds in southeastern Quebec. Entomophaga 37:515-523.

Sohati, P. H., R. K. Stewart, and G. Boivin. 1989. Egg parasitoids of the tarnished plant bug, *Lygus lineolaris* (P. de B.) (Hemiptera: Miridae), in Quebec. Can. Entomol. 121:1127-1128.

Steinkraus, D. C. 1996. Control of tarnished plant bug with *Beauveria bassiana* and interactions with imidacloprid. Proc. Beltwide Cotton Conf., pp. 888-889. National Cotton Council, Memphis, TN.

Steinkraus, D. C., and N. P. Tugwell. 1997. *Beauveria bassiana* (Deuteromycotina: Moniliales) effects on *Lygus lineolaris* (Hemiptera: Miridae). J. Entomol. Sci. 32:79-90.

Sterling W. L., A. Dean, and N. M. A. El-Salam. 1992. Economic benefits of spider (Araneae) and insect (Hemiptera: Miridae) predators of cotton fleahoppers. J. Econ. Entomol. 85:52-57.

Stoner, A., and D. E. Surber. 1969. Notes on the biology and rearing of *Anaphes ovijentatus*, a new parasite of *Lygus hesperus* in Arizona. J. Econ. Entomol. 62:501-502.

Streams, F. A., M. Shahjahan, and H. G. LeMasurier. 1968. Influence of plants on the parasitization of the tarnished plant bug by *Leiophron pallipes*. J. Econ. Entomol. 61:996-999.

Tilmon, K. J., B. N. Danforth, M. P. Hoffmann, and W. H. Day. 1997. Determining parasitoid species composition in a host population: A new molecular approach. Display no. 546, Annual meeting of the Entomol. Soc. of America, Nashville TN (14-18 Dec. 1997).

Wheeler, A. G., Jr., and T. J. Henry. 1992. A synthesis of the Holarctic Miridae (Heteroptera): Distribution, biology, and origin, with emphasis on North America. Thomas Say Found. Monograph 15, 282 pp.

Young, O. P. 1986. Host plants of the tarnished plant bug, *Lygus lineolaris* (Heteroptera: Miridae). Ann. Entomol. Soc. Am. 79:747-762.

Young, O. P. 1989a. Predators of the tarnished plant bug, *Lygus lineolaris* (Heteroptera: Miridae): Laboratory evaluations. J. Entomol. Sci. 23:174-179.

Young, O. P. 1989b. Relationships between *Aster pilosus* (Compositae), *Misumenops* spp. (Araneae: Thomisidae), and *Lygus lineolaris* (Heteroptera: Miridae). J. Entomol. Sci. 24:252-257.

Young, O. P. 1989c. Field observations of predation by *Phidippus audax* (Araneae: Salticidae) on arthropods associated with cotton. J. Entomol. Sci. 24:266-273.

Young, O. P. 1989d. Predation by *Pisaurina mira* (Araneae, Pisauridae) on *Lygus lineolaris* (Heteroptera, Miridae) and other arthropods. J. Arachnol. 17:43-48.

Young, O. P., and W. C. Welbourn. 1987. Biology of *Lasioerythraeus johnstoni* (Acari: Erythraeidae), ectoparasitic and predaceous on the tarnished plant bug, *Lygus lineolaris* (Hemiptera: Miridae), and other arthropods. Ann. Entomol. Soc. Am. 80:243-250.