**Biological Control in Pest Management Systems of Plants   
ANNUAL REPORT OF CONTRIBUTING PROJECT TO**

**COOPERATIVE REGIONAL PROJECT W5185**

January 2023 to December, 2023

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# 3. PROGRESS OF WORK AND PRINCIPAL ACCOMPLISHMENTS:

## Objective 1: Import and Establish Effective Natural Enemies

*Objective 1a. Survey indigenous natural enemies.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Heraty - We have continued to follow up on the accidental introduction of *Orasema minutissima* to the island of Hawai'i . As a potential biological control agent against *Wasmannia*, this is an important find. We have found it in the early stages of spread, which allows for the documentation of its spread and impact on the ant. A survey in spring 2022 showed that the wasp has spread around the entire island of Hawai'i, but does not yet occur on the island of Oahu or Maui (and likely not on any of the other Hawaiian islands). Our current efforts center on sequencing populations of the ants and parasitoids from different locations on Hawai'i and islands in the Caribbean and south Florida to determine the site of origin.

We continue to work on a phylogeny of all Chalcidoidea. We have one publication that is a molecular phylogenetic analysis of the entire superfamily using Anchored Hybrid Enrichment Approaches and Ultraconserved elements (Cruaud et al. 2023). The associated book on the classification and biology of Chalcidoidea is well underway with an expected submission to the publisher (CABI) by January 2024. We have received drafts and final copies of 70 chapters.

We have also been funded for a survey of the insects of California. This is a multi-intitutional initiative to assess the diversity of insects in California and provide genetic COI barcodes for all species. The project was funded in October 2022 through the California Institute of Biodiversity.

Miller - *Orasema minutissima* (Hymenoptera: Eucharitidae), a parasitoid of the little fire ant, *Wasmannia auropunctata* which is present on the Big Island of Hawaii has not been observed parasitizing *W. auropunctata* on Guam.

Rene Sforza

100% for *Euphyllura olivina* with 21 days total in France

100% for Dittrichia graveolens, Vincetoxicum sp

75% for Brassica tournefortii

50% for Tree of heaven: samples have been collected and detection methods are being developed.

Wright - Surveyed for parasitoids of exotic Scolytinae: New species described from Hawaii (*Phymastichus holoholo*, Eulophidae), plus several descriptions in prep.

Moran - A stem-boring weevil and several other candidate agents were collected on crystalline ice plant (*Mesembryanthemum crystallinum*) (26) in South Africa

Danne - In collaboration with Dr. Hogg and SWD SCRI team members, we have surveyed northern, interior and central California sites for the larval and pupal parasitoids attacking the spotted wing drosophila.

1. Incomplete work or areas needing further investigation:

Miller - Further surveys are planned to ascertain its presence or absence on Guam and Yap in Micronesia. However, due to its complex life cycle it is unlikely to prove an effective biological control agent against *W. auropunctata*.

*Objective 1b. Conduct foreign exploration and ecological studies in native range of pest.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Lara Ricky- In September 2023, I conducted foreign exploration in Europe for co-evolved larval parasitoids of *Plutella xylostella* in collaboration with the USDA European Biological Control Lab (USDA-EBCL) in France. USDA-EBCL is rearing parasitoids in preparation for host-range studies. Objective is 68% complete.

Rene Sforza - 100% for Euphyllura olivina

Danne - We have continued our research on the spotted wing drosophila, however, no trips to So. Korea or China were made in 2023. In collaboration California Dept of Food and Agriculture (Charlie Pickett and Ricky Lara) and USDA Biological Control Laboratory (EBCL) in France (Rene Sforza, Marie Claude Bon) and their colleagues, we continued importation of Psyllaphaegus spp. attacking the olive psyllid. A permit for the wasp has been obtained from the USDA APHIS and releases will begin in 2024.

1. Incomplete work or areas needing further investigation:

*Objective 1c*.  *Determine systematics and biogeography of pests and natural enemies.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Heraty –

a) We continue to research parasites of the imported fire ant (*Solenopsis*) in South America and of the Little Fire Ant (*Wasmannia*) in the Caribbean and Central America. Our current research is focused on the population genetics of the eucharitid and LFA to determine the genetic structure of the two species on the main island and try to determine the points of origin for both species. This will be instrumental in determining future exports of the wasp to other Pacific Islands for biological control of LFA.

b) We are continuing on new research program on the genus *Encarsia*, which are aphelinid parasitoids of armored scales and whiteflies. The initial objectives are a revision of the *Encarsia strenua* species group and a molecular phyogeny of the entire genus. This research is being conducted by a graduate student (Robert Kresslein).

c) Research is underway on developing a molecular phylogeny for the egg-parasitic Mymaridae by a relatively new graduate student (Krissy Dominguez). Her research is utilizing three different molecular approaches to look at congruence of results, and ultimately the proposal of a new classification for the group.

d) We are continuing our work on a previous National Science Foundation grant to revise the classification of the entire superfamily Chalcidoidea. This is a massive undertaking that involves molecular, morphological and bioinformatic approaches to resolve the relationships of the superfamily, and to disseminate information on the group through electronic resources and a new book that outlines the classification and biology of the group. Members of this superfamily are among the most important natural and introduced control agents of other pest insects, and this will form a foundation for all future studies on the group. One paper is in press and another under review. We are continuing to develop a new database to house all of the taxonomic and biological information on the superfamily in TaxonWorks, which is based on a migration of data from the Universal Chalcidoidea Database. This system manages data for more than 30,000 taxonomic names and over 50,000 literature references, including information on their hosts and distributions.

f) Identification. We regularly provide identifications of parasitoids that are directly related to biological projects worldwide.

g) As well, more than 1000 specimens of Aphelinidae and other Chalcidoidea were curated and added to the Entomology Research Museum collection of parasitic Hymenoptera.

Rene Sforza – Arthropods

* Conducted a phylogeography study of *Pyrrhalta viburni* (Coleoptera: Chrysomelidae), a pest causing extensive damage to native and exotic *Viburnum* species in managed landscapes and natural areas in North America.
* Pursued an integrative taxonomic inventory of larval hymenopteran parasitoids of *Plutella xylostella* (Lepidoptera: Plutellidae) in Greece, France and Bulgaria, mostly belonging to 8 species in the Ichneumonidae and Braconidae families.
* Conducted an integrative taxonomic inventory of hard ticks in Vietnam including the cattle fever ticks (Rhipicephalus microplus), (formerly *Boophilus* microplus), (Arachnida: Ixodidae) and congeners of the Asian longhorned tick Haemaphysalis *longicornis* (Arachnida: Ixodidae) and attempts to detect potential parasitoids parasitizing these hard ticks.
* Started an integrative taxonomy inventory of parasitoids and hyperparasitoids of *Euphyllura olivina* (Hemiptera: Psyllidae), a pest of olive trees which recently reached the olive production area in California.

Rene Sforza – Weeds

* Pursued an integrative taxonomic inventory of foliage feeder moths (Lepidoptera) on stinkwort (*Dittrichia graveolens*) (Asteraceae) in Greece, Cyprus and southern France, mostly belonging to four families i.e. Noctuidae, Pyralidae, Tortricidae and Geometridae
* Started a phylogeography study of stinkwort (*Dittrichia graveolens*) (Asteraceae)

Degree to which objective has been accomplished:

100% *for Pyrrhalta viburni*

100% for *Plutella xylostella*

100% for *Euphyllura olivina*

50% for hard ticks

50%for of foliage feeder moths on *Dittrichia graveolens*

30% for *Dittrichia graveolens*

Dillman - We have been working to isolate and identify new species of entomopathogenic nematodes (EPNs). We have isolated a new species from Thailand and have just finished describing it. The manuscript should be published soon.

Danne - We are working closely with USDA taxonomist (Mathew Buffington) and research entomologist (Keith Hopper) and Italian taxonomists (Emilio Guerrieri and Massimo Giorgini) on the description of Drosophila suzukii parasitoids Asobara spp. (Braconidae), Leptopilina japonica and, in particular, Ganaspis brasiliensis (Figitidae). We are working closely with UC Riverside taxonomist (Serguei Triapitsyn) on the description of Anagrus spp. collected in vineyards.

1. Incomplete work or areas needing further investigation:

Heraty - We continue to work with researchers in Argentina to revise species that are parasitoids of *Solenopsis* ants. Javier Torréns is working on a revision of the *Orasema susanae* species group. There are many different research areas in progress, especially on Aphelinidae, Eucharitidae and Mymaridae.

Rene Sforza –

* Sampling of parasitized natural populations of hard ticks is still ongoing in Vietnam and detection of potential hymenopteran parasitoids is a continued effort.
* Sampling of the natural enemy assemblage of stinkwort is still ongoing across their Eurasian native range and taxonomic investigation is a continued effort.
* Sampling of populations of stinkwort is still ongoing across its Mediterranean native range but the sampling in the invasive range in California has been completed by Patrick Moran (ARS, Albany)

Dillman - This nematode remains to be tested for its host range and specificity against different insect hosts.

*Objective 1d*. *Determine environmental safety of exotic candidates prior to release.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Littlefield - Rush skeletonweed: The crown moth *Oporopsamma wertheimsteini* (Fam.: Tortricidae) was received from the BBCA and overseas cooperators in August 2022 and again in 2023. A laboratory colony was established and used for continued impact studies on non-target plants and to maintain a rearing colony. Impact studies on *Kigia biflora* indicated no impact on biomass, plant height, flowering or seed production when plants were exposed to 0, 5 or 10 first instar larvae. A TAG petition is currently being drafted for the field release of this moth.

Danne - In collaboration with researchers at USDA (Kim Hoelmer and Xingeng Wang), CABI (Marc Kenis and colleagues), Oregon State University (Vaughn Walton), and Canada (Paul Abram and company) and colleagues in China and South Korea, we imported 8 parasitoid species that attack the spotted wing drosophila (Drosophila suzukii). These parasitoids included at least three larval parasitoids Asobara japonica (Braconidae), Leptopilina japonica and Ganaspis nr. sp. brasiliensis (Figitidae). This material was studied in Quarantine and release permits were developed for Ganaspis nr. sp. brasiliensis. Currently, studies are underway to determine potential species or strain differences among Gb populations.

1. Incomplete work or areas needing further investigation:

*Objective 1e. Release, establish and redistribute natural enemies.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Biological control of swallow-wort vines:

Experimental releases of *Hypena opulenta* against invasive swallow-worts continued in Michigan. We released 1035 *H. opulenta* adults and 74 larvae representing inbred, outbred and Canadian colonies at 15 field sites to test the importance of genetic background on establishment success. In addition, we released 2446 *H. opulenta* adults with mixed genetic backgrounds at three field sites.

Biological control of knotweeds:

A total of 40,000 Aphalara itadori psyllids were released against Japanese and Bohemian knotweeds at 26 sites in Michigan. The releases aim to test the importance of release frequency and A. itadori host race on establishment success.

Lara Ricky - Several thousand *Trissolcus japonicus* parasitoids were released in Northern California during 2023 as part of biocontrol efforts targeting *Halyomorpha halys* populations.

Littlefield - Hoary cress: We are currently rearing two colonies of the gall mite, Aceria drabae (Fam.: Eriophyidae): one from Bulgaria collected by the BBCA in 2016 (supplement in 2018), and a second colony from Trygona, Greece (2021) which is our primary source of mites for expanded releases in 2023.

Eight releases of the mite were made in Montana in May 2023. Releases were made in Judith Basin, Lake and Sanders Counties. Galls were observed at four releases, although in relatively low numbers. Mites were also consigned to cooperators in Colorado, Idaho and Wyoming.

Oxeye daisy: Eggs of the oxeye daisy root moth, *Dichrorampha aeratana* (Fam.: Tortricidae) were sent by CABI to the containment facility at Montana State University for rearing. Approximately 420 of 528 eggs hatched and larvae were transferred to plants. Infested plants are being overwintered in a refrigerator at 8o C. We plan to remove plants in early April 2024. Adults will be collected upon emergence for further rearing, and eventually for potential release in 2025.

Miller - The rhino beetles invading Guam (2007), Hawaii (2013), Papua New Guinea (2015), and Solomon Islands (2015) are genetically different from other CRB populations, are resistant to common strains of Oryctes nudivirus, the biocontrol agent of choice for this species, and behave differently. For these reasons, they are being referred to as the "the Guam Biotype" CRB-G.  Ongoing testing of O. nudivirus strains collected from the Philippines in 2017 have revealed a single strain that showed virulence to CRB-G. This strain was purified by Sean Marshal in New Zealand, and was subsequently sent to Guam where A. Moore released it into the field using infected CRB as vectors. Results of releases of this strain of Oryctes nudivirus on Guam have revealed no virulence against CRB.

Prior to first detection of Aulacaspis yasumatsui on Guam during 2003, the endemic plant, Cycas micronesica, was the most abundant tree in Guam’s forests. To date, more than 90% of these plants have been killed by CAS resulting in C. micronesica being added to the US Threatened and Endangered Species list. Currently, there is no recovery taking place on Guam because all seeds and seedlings are being killed by CAS. At the start of the CAS infestation on Guam, conservation plots for C micronesica were established on Tinian Island, which was free of CAS. Unfortunately, CAS was detected in these plots about three years ago and many plants have been killed. Examination of leaf samples and yellow sticky traps from these plots indicated that no biocontrol agents were present.

Andreas- Over 135 biocontrol agent releases occurred across Washington State. Nine biocontrol agent species were released and redistributed to control eight weed species, including: giant and Bohemian knotweed, gorse, purple loosestrife, Scotch broom, Dalmatian toadflax, and Russian, diffuse and spotted knapweed.

Wright - Permits issued for release of *Phymastichus coffea* in Hawaii; currently preparing to import wasps from CENICAFE in Colombia, for two months quarantine rearing, prior to mass rearing for field release in coffee.

Moran - The shoot tip-galling arundo wasp Tetramesa romana was confirmed as established at five additional sites in the Central Valley of northern California (10 total established).

The rhizome- and shoot-feeding arundo armored scale *Rhizaspidiotus donacis*, was confirmed as established at 2 additional sites in the Central Valley of northern California (9 total established).

The shoot tip-galling fly Parafreutreta regalis, was confirmed as established at 3 additional sites (13 total established) along the California coast.

The leaf-feeding planthopper Megamelus scutellaris was confirmed as established at only 1 site (previously 3) in the Sacramento-San Joaquin Delta of northern California.

In collaboration USDA ARS (Xingeng Wang) California Dept of Food and Agriculture (Charlie Pickett and Ricky Lara) and USDA Biological Control Laboratory (EBCL) in France (Marie Claude Bon) and their colleagues, we are continuing our evaluation of California releases of P. lounsburyi against the olive fruit fly.

We continued to monitor our 40 field sites for the establishment and abundance of two gall-forming insects (stem gall wasp Aulacidea acroptilonica and gall midge Jaapiella ivannikovi) attacking Russian knapweed. We recorded the presence/absence of midge and wasp galls as the abundance of both gall species in terms of the number of galls per transect. We continued to gather weather (esp. rainfall) data to correlate with presence/absence and abundance measures.

We worked closely with approximately 150 landowners and county weed managers across the state of Colorado, distributing wasp and midge galls, providing advice on how and where to release these insects and manage their knapweed infestations to maximize establishment of these biocontrol agents.

1. Incomplete work or areas needing further investigation:

Swallow-wort biocontrol: Signs of overwintering success of *H. opulenta* in Michigan were detected in summer 2023 at two sites. Monitoring of establishment success of *H. opulenta* will continue in the next two years.

Knotweed biocontrol: Psyllids that overwintered successfully were found at five field sites during May and June but no psyllids were seen later in the summer. Monitoring will continue next year to see if self-sustaining populations of *A. itadori* may be present in the field.

Miller - Further research is needed to collect and identify additional OrNV virus strains that might prove lethal to the Guam CRB-G biotype. Foreign exploration for OrNV isolates pathogenic to CRB-G may occur in 2024. *M. majus* will continue to be spread and by infested CRB throughout Guam and the impact monitored.

Further research will be conducted to assess the extent of control of Asian cycad scale due to introduced predators, *Rhizobius lophanthae*, and parasitoids, *Arhenophagus* sp. Other biocontrol agents suitable for introduction to Guam will be investigated.

*Objective 1f.*  *Evaluate natural enemy efficacy and study ecological/physiological basis for interactions.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

A field cage experiment was setup to test the impact of H. opulenta with different genetic backgrounds on swallow-worts. All cages were placed at a site in Oakland County with a dense infestation of pale swallow-wort. We released 4 pairs of adults in each cage with three treatments coinciding to the three colonies (Inbred, Canadian, Outbred) on 6/14/2023. In total we set up 42 cages for 14 cages per treatment. The amount of defoliation per cage was quantified and second-generation emergence was tracked to determine success. Stem densities in each cage were taken as a covariate to account for differences in swallow-wort availability. We found that defoliation was highest for the outbred, second for the Canadian colony, and lowest for the inbred laboratory colony (Out =17%, Can = 13%, Lab = 4%).

Littlefield - Hoary cress: Eight previous releases of *Aceria drabae* were monitored in 2023. Galls were present at all sites, except for one that was inadvertently sprayed with herbicide. At our established sites we noted an exponential increase of infested stems. For example, at our original release site (released 2019) we observed nearly 88 thousand total infested stems (up from 6,121 in 2022). Future population increase is largely dependent upon site size and total number of available stems. We also noted an increase in gall intensity with entire inflorescences galled, as well as secondary stems. We have begun to characterize mite impact on seed production, plant height and secondary branching. To help land managers to more easily characterize gall intensity, we are developing a simplified rating system from 0-5, where 0 is an uninfested stem and a 5 is an entire or nearly completely galled stem. For preliminary analysis we plotted variables against percent galling/infestation and eventually against impact categories. As expected, the number of seeds produced decreased with percent infestation of the crown. Very few seeds were produced at higher gall intensities. However in our samples, seed production significantly decreased with only a slight amount of galling. Stem height did not seem to be highly impacted by gall intensity. A slight reduction in height was observed at the higher impact categories. However, the impact of galls may differ as to site or microhabitats. We will further characterize mite impact in 2024 and refine or modify the rating system.

The shoot-tip galling wasp Tetramesa romana was four-fold more abundant per main shoot on regrowth of Arundo donax that occurred after herbicide application than at on untreated plants, at three sites in thew Sacramento-San Joaquin Delta of northern California.

Danne - Ganaspis nr. sp. brasiliensis is being released across the US and Canada to control the spotted wing drosophila. Along with colleagues that form the USDA SCRI and OREI teams, we are evaluating the establishment and impact of this parasitoid in different regions and within different ecozones.

1. Incomplete work or areas needing further investigation:

Ode - We are actively investigating the role of soil and rhizosphere microbiomes in the successful establishment of both gall-forming agents against Russian knapweed.

## Objective 2: Conserve Natural Enemies to Increase Biological Control of Target Pests.

Objective 2a. *Characterize and identify pest and natural enemy communities and their interactions.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Erin Wilson UC Riverside- We integrate surveys, field studies and molecular approaches to evaluate trophic dynamics and assess the strength of predation in food webs. We have been monitoring populations of social yellowjackets (*Vespula pensylvanica*) in California aiming to understand the factors driving the increasing incidence of overwintering and multi-year nesting in this species. Colonies that overwinter and persist for multiple years continue to produce workers and brood throughout the year. Ongoing efforts aim to quantify the predation pressure of this yellowjacket on local pest populations during the traditional peak season (late summer/early fall) and during the overwintering period (winter/early spring). We have also been investigating the interactions between predators (e.g., mantids and lady beetles) and plant pests with attention to quantifying biocontrol services.

In a series of collaborative projects, we have led the diet analysis of avian predators to assess the degree to which these species provide pest control services (e.g., consume pest arthropods). In the past year, we have been finishing up our work in strawberry, and focusing on assessing the biocontrol services provided by blue birds in California vineyards. We are currently conducting molecular diet analyses on a subset of bird fecal samples and are developing species-specific primers for a set of high priority vineyard pests.

Heraty - Dominguez (graduate student) is addressing relationships in the *Gonatocerus* species group, which include important egg parasitoids of sharpshooters in California. This will be the first molecular analysis of the group and will try to address some recent controversial taxonomic changes that have been made at the genus level.

Wright - Assessing resident natural enemies of a new invasive insect, *Actre coerulla*, ramie moth, and their impacts on invasive status of this moth.

Jabbour - We are interested in how interseeding cover crops into standing corn impacts natural enemies. This practice is becoming more common due to other environmental benefits, but we are unsure of the impact on natural enemies such as ground beetles. Ground beetles can help reduce both insect pest and weed populations through weed-seed feeding.

We have collected and pinned ground beetles from two years of research in a field experiment including 6 different cover crop treatments and a control. Beetles were collected using pitfall traps. In 2023, we began sorting and identifying these beetles. We plan to continue with this identification, and subsequent data analysis in the coming year. In particular, we have one student intern dedicated to this research thanks to support from this project.

Mauck - The two aims we pursued within this sub-objective are: Aim 1. Quantify insect vectors responses to chemical cues of predators and determine their relevance for plant virus transmission. Aim 2. Identify chemical mediators of behavior among vector and natural enemy organisms. Within this sub-objective, we completed a project to characterize the behavioral responses of insect vectors (the aphid Myzus persicae, a target pest of this group) to chemical cues left behind on plants by biological control agents (in this case, a predatory lady beetle) and by non-predatory insects (fruit flies) (Aim 1). We also completed identifications of chemical constituents of lady beetle “footprints” that we determined elicit behavioral dispersal responses in the aphid prey (Aim 2). We combined this work with the results of experiments to quantify the impacts of aphid responses to predator footprints on transmission of a plant virus and produced a manuscript that was published in the journal Food Webs.

Hoddle – Two parasitoids of Asian citrus psyllid, Diaphorina citri, imported from Punjab Pakistan. One species, Tamarixia radiata, established readily, spread rapidly, and since the inception of this classical biological control program, ACP densities have declined by > 70%. The second species, Diaphorencyrtus aligarhensis, did not establish.

Hoodle - The efficacy of floral resources for enhancing native natural enemies, predatory syrphid flies, were evaluated. Results indicated that access to floral resources that provide adult hover flies nectar and pollen in citrus orchards, were associated with increased natural enemy activity and subsequent predation of the target pest, Asian citrus psyllid nymphs, increased and pest densities declined significantly when compared to control plots lacking floral resources.

Combining floral resources with ant control are being investigated as a potential way to “synergize” biocontrol agents attacking Asian citrus psyllid nymphs and other sap sucking pest species infesting citrus.

1. Incomplete work or areas needing further investigation:

Wright – continuing identification of parasitoids attacking ramie moth.

Hoodle - Argentine ant (AA), Linepithema humile, and invasive pest in California, has developed disruptive mutualisms with ACP and other sap sucking pests in California citrus orchards. AA protect sap-sucking pests from natural enemies and in return for this protection, sap sucking insects “reward” ants with honeydew, a sugary waste product that results from a phloem feeding habitat. When ants are suppressed, natural enemies provide exceptional levels of pest control. Efforts are currently focusing on the development of low toxicity baiting systems to control AA, use of IR sensors to automate counts of ants on irrigation pipes (AA uses long linear runs of smooth polyethylene pipes as super-highways to move from subterranean nests to trees to harvest honeydew), and cultural controls, such as 3D printed barriers attached to irrigation pipes to block/slow AA use of pipes.

*Objective 2b. Identify and assess factors potentially disruptive to biological control.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Erin Wilson - As detailed above, we have led the diet analysis of avian predators to assess the degree to which these species potentially disrupt pest control via the consumption of natural enemies and/or biocontrol agents.

R. Miller continued to survey invasive ants on the islands of Guam, Saipan, Tinian, and Rota in the Mariana Islands during 2023. This activity is part of an ongoing USDA-APHIS-CAPS funded project on the surveillance of *Wasmannia auropunctata* and *Solenopsis invicta* on Guam and the CNMI. A related study seeks to describe attendance behavior of Guam’s invasive ants towards aphids, scales and mealybugs commonly encountered in the Marianas, and the effects this might have on biological control agents against hemipteran plant pests. This project is ongoing due to the continued threat of new invasive ants arriving into the islands of Micronesia.

Wright - Determining effects of predatory insects and parasitoids on effectiveness of *Episimus utilis*, biocontrol agent of Christmas berry. Have identified a number of egg and larval parasitoids, and ants that act as predators of the larvae.

Rosenhiem - I have worked to understand how the parasitoid Aphidius ervi manipulates its host’s behavior in order to reduce the likelihood that the mummified aphid would be subsequently attacked by predatory ladybeetles, including Hippodamia convergens. I have also worked to understand how the omnivorous biocontrol agent Forficula auricularia (the European earwig) may also generate damage in citrus crops by functioning as an herbivore.

Jabbor - Alfalfa weevil is the pest of concern that we have been working on in this area. In 2023, PhD student in our group Judith Herreid continued her work to characterize the extent of hyperparasitism of biological control agent *Bathyplectes curculionis*, the most common parasitoid of alfalfa weevil in our region. We found that hyperparasitoids differentially attached diapause and non-diapause cocoons of *B. curculionis.* Hyperparasitoids collected included *Gelis* sp. and members of the Pteromalinae subfamily. Currently these findings to date are present in Dr. Herreid’s dissertation. Dr. Herreid successfully defended and graduated in Spring 2023, thanks to support from this multi-state project.

We have a large study looking at pesticides used in vineyards, and the focus has been on the application of materials that do not disrupt natural enemies.

1. Incomplete work or areas needing further investigation:

Wright - Developing molecular techniques for identification of *Episimus* DNA form predator gut content.

Jabbour - Dr Herreid plans to attempt to further identify the hyperparasitoid wasps in the coming year, which will be followed by our pursuit of publication of this work.

*Objective 2c. Implement and evaluate habitat modification, horticultural practices, and pest suppression tactics to conserve natural enemy activity.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Mauck - The two aims we pursued within this sub-objective are:

Aim 3. Quantify the effects of biologically active frass fertilizer derived from industrial insect rearing on plant resistance to viral pathogens.

Aim 4. Characterize the composition of frass fertilizer organisms and insect-derived natural products underlying effects on plant health. Within this sub-objective, we have been exploring the use of elicitors that prime plant defenses against pests and insect-transmitted pathogens. We focused on biologically based elicitor materials (manure) derived from industrial rearing of insect decomposers (frass from rearing black soldier flies on food waste). These substrates are enriched in compounds (e.g., chitin/chitosan) that promote populations of microbes that activate plant defenses when present in the rhizosphere. In the project period, we carried out experiments to evaluate the effects of frass on plant growth and resistance to plant pathogens. We found that frass applied to the soil primes plant defenses in lettuce, resulting in resistance to a damaging plant virus (impatiens necrotic spot virus). Similar experiments with cantaloupe plants did not show positive effects on plant resistance to potyvirus. However, in all cases, frass addition to soil stimulated increased plant growth independent of effects on resistance to viruses. These data suggest that frass could be useful as a biological stimulant for plant pathogen resistance. Alongside these experiments, we also collected soil samples from soils amended with frass or no frass in greenhouse and field experiments. These will be used to assess frass effects on soil microbial communities.

1. Incomplete work or areas needing further investigation:

## Objective 3: Augment Natural Enemies to Increase Biological Control Efficacy.

Mauck - Samples from experiments completed in the prior project period are stored. We still need to extract DNA from these samples and perform amplicon sequencing to characterize the microbial communities (fungal and bacterial).

*Objective 3a. Assess biological characteristics of natural enemies.*

1) Arthropod or weed pests

Rene Sforza

* *Genista monspessulana* : Evaluating the microbes associated to the plant feeder *Lepidapion argentatum,* especially potential plant pathogenic fungi. Eight saprophytic fungi or opportunistic plant pathogens identified.

1. Degree to which objective has been accomplished:

Rene Sforza- -100% for *Lepidapion argentatum*

1. Incomplete work or areas needing further investigation:

*Objective 3b. Develop procedures for rearing, storing, quality control and release of natural enemies, and conduct experimental releases to assess feasibility.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Leppla- The purpose of this research was to assess the host preference of field-collected *T. pennipes* and their laboratory-propagated first generation progeny (F1) by conducting choice tests using host species of Pentatomidae, the southern green stink bug, *Nezara viridula* (L.) (NV), and two Coreidae, the squash bug, *Anasa tristis* (DeGeer)(AT), and eastern leaf-footed bug, *Leptoglossus phyllopus* (L.) (LP)*.* The preference of *T. pennipes* for NV, AT, and LP adults was assessed through a series of choice tests using P generation flies from field-collected hosts. The number of eggs collectively oviposited on each host species were compared to determine if the P generation of *T. pennipes* preferred to oviposit on its host species of origin, and if this pattern would persist in host-specific lines of the F1 generation. When choice tests were conducted on generation P, *T. pennipes* oviposited significantly more eggs on its host of origin when compared to the other two equally available hosts. This preference for the host of origin was observed in flies that had emerged from all three host species. This finding is consistent with the hypothesis that *T. pennipes* females prefer to oviposit on their host of origin. When the same choice tests were conducted on F1 progeny, AT-AT and AT-LP females oviposited an equal number of eggs on AT hosts and relatively few on NV and LP hosts. AT adults are larger and more suitable than LP adults for parasitoid larval development. The AT-NV females did not oviposit. The NV-AT females oviposited a small number of eggs on all three host species, NV-NV preferred NV hosts, and NV-LP did not oviposit. No eggs were oviposited by LP-AT, LP-NV or LP-LP. Thus, species-specific host preference persisted in the F1 *T. pennipes* NV-NV pentatomid host line, whereas the F1 AT-AT and AT-LP coreid hosts received the same number of eggs.

Dillman - We have been optimizing freezing procedures for a new species of EPN from Thailand, this would be useful for long-term storage.

We have studied cold storage and mass production techniques of the Drosophila suzukii parasitoids Pachycrepoideus vindemiae (Pteromalidae), Trichopria drosophilae (Diapriidae) in order to improve mass production.

1. Incomplete work or areas needing further investigation:

Leppla - *Trichopoda pennipes* has considerable potential as an augmentative biological control agent, parasitizing insects from at least six true bug families of Coreidae, Largidae, Pentatomidae, Scutelleridae, Pyrrhocoridae, and Alydidae, with representatives from over 15 genera. For unknown reasons, however, *T. pennipes* causes high levels of parasitism in some hosts, locations and cropping systems but not others. Therefore, we are conducting research to: 1) design and test efficient and reliable systems for rearing the host pentatomids and coreids for producing host-specific *T. pennipes* lines, 2) determine the preference of *T. pennipes* for alternative pentatomid and coreid hosts and associated host suitability, and 3) establish and test colonies of *T. pennipes* that are effective against individual pentatomid and coreid pest species. Studies are needed on a range of these parasitoid-host relationships, including how genetic and phenotypic variation of the host affects parasitoid host selection and suitability. Research is also needed on rearing methods, host ranges, potential effectiveness, release strategies, and impact monitoring.

*Objective 3c. Implement augmentation programs and evaluate efficacy of natural enemies.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Dillman - We have sequenced the genome of *Steinernema hermaphroditum*, an EPN that could be useful in biological control.

Danne - In collaboration with researchers at USDA (Brian Hogg), we have released two pupal parasitoids, Pachycrepoideus vindemiae (Pteromalidae) and Trichopria drosophilae (Diapriidae) near blue berry and strawberry fields to ‘inoculate’ these resident parasitoids before and after the harvest cycle.

1. Incomplete work or areas needing further investigation:

Dillman- We are using the genome now to test strategies for genetic manipulation. This could lead to augmentation of EPNs.

## Objective 4: Evaluate Environmental and Economic Impacts and Raise Public Awareness of Biological Control.

*Objective 4a. Evaluate the environmental and economic impacts of biological control agents.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Erin Wilson UC Riverside - As part of our quantification of pest predation, we also aim to assess the ecological and economic impacts of the predators. This involves quantifying response of prey populations (both target pest taxa and non-pest, native taxa) to predatory pressure in the field. In addition to quantifying correlations between pest and predator populations, we aim to evaluating predators’ contributions to ecosystem services and using genomic methods to identify cryptic trophic links in invaded food webs. These efforts aim to further our understanding of trophic dynamics in natural and agroecosystems in California and the Pacific. These efforts are ongoing.

Lara Ricky - During 2023, the establishment of Trissolcus japonicus and its impact on target Halyomorpha halys populations were tracked at urban and agricultural field sites across various California counties with support from the University of California. This project is still underway.

Andreas –

Developed, in partnership with other biocontrol specialists, a Weed Biocontrol 101 curriculum for the North American Invasive Species Management Association’s (NAISMA) InvasivesU. <https://naisma.org/programs/professional-development/biological-control-101/>

Developed and reviewed peer-reviewed weed and biocontrol agent factsheets for NAISMA. Factsheets are developed with other biocontrol specialists. <https://naisma.org/naisma-resources/biocontrol/biocontrol-factsheets/>

Developed, in partnership with other biocontrol specialists, a special session entitled “The role of chemical ecology in weed biological control” for the NAISMA conference in Lincoln, NE.

Co-presented a NAISMA webinar entitled: Reviewing the Impacts of Climate Change on Biological Control Agents: Identifying Research Priorities and Knowledge Gaps. <https://naisma.org/event/september-webinar/>

Provided five weed biocontrol presentations on theory, principles, uses, weed/biocontrol systems, and research to landowners, land-managers, and researches.

Hoodle - Comprehensive field evaluations of the impacts of Tamarixia radiata and native natural enemies on the invasive citrus pest, Asian citrus psyllid (ACP), were completed. Studies conducted across numerous sites and 2-3 years conclusively demonstrated that target pest densities declined by >70% since the inception of the classical biocontrol program targeting this pest. When invasive Argentine ants are present at study sites, ACP densities tend to be about 3x higher than sites lacking ants, and percentage parasitism levels of ACP nymphs are significantly lower too.

1. Incomplete work or areas needing further investigation:

Andreas - Preparing tree-of-heaven spotted lanternfly/eriophyid mite education material. Will be completed in early 2024.

Danne - During 2018, the Daane laboratory has presented at 21 research or grower-oriented programs to reach an estimated audience of about 2000 persons (estimated at 100 persons per presentation).

*Objective 4b. Develop and implement outreach activities for biological control programs.*

1) Arthropod or weed pests

1. Degree to which objective has been accomplished:

Rory McDonnell - Maintained an Association website to aid in networking for the commercial biocontrol industry.

Maintained a database of all commercially-produced natural enemies for sale in North America for biocontrol in IPM systems

Organized a meeting with USDA, APHIS and the Association of Natural Biocontrol Producers on November 6, 2023 to meet the new biocontrol permitting scientist and learn all new items on the APHIS list for eFileing and permitting. (Held during the same week as the ESA National meeting in D.C.).

Lara Ricky - In July 2023, I co-organized a biological control and IPM workshop with the University of California focused on providing research updates to students training to become future farmers. The workshop allowed participants to see general cole crop pests and associated natural enemies (predators and parasitoids) representative of the Salinas Valley in California.

Heraty - As part of our NSF project we developed online modules that explain parasitoids to high school students, Master Gardeners and other venues (http://outreach.chalcid.org/). The approach is to teach more upper-division students or adults about the importance of parasitoids in biological control. We developed outreach materials to teach about chalcidoids and other parasitic Hymenoptera in the classroom. The idea is to develop independent modules for classrooms centered on yellow pan trap ‘observatories’ as a means to discuss ‘true’ biodiversity. Our ideas for outreach were vetted through a broad group of local teachers, and extension researchers at UC Riverside and Texas A&M University. We developed an online powerpoint presentation, with audio, on biodiversity of parasitic Hymenoptera that we have been able to get introduced into high school curriculums on ecology.

R. Miller conducted workshops on Guam, Saipan (CNMI), Yap (FSM), Palau, and Majuro (RMI) discussing the impacts of invasive species with emphasis on W. auropunctata and O. rhinoceros, and the role that biological control may play in mitigating these pests in island ecosystems. These workshops will continue with plans to hold new workshops on Pohnpei, Kosrae, and Chuuk (FSM) in 2024.

***Extension - Oral Presentations***

1. **Szűcs M**. **2023.** Can this moth help save monarchs? Swallow-wort biological control efforts in Michigan. **NotMISpecies Webinar Series.** Department of Environment, Great Lakes, and Energy (EGLE). 484 registrants. 198 people online. Webinar recorded and available for later viewing. <https://rb.gy/l6lv8>.
2. **Szűcs M**. **2023.** Biological control of the lily leaf beetle. **73rd Annual International Lily Show and Symposium,** Chicago, IL.
3. **Szűcs M**. **2023.** Biological control of knotweeds and swallow-wort vines. **Michigan Invasive Species Coalition Annual Meeting**, Gaylord, MI Jan 25-26. Hybrid meeting. In person presentation. In-person attendance 75 people.
4. **Szűcs M**. **2023.** If you can’t beat ‘em, find something that will eat ‘em: Biological control for invasive knotweeds. **NotMISpecies Webinar Series** Department of Environment, Great Lakes, and Energy (EGLE). 576 registrants. 291 people online. Webinar recorded and available for later viewing. <https://us06web.zoom.us/rec/share/sYgOth1txcNOs6vgJOIxCPFWjnJDphw_INSVh29_et2AJq03QKP-gOBrqYFzn6c.bAy9DGgatJbmi1WP>.
5. **Szűcs M**. **2022.** Swallow-wort biological control in Michigan. **St. Lawrence Eastern Lake Ontario Partnership for Regional Invasive Species management (SLELO-PRISM)**. **Eastern Lake Ontario Swallow-wort Collaborative**. State of the Science Swallow-wort Biocontrol. Virtual presentation. 215 people registered and recording is uploaded to YouTube for later viewing. <https://swallowwortcollaborative.org/webinar-recordings/>

***Extension - Poster Presentations***

1. **Szűcs M,** O. Istas\*. **2023.** *Ganaspis brasiliensis* releases for biological control of spotted wing drosophila across lower Michigan. **Great Lakes Expo**. Dec 2023.
2. Michaelson J\*, JK. Wilson, **M. Szűcs. 2022.** Establishing the Samurai Wasp in Michigan for Biological Control of the Brown Marmorated Stink Bug. **Great Lakes Expo. Dec 2022.**

***Extension – Publications***

1. Tewksbury L, **M. Szűcs,** Milbrath LR, Bourchier RS, Cappuccino N. **2023.** Swallow-worts, *Vincetoxicum* spp. History and Ecology in North America. **Factsheet.** <https://bugwoodcloud.org/resource/files/27697.pdf>
2. Tewksbury L, **M. Szűcs,** Milbrath LR, Bourchier RS, Cappuccino N. **2023.** Swallow-wort Biocontrol Agents. History and Ecology in North America. **Factsheet.** <https://bugwoodcloud.org/resource/files/27698.pdf>
3. **M. Szűcs**, J. Littlefield, CB Randall, JE Andreas. **2022.** Tansy ragwort, *Jacobaeae vulgaris* Gaertn. History and Ecology in North America. **Factsheet.** [https://www.ibiocontrol.org/view.cfm?rid=35341&#](https://www.ibiocontrol.org/view.cfm?rid=35341&); <https://bugwoodcloud.org/resource/files/25374.pdf>
4. **M. Szűcs**, J. Littlefield, CB Randall, JE Andreas. **2022.** Tansy ragwort biocontrol agents. History and Ecology in North America. **Factsheet.** <https://www.ibiocontrol.org/view.cfm?rid=35342&>; <https://bugwoodcloud.org/resource/files/25373.pdf>
5. Michaelson J.\*, JK. Wilson, **M. Szűcs. 2022** An update on increasing the abundance of samurai wasp for biological control of the brown marmorated stink bug <https://www.canr.msu.edu/news/increasing-samurai-wasp-for-biological-control-of-brown-marmorated-stink-bug>. **MSU Extension News.**
6. Incomplete work or areas needing further investigation:

# 4. USEFULNESS OF FINDINGS (According to the guidelines, impacts are the economic, social, health or environmental benefits derived by the intended users. Further, each impact statement should be a single sentence and should quantitatively define the benefit.)

1. Outputs/Impacts:

The Association of Natural Biocontrol Producers connects commercial rearing and distribution professionals, university and USDA biocontrol scientists, and the USDA regulatory staff to maintain the availability and quality of natural enemies used in agriculture today.

Erin Wilson - Quantification of ecosystem services/disservices and identification of management strategies and landscape features associated with these services/disservices help resource managers and environmental stakeholders develop prioritization frameworks.

Lara Ricky – Classical biological control agents targeting invasive arthropod pests are being reared and redistributed by CDFA’s biological control program to reduce pest densities for the benefit of specialty crop growers, land managers, and urban communities.

Littlefield - We released the gall mite *Aceria drabae* at a total of sixteen sites in Montana. This is the first biological control agent to be released in North America against hoary cress. The mite appears to be established and/or increasing in numbers at eleven sites. At well-established sites we are noting possible impact on seed production and some stunting of plants.

Leppla - An increasing number of invasive stink bug species continue to enter the U.S., become established, spread to new geographical areas, and infest additional crops. Along with native pest species, these recent invaders cost growers of agronomic, fruit, vegetable, and ornamental crops in the U.S. millions of dollars annually due to reduced yields and increased control costs. Stink bugs can be controlled with pyrethroid and organophosphate insecticides but the frequency of applications is increasing and there are significant non-target effects. Vegetable and fruit growers would benefit greatly by having effective augmentative parasitoids available to manage stink bugs in several of their crop production systems. Biological control using *T. pennipes* is a promising option if this parasitoid can be mass reared and applied effectively.

Hearty - Chalcidoidea are economically and biologically one of the most important groups of insects, and yet very little is known of their taxonomy (identification) or relationships. Our research is identifying new potential biological control agents for use against pestiferous leafminers on citrus, whitefly on citrus, aphids on wheat and other crops, and for wasps attacking pestiferous ants. New research on cryptic species complexes (morphologically identical but reproductively and biologically distinct species) using molecular markers has tremendous potential for the identification of new biological control agents. Identification keys and other products will help other researchers to better understand the impact of these groups, and identify gaps that aid in targeting new biological control agents.

Rene Sforza - The phylogeography study conducted on *Pyrrhalta viburni* collected in U.S, Canada and North and Southwestern Europe evidenced for the first time that the North American populations primarily resulted from multiple introductions from Northwestern Europe, but not only, pinpointing partially the sources for collecting promising natural enemies.

The identification of the assemblage of parasitoids associated with the olive psyllid in France confirmed that populations of the biocontrol agent *Psyllaephagus euphyllurae* are present in Southern France and genetically similar to those in Spain which are being released in California by CDFA, broadening access to larger populations of the biocontrol agent.

*Diadegma semiclausum* was one of the most common larval parasitoid of *Plutella xylostella* evidenced in the European countries surveyed by EBCL and has been genetically characterized. The genetic data obtained were merged with those retrieved from other populations worldwide, serving as basis for future development of detection molecular tools to be applied in the field.

On French broom (Genista monspessulana), the absence of plant or insect pathogens associated to *Lepidapion argentatum*, in addition to its double ability to develop in stems and pods indicate that it could be an efficient and safe candidate for the control of the invasive Broom

First surveys ever on Brassica tournefortii (Sahara mustard) in its native range in Egypt and Israel, with few curculionids and moths collected with herbivory impact

The identification of the assemblage of natural enemies of stinkwort (*Dittrichia graveolens*) from collections made in the Mediterranean basin Moths and rusts were of particular interest

Andreas - Using the USFS standard that one biocontrol release treats five acres, over 675 acres were treated in Washington in 2023.

Wright - Release of natural enemy of coffee berry borer should provide significant economic benefits to coffee growers.

Dillman- The discovery and description of new species of EPNs may lead to their effective use in biological control. Every new EPN species may help alleviate insect herbivory of important agricultural crops.

Jabbour - Documentation of hyperparasitism of *Bathyplectes curculionis* highlights a disruptive factor to biological control of alfalfa weevl *Hypera postica.* Alfalfa weevil remains very problematic, and the current agents are not providing enough of a benefit.

Danne - Outputs. The Daane laboratory conducted research and compiled results on invasive pests (spotted wing drosophila, olive psylla, brown marmorated stink bug, vine mealybug) and native pests (stink bugs and leaffooted bugs). The work resulted in numerous presentations to growers and researchers, peer-reviewed publications, and USDA APHIS petitions to release natural enemies of invasive species (spotted wing drosophila and olive psylla).

Impacts. Growers were presented a greater number of control tools for invasive and native pests of vineyards, nut crops and various row crops, including hemp. This information has aided growers in more sustainable farming techniques, resulting in a reduction of the pesticide load in the environment, a reduction in pest damage and an increase in farm profitability.

Mauck - Our discovery that insect vector behavior is modified by chemical cues from predators could be leveraged to develop novel, environmentally safe pest repellants.

Biologically active substrates derived from insect decomposers may help promote biological control and assist with priming plant defenses against diverse threats.

Hoodle - Our data for the Asian citrus psyllid biological control project strongly suggests that target pest populations have been reduced by 70% since project inception. The impact of this successful program has been to maintain pest populations almost exclusively in urban grown citrus. This was the goal of the biocontrol program, to reduce the spread of ACP populations out of heavily infested urban areas into commercial citrus production areas. Consequently, ACP and the lethal citrus-killing bacterium that this pest vectors, CLas, which caused the disease huanglongbing (HLB), has been restricted to urban citrus and has not moved aggressively into commercial citrus for > 12 years. This has not been achieved in any other area where ACP-CLas has invaded.

1. Projected outputs or impacts:

Establishment and control by *Hypena opulenta* would reduce the amount of herbicide used to control swallow-worts.

Establishment and control by *Aphalara itadori* would reduce the amount of herbicide used to control knotweeds.

Littlefield - These projects will contribute to the selection of potentially new biological control agents for the control of noxious weeds. New agents are being investigated for the biological control of Russian knapweed, hoary cress, common tansy, oxeye daisy, invasive hawkweeds, and rush skeletonweed. The target weeds have either no biological control agents currently available or the agents already established are not effective over the range of the target weed. In addition, a better understanding of biological control and its implementation will be achieved by monitoring the impacts associated with these biological control agents.

Danne - If our USDA APHIS petitions are approved, we expect significant work over the next 5 years on the release and evaluation of these natural enemies, used in a classical biological control program.

Hoodle - California’s citrus industry will not suffer from massive CLas outbreaks resulting in the mortality of millions of citrus trees. This catastrophic outcome has been observed in Florida where ACP-CLas are widespread.

# 5. PUBLICATIONS ISSUED AND MANUSCRIPTS APPROVED

(Any common format is acceptable here. Publication date should be within the last year)

1. Yonow, T., Kriticos, D.J., Zalucki, M.P., Mc Donnell, R.J. and Caron, V. (in press) Population modelling for pest management:  a case study using Cochlicella acuta and Sarcophaga villeneuveana in Australia. Ecological Modelling.
2. Mc Donnell, R.J., Vendetti, J., Paine, T.D. and Gormally, M.J. (in press) Slugs: A Guide to the Invasive and Native Fauna of California. 2nd Edition. University of California Agricultural and Natural Resources Publications.
3. Kunkel, B., Cissel, B., Tooker, J.F., Howe, D.K., Denver, D.R., Mc Donnell, R., and Hiltpold, I. (2023) Nematodes associated with terrestrial slugs in mid-Atlantic (Delaware, USA) soybean. Agronomy 13: 645
4. Patuwatha Withanage, D.B.M., Howe, D.K., Richart, C., Mc Donnell, R.J., Denver, D.  & Luong, L.T. (2023) Pestiferous slugs and their associated nematodes in agricultural fields, greenhouses, and nurseries in Alberta, Canada. Journal of Helminthology 97: e41, 1-9
5. Mc Donnell, R.J., Howe, D.K., and Denver, D.R.  (2023) First Report of the Gastropod-Killing Nematode, Phasmarhabditis californica, in Washington, U.S.A. Journal of Nematology 55: 20230013
6. Istas O\* and **M. Szűcs. 2023**. Biological control potential of a laboratory selected generalist parasitoid versus a co-evolved specialist parasitoid against the invasive *Drosophila suzukii*. **Evolutionary Applications.** https://doi.org/10.1111/eva.13605
7. Simaz O\*, J. Michaelson\*, JK. Wilson, E. Talamas, L. Gut, J. Pote, **M. Szűcs**. **2023.** Field releases of the exotic parasitoid Trissolcus japonicus and survey of native parasitoids attacking Halyomorpha halys in Michigan. **Environmental Entomology**. doi: 10.1093/ee/nvad102.
8. Linder S\*, BJM. Jarrett\*, **M. Szűcs. 2023.** Non-target attack of the native stink, *Podisus maculiventris* by *Trissolcus japonicus*, comes with fitness costs and trade-offs. **Biological Control.** 177:105107 doi.org/10.1016/j.biocontrol.2022.105107
9. Linder S\*, Jarrett BJM\*, PD Fanning, R. Isaacs and **M. Szűcs. 2022**. Limited gains in native parasitoid performance on an invasive host beyond three generations of selection. **Evolutionary Applications**. 15: 2113-2124 doi.org/10.1111/eva.13504. (Open Access)
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**See next page for Appendix C: Arthropod Pests. Review the species lists to ensure all relevant species are included. Additions and changes in species names are welcome. Indicate new text by highlighting.**

**Appendix C**

**W5185 Current Target Pest Groups and Species (2022)**

**Arthropod Pests**

Aphids: (1) *Acyrthosiphon pisum*, (2) *Aphis craccivora,* (3) *Aphis gossypii*, (4) *Melanocallis caryaefoliae*, (5) *Monellia caryella*, (6) *Monelliopsis pecanis*, (7) *Myzocallis* *walshii,* (8) *Myzus* *persicae,* (9) *Pentalonia nigronervosa*, (10) *Toxoptera citricida*, (11) *Diuraphis noxia,* (12) Unspecified species

Beetles: (1) *Ceutorhynchus obstrictus,* (2) *Diabrotica virgifera virgifera*, (3) *Hypera postica,* (4) *Lilioceris lilii,* (5) *Oulema melanopus,* (6) *Cylas formicarius,* (7) *Oryctes rhinoceros*,(8) *Rhynchophorus ferrugineus,* (9) *Rhynchophorus vulneratus,* (10) *Rhynchophorus palmarum*, (11) *Agrilus auroguttatus,* (12) *Hypothenemus hampei*, (13) *Leptinotarsa decemlineata*, (14) *Anoplophora glabripennis*,(15) *Anaplophora chiniensis,* (16) *Pyrrhalta viburni,* (17) *Euwallacea fornicatus* species complex, (18) *Agrilus planipennis* (19) Unspecified species

Tumbleweeds:

Heteroptera: (1) *Anasa tristis*, (2) *Erythroneura variabilis,* (3) *Leptoglossus clypealis*, (4) *Lygus* spp., (5) *Nezara viridula*, (6) *Bagrada hilaris*, (7) *Halyomorpha haly*s, (8) *Pseudacysta perseae*, (9) *Megacopta cribraria*, (10) *Leptoglossus zonatus,* (11) *Erythroneura ziczac,* (12) Unspecified species

Lepidoptera: (1) *Acropsis muxnoriella*, (2) *Acrolepiopsis assectella*, (3) *Adoxophyes orana,* (4) *Amyelois transitella*, (5) *Anarsia lineatella*, (6) *Choristoneura rosaceana*, (7) *Enarmonia formosana,* (8) *Heliothis zea*, (9) *Marmara* spp., (10) *Pandemis limitata*, (11) *Pandemis heparana*, (12) *Pectinophora gossypiella*, (13) *Phyllocnistis citrella*, (14) *Plutella xylostella*, (15) *Spodoptera exigua* (16) *Epiphyas postvittana,* (17) *Lobesia botrana,* (18) *Stenoma catenifer,* (19) Unspecified species

Sessile Hemiptera (Sternorrynchus):

(1) *Aonidiella aurantii*, (2) *Coccus pseudomagnoliarum,* (3) *Dysmicoccus* brevipes, (4) *Dysmicoccus neobrevipes*, (5) *Glycaspis brimblecombei*, (6) *Maconellicoccus hirsustus*, (7) *Planococus ficus*, (8) *Pseudococcus maritimus*, (9) *Pseudococcus viburni*, (10) *Quadraspidiosus perniciosus*, (11) *Saissetia oleae*, (12) *Icerya seychellarum*, (13) *Icerya purchasi*, (14) *Aspidiotus destructor*, (15) *Pseudaulacaspis pentagona*, (16) *Quadraspidiotus juglansregiae,* (17 ) *Quadrastichus erythrinae,* (18) *Diaphorina citri*, (19) *Euphyllura olivine*, (20) *Bactericera cockerelli*, (21) *Rhipicephalus annulatus,* (22) Unspecified species

Fruit flies (tephritids*)*:

(1) *Zeugodacus cucurbitae*, (2) *Bactrocera dorsalis,* (3) *Bactrocera latifrons*, (4) *Bactrocera oleae*, (5) *Ceratitis capitata,* (6)Unspecified species

Whiteflies: (1) *Bemisia* spp., (2) *Aleurodicus dugesii*, (3) *Paraleyrodes* spp., (4) Unspecified species.

Hymenoptera: (1) *Wasmannia auropunctata*

Other arthropods:

(1) *Cacopsylla pyricola*, (2) *Cephus cinctus,* (3) *Delia radicum,* (4) *Eucalyptolyma maideni*, (5) *Homalodisca vitripennis (*= *coagulata*), (6) *Liriomyza trifolii*, (7) *Scirtothrips perseae,* (8) *Scirtothrips citri,* (9) *Panonychus citri*, (10) *Tetranychus urticae*, (11) *Tetranychus marianae,*(12) *Tetranychus pacificus* , (13) *Oligonychus perseae,* (14) *Quadrastichus erythrinae,* (15) *Piezodorus guildinii*, (16) *Drosophila suzukii,* (17) *Frankliniella occidentalis*, (18) *Caliothrips fasciatus*,(19) *Contarinia nasturtii*, (20) *Rhipicephalus microplus* (21) Rhipicephalus annulatus (22) *Phytomyza gymnostoma* (23) *Lycorma delicatula* (24) Neoscapteriscus spp. (25) Unspecified species (26) Hamaephysalis spp.

**Weeds**

Brassicas: (1) *Alliaria petiolata,* (2) *Isatis tinctoria,* (3) *Lepidium* (= *Cardaria*) *draba,* (4) *Lepidium latifolium, (5) Brassica tournefortii*

Gorse and broom: (1) *Ulex europaeus*, (2) *Cytisus* spp., (3) *Genista monspessulana*, (4) *Spartium junceum*

Grasses: (1) *Arundo donax*, (2) *Phragmites australis*, (3) *Megathrysus infestus,* (4) *Taeniatherum caput-medusae*, (5) *Ventenata* sp., (6) *Bromus tectorum*, (7) *Megathyrsus maximus* (8) *Imperata cylindrica*

Knapweeds: (1) *Rhaponticum* (*Acroptilon) repens*, (2) *Centaurea diffusa*, (3) *Centaurea stoebe subsp. micranthos*, (4) *Centaurea solstitialis*, (5) *Centaurea virgata spp. squarrosa*

Knotweeds: (1) *Reynoutria japonica* (2) *Reynoutria sachalinensis*, (3) *Reynoutria x bohemica*

Purple loosestrife: (1) *Lythrum salicaria*

Saltcedars: (1) *Tamarix ramosissima*, (2) *Tamarix* spp.

Spurges: (1) *Euphorbia esula*, (2) *Euphorbia virgata*

Thistles: (1) *Carduus nutans*, (2) *Carduus tenuiflorus,* (3) *Cirsium arvense*, (4) *Cirsium vulgare,* (5) *Carduus pycnocephalus,* (6) *Onopordum spp.*

Tumbleweeds: (1) *Salsola australis*, (2) *Salsola paulsenii*, (3) *Salsola tragus*

Other weeds: (1) *Chondrilla juncea*, (2) *Convolvulus arvensis*, (3) *Cynoglossum officinale*, (4) *Delairea odorata*, (5) *Dipsacus laciniatus*, (6) *Galium aparine*, (7) *Pilosella* (*Hieracium)* spp., (8) *Hypericum perforatum*, (9) *Linaria dalmatica,* subsp. *dalmatica*, (10) *Linaria vulgaris*, (11) *Peganum harmala*, (12) *Potentilla recta*, (13) *Salvia aethiopis*, (14) *Salvinia molesta*, (15) *Jacobaea vulgaris* (*Senecio jacobaea)*,(16) *Tanacetum vulgare,* (17) *Elaeagnus angustifolia*, (18) *Tribulus terrestris,* (19) *Eichhornia crassipes,* (20) *Pueraria montana*, (21) *Leucanthemum vulgare*, (22) *Mikania micrantha*, (23) *Vincetoxicum* spp., (24) *Ludwigia* spp., (25) *Dittrichia graveolens,* (26) *Mesembryanthemum crystallinum*, (27) *Crupina vulgaris* (28) Unspecified other species.