**ANNUAL REPORT OF CONTRIBUTING PROJECT TO**

**COOPERATIVE REGIONAL PROJECT W4185**

**Biological Control in Pest Management Systems of Plants**

January 1, 2020 to December 31, 2020

**1. PROJECT:** Regional W4185: Biological Control in Pest Management System of Plants.

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**2020 W4185 Program and Minutes**

The W4185 traditionally meets for 2 days in the fall in a location that fosters a somewhat remote environment excellent for networking and focused discussion. This group works on over 140 arthropod and weed pests. A hotel contract was in place early in 2020 for the meeting to be held at the Tenaya Lodge near Yosemite in October. Fortunately, the contract was forgiven when many regions of the country began to place travel restrictions due to COVID-19. The logistics of doing a virtual meeting were examined and one of the many factors that came into play was the vast geographical spread of the group and their difficulties in “attending”. We have members that attend annually from multiple global time zones, including Europe, Hawaii and Guam (plus 17 US states). Given that it was impossible to find a time that reasonably worked for everyone to meet as a group, it was decided to hold a virtual Administrative meeting only to discuss logistical issues and begin planning for 2021. The following are minutes from a Zoom meeting in October 2020, but email correspondence and phone calls continued through December.

**W4185 Administrative Meeting**

Oct. 2, 2020; 11:00-12:00 PM (PST)

**Participants**

Steve Novak, Boise State, W4185 Chair 2020

Houston Wilson, UC Riverside, W4185 Chair 2019

Paul Ode, Colorado State University, W4185 Chair 2018

Lynn LeBeck, Assoc. Natural Biocontrol Producers (ANBP), W4185 member

**Topics covered**

* Call for Annual Report. Deadline Dec 1, 2020.
* Houston Wilson will be sending a message to all members with the Annual Report template by Oct. 15, with updates on W4185 plans, and information about our Secretary, Ruth Hufbauer (Colorado State). He will also mention we will start taking nominations for the next Member-at-Large.
* Discussion led by Steve Novak about his plans for drafting a proposal of locations and times for the 2021 meeting in Idaho. Steve is aiming for sending out a ppt file or something similar to the membership by early November for their input. Lots of discussion about how the meeting is financed, organized, and many other related issues.
* Discussion about the W4185 Renewal process that starts next year. The project renewal is typically due in the January of the year the new project would start, so January 2022. Data collection and work on the Renewal document would begin next year. Lynn’s advice was to check in with Tim Paine, our Adviser, to see if there are any anticipated new requirements for preparing and submitting that document.

**ACCOMPLISHMENTS** These are only a selection of 2020 results. This large, collaborative group works on **OVER** **140** different species of arthropod and weed pests. Many reports this year emphasized that limited travel (especially international travel) and access to laboratories due to the Covid-19 pandemic impacted the extent of project results.

**Goal A: Import and Establish Effective Natural Enemies**

***Objective 1. Survey indigenous natural enemies.***

Surveys were conducted for native and the self-introduced parasitoid, *Trissolcus japonicus*, attacking the eggs of the brown marmorated stink bugs (BMSB), *Halyomorpha halys* (Hemiptera: Pentatomidae). This project is in its second year. Surveys are concentrating efforts in the Los Angeles Basin, southern California. Survey methods included the deployment of frozen sentinel BMSB egg masses and subsequent collection of these eggs after a 3-4 day exposure period. Field exposed eggs are sent to CDFA for rearing of parasitoids. The goal is to collect the self-introduced BMSB egg parasitoid, *Trissolcus japonicus*, which has been previously collected in the LA Basin by the Hoddle lab. CDFA will use these parasitoids to start *T. japonicus* colonies for mass production and release.

Proactive screening of an egg parasitoid, *Anastatus orientalis*, a natural enemy of the invasive spotted lantern fly, *Lycorma delicatula*, (Hemiptera: Fulgoridae), is underway in quarantine at UC Riverside. The goal of this project is to have host range and host specificity tests completed for *A. orientalis* in advance of the anticipated invasion by *L. delicatula* into California. Significant progress has been made in host range testing and molecular and morphological identification of native non-target fulgorid species. This is a collaborative project with colleagues on the east coast of the USA where SLF has already established and is spreading. This pest presents a significant threat to California’s grape and nut industries.

Isolates of *Oryctes rhinoceros* *nudivirus* (OrNV) are being evaluated as candidates for effective biocontrol of coconut rhinoceros beetle biotype G (CRB-G).

Extant natural enemies of bagrada bug (*Bagrada hilaris*) were sampled throughout northcentral California using sentinel bagrada bug eggs. Parasitism rates were far below 1%, although up to 100% of eggs were consumed by predators at some sites.

Parasitism by resident parasitoids on spotted wing drosophila (*Drosophila suzukii*) was monitored in cane berry fields and adjacent semi-natural habitats in the central coast of California.

A novel strain of the egg parasitoid *Anagrus* *daanei* (Mymaridae), a natural enemy of the Virginia creeper leafhopper (Cicadellidae: *Erythroneura ziczac*) has been identified in California.

Surveyed for natural enemies of insect pests (*Bagrada hilaris, Pyrrhalta viburni, Phytomyza gymnostoma, Bactrocera oleae*), and of weeds (*Genista monspessulana, Vincetoxicum* sp*., Ailanthus altissima, Taeniatherum caput-medusae,* and *Ventenata dubia)* in Europe, Africa and Asia.

Investigations continued on the current distribution, abundance and parasitism of the light brown apple moth (*Epiphyas postvittana*, LBAM) in California. Larval populations were found in landscape plantings from Santa Rosa in the north to Rancho Santa Fe in the south, but frequency of occurrence and abundance varied considerably between regions and locations. No larvae were found in landscape plantings that had been recently pruned. Larval and pupal parasitism levels were slightly lower than in previous years, but continued to be dominated by *Meteorus ictericus*, *Nemorilla pyste* and *Pediobius ni*.

Results were published on ant-parasitoid wasps in the family Eucharitidae (Hymenoptera). Two of these papers were on species in the genus *Orasema*, which are parasitoids of fire ants in the genera *Pheidole, Solenopsis* and *Wasmanni* (Baker and Heraty and Heraty and Baker 2020). One of the most significant discoveries this year was 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.

Also in progress is a large revison of the eulophid genus *Zagrammosoma*, which are parasitoids of lepidopterous leafminers, including a significant number of pest species. The first phylogenomic analysis of relationships in the family Eulophidae was published, which allows us to better predict evolutionary events and host relationships.

***Objective 2. Conduct foreign exploration and ecological studies in native range of pest.***

Several institutions in the western US *normally* conduct foreign exploration and importation of natural enemies for both new and established arthropod and weed pests this past year. Many of these exploratory trips are only partially successful. Species sent to quarantine facilities must survive the trip and reproduce. Subsequent cultures will then be used for non-target host testing and evaluation for potential release. Select studies that reported under this objective are summarized below. Travel restrictions due to the Covid-19 pandemic are cited explaining lack of work progress.

In collaboration with colleagues in Colombia and Brazil, a tentative investigation assessing the feasibility of classical biocontrol of South American palm weevil, *R. palmarum,* with a parasitic tachinid fly, *Billaea rhynchophorae*, has been initiated. The goal of this work is to determine whether or not it is possible to mass rear this fly and to ascertain if live flies can be exported out of Brazil to California for safety evaluations in quarantine. Foreign exploration was supposed to have started in summer 2020. It was postponed by 1 year due to high COVID-19 spread in Brazil.

Field surveys for egg, larval, and pupal parasitoids of the avocado pest, *H. lauri*, in and around Ixtapan de la Sal and Coatepec-Harinas, Mexico in summer 2020 were not initiated due to COVID-19 work restrictions.

Surveys in Africa for candidate biological control agents of Guineagrass are in progress. Two Eriophyoid mite species, *Diptacus* sp. and *Abacarus* sp. have been collected and shipped to stateside quarantine facilities for evaluation.

Intensive field surveys for classical biological control agents of the southern cattle fever tick, *Rhipicephalus microplus* are underway in Vietnam. An unknown microhymenopteran was reared from cattle fever ticks collected in Vietnam.

The following species were collected against the listed weed pests: *Pteromalus* sp. for biological control of *Phytomyza gymnostoma; Aprostocetus celtidis* for biological control of *Pyrrhalta viburni; Chrysochus asclepiadeus* for biological control of *Vincetoxicum* sp.*; Aculops mosoniensis* for biological control of *Ailanthus altissima;* and *Lepidapion argentatum* for biological control of *Genista monspessulana*

Field studies were conducted on the population densities of *Pyrrhalta viburni* in southern France and on the impact of *Chrysochus asclepiadeus* on swallow-worts and milkweeds.

Surveys were conducted at 30 sites (15 in Montana; 15 in Colorado) of *Lepdium draba* (hoary cress) for insect herbivores (both native and previously established introduced species) in preparation for evaluating the effects of releasing the recently approved mite biocontrol agent *Aceria drabae*.

***Objective 3*.  *Determine systematics and biogeography of pests and natural enemies.***

Molecular and morphological studies of native Fulgoridae have been undertaken as part of the proactive biological control project targeting spotted lantern fly. The 28S, ITS2 and CO1 regions have been sequenced. The 28S sequences need a second round of amplification with different primers to properly identify the three putative native lanternflies species currently designated as A, B, and C. Preliminary analyses have confirmed three important results: the three morphospecies, A, B and C that have been characterized based on morphology, are genetically different and represent three different species. *Poblicia fuliginosa* from the eastern USA is genetically different from specimens collected from the western USA which are also currently recognized as *P. fuliginosa*. And finally, the three native lanternfly nymphs collected from fogging surveys of juniper at the South Western Research Station of the Natural History Museum in summer 2019 do not belong to one of the three morphospecies (A, B or C) that have been characterized molecularly.

Eriophyoid species collected from Guineagrass in Africa are being described.

The following projects between our US and International W-4185 cooperating members all feature species that have been the subject of molecular and genetic work this year; a population comparison of a stem-feeding shoot fly (*Cryptonevra nigritarsis*) infesting *Arundo donax* in the south of France; genetic fingerprinting of a common garden experiment conducted in Greece to test the host plant specificity of the prospective biological control agent *Larinus filiformis* for *Centaurea solstitialis*; preliminary genetic comparisons between populations of the allium leaf miner (*Phytomyza gymnostoma*) in France and in the USA; genetic monitoring in choice and no-choice testing to ascertain the specificity of *Psyttalia ponerophaga*, a potential biocontrol agent of the olive fruit fly; phylogenetic analysis, species delineation and taxonomic revision of egg parasitoids of *Bagrada hilaris*; a study that resolved the taxonomic status of *Aprostocetus celtidis* and *A. suevius,* two *Pyrrhalta viburni* parasitoids; a genetic fingerprinting of *Trissolcus japonicus* on *Halyomorpha halys* from USA and Europe; and a genetic and morphological comparison of parasitoid assemblages of *Pyrrhalta viburni* and the closely related beetle *Xanthogaleruca luteola*

Common mullein is an invasive weed in the USA that causes economic and ecological damage in pastures, rangeland, and disturbed and natural areas, especially in California and Hawaii, from sea level to more than 13,000 ft elevation. ARS researchers in Sidney, MT, using molecular tools, have determined that the invasion is mostly dominated by a single genotype that exists across the western states, with origins of Belgium and Germany. This information helps land managers protect against development of herbicide resistance in the invasion, and helps researchers ensure that future biological control agents will have highest control efficacy against the most common genotypes.

All five species of the plumeless thistle genus *Carduus* are exotic invasives and listed as state noxious weeds in the USA. Multiple populations of an unknown plumeless thistle species were found in remote areas of the deepest river gorge in North America, Hells Canyon National Recreation Area in Oregon and Idaho. The plants were unrecognizable, so ARS Researchers in Sidney, Montana analyzed the plant’s DNA and matched it to specimens from the eastern Mediterranean.Then ARS, working with botanists from Oregon, California and Spain, definitively identified the plants as *Carduus cinereus*, a species never before found in the Americas. Northwestern states are now taking EDRR (Early Detection, Rapid Response) action on this new invasive threat.

Research continues on parasites of the imported fire ant (*Solenopsis*) in South America and of the Little Red Fire Ant (*Wasmannia*) in the Caribbean and Central America. In a larger phylogenetic analysis of the subfamily Oraseminae, results support an ancestral association with the ant genus *Pheidole*, followed by an ancient shift to the New World and diversification onto a wider variety of ant hosts, including *Solenopsis*, *Wasmannia* and other myrmicine ant hosts. Collaboration work continues with an Argentinian researcher on the molecular and morphological recognition of ants attacking the *Solenopsis saevissima* complex, which includes the fire ant. Other papers on parasitoids of ants included a phylogenetic analysis of the genus Kapala, which attack some of the larger ants in the subfamilies Ectatomminae and Ponerinae.

A graduate student is studying the taxonomy and relationships of the tribe Cirrospilini (Eulophidae), which include important parasitoids of the Citrus leafminer and the Citrus Peelminer. This resulted in an upcoming monograph of the genus *Zagrammosoma*, a group of 24 species that all attack leafmining Lepidoptera. His studies were focused on addressing the evolution of host breadth in the genus. In a final paper relationships are being addressed for species across the entire tribe and a revision to the genera to provide a better taxonomic framework for understanding the underlying pattern of host association and distribution is being developed.

A new research program continues 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 phylogeny of the entire genus.

Research is underway on developing a molecular phylogeny for the egg-parasitic Mymaridae. This project is utilizing three different molecular approaches to look at congruence of results, and ultimately the proposal of a new classification for the group.

Work continues on a 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. The first publication from this is an analysis of the transcriptomes across Chalcidoidea. Investigators have also obtained nexgen sequencing data for over 600 taxa that cover the breadth of the entire superfamily. The final results are in progress and work continues on an edited book to cover the entire superfamily. This research is taking a bioinformatic approach by developing 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 will manage data for more than 30,000 taxonomic names and over 50,000 literature references, including information on their hosts and distributions.

Besides the large molecular and genetically based revision work, members of this group regularly provide identifications of parasitoids that are directly related to biological projects worldwide. The benefit of this work to biological control overall is enormous.

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

***Objective 4*. *Determine environmental safety of exotic candidates prior to release.***

The egg parasitoid, *Anastatus orientalis*, native to China and a natural enemy of spotted lantern fly, is being subjected to host range and host specificity testing in quarantine at UC Riverside. Eggs from twelve species (8 hemipterans [this total includes 3 native fulgorid species] and 4 lepidopterans) have been exposed to *A. orientalis* to assess their suitability as hosts. Data are being analyzed. Preliminary results indicate that eggs of the pestiferous brown marmorated stink bug are suitable for *A. orientalis* development. This tentative finding confirms observations made by colleagues on the east coast.

*Oporopsamma wertheimsteini*, a natural enemy of rush skeletonweed, was received from the BBCA in October 2019. This shipment was delayed for one month and all moths emerged while in transit. A few adults were still alive and laid eggs, although most eggs were not viable. Only one male moth emerged from inoculated plants in 2020.

A thrips from South America, *Liothrips ludwigi*, was tested as a candidate agent for control of three water primrose species (*Ludwigia* spp.) that are non-native and invasive in the western US. This thrips was able to feed, survive and reproduce on three native congeners in lab tests, precluding further consideration for biocontrol.

Two exotic parasitoids have been tested for host specificity of the bagrada bug; thus far, the parasitoids have been tested on 10 non-target stinkbug species.

A study was conducted on the microbiome of the psyllid, *Arytinnis hakani*, a biocontrol agent under evaluation against the French broom *Genista monspessulana*, and *Arytainilla spartiophila* attacking the Scotch broom *Cytisus scoparius*. Additional host specificity trials were conducted for *Aprostocetus celtidis* for biological control of *Pyrrhalta viburni*; host specificity and investigation of foraging behavior of *Psyttalia ponerophaga* for biological control of *Bactrocera oleae;* and host specificity tests in open door experiments for *Chrysochus asclepiadeus on Vincetoxicum* species and milkweed.

*Phymastichus coffea* LaSalle(Hymenoptera: Eulophidae) is an adult endoparasitoid of the coffee berry borer (CBB),*Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae: Scolytinae), which has been introduced in many coffee producing countries as a biological control agent. To determine the effectiveness of *P. coffea* against *H. hampei* and environmental safety for release in Hawaii, we investigated the host selection and parasitism response of adult females to 43 different species of Coleoptera, including 23 Scolytinae (six *Hypothenemus* species and 17 others), and four additional Curculionidae. Nontarget testing included Hawaiian endemic, exotic, and beneficial coleopteran species. Using a no-choice laboratory bioassay, we demonstrated that *P. coffea* was only able to parasitize the target host *H. hampei* and four other adventive species of *Hypothenemus*: *H. obscurus, H. seriatus, H. birmanus* and *H. crudiae. H. hampei* had the highest parasitism rate and shortest development time of the five parasitized *Hypothenemus* spp. Parasitism and parasitoid emergence decreased with decreasing phylogenetic relatedness of the *Hypothenemus* spp. to *H. hampei*, and the most distantly related species, *H. eruditus*, was not parasitized. These results suggest that the likelihood of non-target impacts is low because there are no endemic species of *Hypothenemus* in Hawaii, and *P. coffea* could be safely introduced for classical biological control of *H. hampei* in Hawaii.

***Objective 5. Release, establish and redistribute natural enemies.***

Many releases and redistributions of natural enemies (millions) were carried out against pests in 2020. *Travel restrictions due to the* ***Covid-19*** *pandemic are cited explaining lack of work progress.*

Galls of *Aulacidea acroptilonica* were collected in Broadwater County in late April 2020. Adult wasps were reared and separated from parasitoids. Approximately 12,000 adults were collected and consigned to cooperators in Montana to distribute against Russian knapweed.

Initial releases of *Aceria drabae* were made against hoarycress in June 2019, at two sites in Montana. At the primary release site located in Broadwater County, galls were observed at approximately 3% of the plant stems inoculated. Despite heavy grasshopper feeding in 2019, additional galls were located in 2020 on 7 percent of the 2019 stems. Gall formation was also observed at smaller release site located in Gallatin County. In 2020, over 600 galls were used to inoculate stems using three release techniques. Galls were observed on 4 percent of the inoculated stems.

The Coconut Rhinoceros (CRB) invading Guam (2007), Hawaii (2013), Papua New Guinea (2015), and Solomon Islands (2015) are genetically different from other populations off this pest, are resistant to *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.  Earlier this year positive PCR tests resulted for OrNV in field-collected CRB-G. However, a tightly controlled follow-up survey did not detect OrNV in the Guam CRB-G population. It was concluded that the positive tests were a result of lab contamination.

A Guam scientist was to hand carry the parasitoid *Tamarixia radiata* from the CDFA insectary at UC-Riverside for release against Asian citrus psyllid, *Diaphorini citri*, on Guam. This has been put on indefinite hold due to travel and quarantine restrictions resulting from the Covid-19 pandemic.

A classical biological control program against invasive black and pale swallow-worts (*Vincetoxicum nigrum* and *Vincetoxicum rossicum*) was initiated in Michigan using the biological control agent, *Hypena opulenta*. In summer 2020, 420 *H. opulenta* were released at 18 field sites. Common garden field experiments were used to evaluate the synchrony of *H. opulenta* phenology with the climate in Michigan.

Introductions of *A. daanei* were made into the California North Coast region from 2015-2017 for control of the Virginia creeper leafhopper, which led to some increase in biological control, but populations have not established.

The first release of the root and rosette-feeding weevil *Ceratapion basicorne* for biological control of yellow starthistle (*Centaurea solstitialis*) in California was made on 9 April, 2020.

The Cape-ivy shoot-tip galling fly, *Parafreutreta regalis*, released for biological control of Cape-ivy *(Delairea odorata*), has established populations at five sites along the central and northern California coast.

The arundo shoot-tip galling wasp *Tetramesa romana*, released for biological control of arundo (*Arundo donax*), has established populations at two sites in the Central Valley of northern California.

Biological control agents for giant reed have been released and impacts have been documented. Post release monitoring has been conducted and no non-target damage has been discovered.

Plans were made to continue monitoring all release sites of *Aphthona* spp. and *Oberea erythrocephala* against leafy spurge in New Mexico in 2021. Investigators were unable to visit any sites in 2020 due to travel restrictions.

*Mecinus janthiniformis* for biocontrol of Dalmatian and yellow toadfax are established at the southern release site in Grant County. Releases were made of beetles at two new sites in Grant County near Silver City, NM. Visits to the northern insectary of *M. janthiniformis* or any of the *Mecinus janthinus* release sites did not occur in 2020 due to travel restrictions.

Visits were curtailed to the northern insectary sites of *J. ivannikovi* in San Juan in 2020 due to travel restrictions. The small insectary in Chavez County (near Roswell) is still producing small numbers of early summer galls.

*Aulacidea acroptilonica* continues to increase exponentially at two release sites. At the original site in Rio Arriba County near El Rito, populations exceed 50/square meter over a 5 ha area. It seems a new site is established in Otero County near La Luz, NM. Hundreds of galls can be found near the original release locations. Plans are to collect from both of these sites in the spring of 2021 for redistribution throughout New Mexico.

Releases continued (including redistributions) of *Jaapiella ivannikovi* (30 sites) and *Aulacidea acroptilonica* (15 sites) in the Arkansas Valley, San Luis Valley, and Gunnison Basin. These target Russian knapweed (*Rhaponticum repens*).

***Objective 6.*  *Evaluate natural enemy efficacy and study ecological/physiological basis for interactions.***

Studies in Utah were completed to assess factors influencing the expression of partial bivoltinism in *Tetrastichus julis* Walker (Eulophidae), a specialist parasitoid introduced to North America to attack the cereal leaf beetle, *Oulema melanopus* (L.). Field populations of the gregarious endoparasitoid were examined to determine the percentage of individuals forgoing larval diapause over the winter to emerge instead in the same summer that they developed within their host. This percentage decreased with seasonal advancement from spring through summer, but was positively correlated during a given time of season with the number of parasitoid individuals sharing a host larva.

*Aulacidea acroptilonica* and *Jaapiella ivannikovi* release sites continued to be monitored in Montana for changes in Russian knapweed density and cover. At some sites the density of Russian knapweed has declined, and plants appeared stunted, but it is uncertain if that is due to the presence of biocontrol agents, environmental factors; or a combination of both.

Research was conducted to understand the importance of non-consumptive effects of biological control agents on their hosts/prey. The Investigators completed a synthetic review of this topic, and are working on laboratory experimentation to examine how pea aphids, *Acyrthosiphon pisum*, respond to cues of predation and parasitism risk.

The competitive and foraging abilities of two candidate parasitoids for bagrada bug were assessed in quarantine.

Field studies of the entomopathogenic nematode, *Steinernema riobrave,* have been conducted and this indigenous natural enemy has proven to be effective against cattle fever ticks. Recently studies have shown that the nematode can remain viable in water droplets on vegetation for up to 3 hours. This allows for the nematode to be passively transferred to tick infested wildlife.

Parasitism rates of *Pyrrhalta viburni* by *Aprostocetus celtidis* in the field were evaluated.

*Chrysochus asclepiadeus* exposedin open field tests to non-target plants and milkweeds, showed no herbivory impact.

*Gryon gonikopalense* was testedon *Bagrada hilaris* and several closely related pentatomids.

Studies have now determined that the southward spread of *Tamarix* leaf beetle (*Diorhabda carinulata*) is unlikely to be due to the evolution of increased flight tendencies at the range edge. Common environment experiments show that individual female beetles from edge populations are larger, and have a tendencies towards higher fecundity than individuals from the core of the range, suggesting those populations are evolving in response to high host abundance and weak competition. There is substantial heritable variation for the evolution of cues leading to winter diapause. Populations in the south have evolved to initiate diapause at a shorter day length than northern (core) populations. Host choice evaluation of beetles from populations where hybrids are common between the *Diorhabda* species indicate they prefer tamarisk.

Greenhouse and field cage studies of the interactions (facilitation and competition) between the two biocontrol agents, *Jaapiella ivannikovi* and *Aulacidea acroptilonica* and their impact on Russian knapweed stem densities was conducted.

Year two of a study of reciprocal, common garden experiments involving 15 Montana and 15 Colorado populations of hoary cress continued. It is currently comparing growth architecture, flowering phenology, and susceptibility to herbivory in these 30 populations.

Host-seeking behavioral assays of the gastropod-parasitic nematode *Phasmarhabditis hermaphrodita* were performedagainst several different species of slugs. Other studies included; evaluation of the virulence of different species of *Phasmarhabditis* against the invasive white garden snail, *Theba pisana*; host-seeking behavioral assays of entomopathogenic nematodes, evaluating the effects of storage time on host-seeking behavior; as well as evaluating the potential of a new nematode, *Tarantobelus jeffdanielsi*, in the biological control of insects. This nematode was found in association with tarantulas.

An improved invasive species distribution model was developed for the light brown apple moth, *Epiphyas postvittana* (LBAM), and a positive linear relationship was found between model predictions of environmental suitability and observed relative abundance of LBAM larvae for localities in coastal California.

**Goal B: Conserve Natural Enemies to Increase Biological Control of Target Pests.**

**Objective 7. *Characterize and identify pest and natural enemy communities and their interactions.***

Assessments were made on the occurrence and abundance of indigenous early egg parasitoids, *Trissolcus japonicus* on *Halyomorpha halys* in the U.S.

The presence of *Aculops moisonensis* as a foliage herbivore was noted on *Ailanthus altissima* in France and Greece

Comparisons of parasitoid assemblages of *Pyrrhalta viburni* and *Xanthogaleruca luteola* were performed.

Investigations were made of the assemblage of parasitoids associated with Scolytinae in Hawaii as potential conservation biocontrol agents. Numerous species were identified attacking various Scolytinae (but not coffee berry borer), including *Euwallacea* sp., and one of the putative vectors of the Ohia Rapid Death causative pathogen.

Research on the citrus peelminer (*Marmara gulosa*) and citrus leafminer (*Phyllocnistis citrella)* has involved assistance with the identification of parasitoids from field studies in California and central Mexico. Work continues researching the eulophid parasitoids associated with Citrus Leafminers

Work will be 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.

***Objective 8. Identify and assess factors potentially disruptive to biological control.***

Progress has been made on “Disrupting Food for Protection Mutualisms in Citrus: Argentine Ant and Asian Citrus Psyllid, *Diaphorina citri* (Hemiptera: Liviidae)”: Current efforts are focused on automated in-field monitoring of foraging Argentine ants. Ants use smooth PVC irrigation pipes as superhighways to move over the orchard floor from subterranean nests to tree trunks where they tend colonies of sap sucking pests, including ACP. Ants harvest honeydew and return it to the nest. In return for food ants protect pests from natural enemies. The goal of this work is to use infrared sensors attached to irrigation pipes and the internet of things to monitor ant activity in near real time to identify hot spots within orchards that require ant control. Additionally, investigations will probe the efficacy of cover crops for increasing natural enemy activity against sap sucking citrus pests, and whether or not conservation biocontrol is synergized when ants are controlled. To control ants a novel control method is being developed, biodegradable hydrogel beads to deliver ultra-low concentrations of insecticide in 25 percent sucrose solution. Ants drink this poisoned sugar water, return it to the nest where they share it with other workers and queens. This transferal process intoxicates nests and kills them. This work, planned for summer 2020, was significantly curtailed due to COVID-19 work restrictions.

Scientists in Guam continued to survey invasive ants on the islands of Saipan, Tinian, and Rota in the Mariana Islands through March 2020 at which time travel to the CNMI and elsewhere was prohibited due to Covid-19 quarantine restrictions. However, ant surveys continued on Guam throughout the year. 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.

Field studies suggest that a new Bt cotton targeting plant bugs and thrips has minimal non-target impacts based on natural enemy community sampling and life tables to assess impacts on biological control of whiteflies.

Field studies showed that 4 new insecticides for whitefly are highly selective; they do not harm arthropod natural enemies in cotton and provide for favorable predator to pest rations favoring biological control. Plot sizes of 18 x 18m appear to be sufficient to optimally measure non-target effects.

Work continued to understand the impact of RNA viruses on the efficacy of the predatory biocontrol agent *Geocoris pallens*. This includes work on virus discovery, assessment of which viruses are virulent (causing decreased body condition or fecundity), and assessment of which viruses might be candidates for causing elevated expression of cannibalism by *G. pallens*. This project is also conducting modeling studies to determine the impact of a cannibalism-amplifying pathogen on the population dynamics of *G. pallens.*

Studied measured overwintering survival of *Chrysochus asclepiadeus* larvae, a candidate for biological control of *Vincetoxicum* spp.

Populations of *Bagrada hilaris* and the two parasitoids *Gryon gonikopalense* and *Trissolcus hyalinipennis* were tested for the presence of the reproductive manipulator *Wolbachia.*

Drought seems to be an important limiting factor for the successful expansion of the gall midge, *Jaapiella ivannikovi,* on Russian knapweed.Studies followed populations of gall midges through an extended drought during 2018 and 2019. In 2017, thousands of galls were present in NM insectaries and by the end of 2019 populations were difficult to find. Researchers will follow up on these observations in 2021.

A team at the University of Wyoming focused efforts on understanding factors that limit biological control of alfalfa weevil *Hypera postica*. The most common parasitoid of alfalfa weevil in Wyoming is the wasp *Bathyplectes curculionis*, at levels as high as 50 percent of alfalfa weevils assays. However, alfalfa weevil remains quite problematic, so in 2019 the focus was shifted to evaluate which hyperparasitoids are infecting this wasp, to learn if this is disruptive to biological control in this system. Thus far, 4 different species of hyperparasitoids were found, and investigators are still working on identifying these species. Fieldwork continued in 2020, with a new methods study focused on establishing best practices for rearing parasitoids and hyperparasitoids out of *B. curculionis* cocoons. This methods study remains in progress and results will be summarized in next year’s report.

***Objective 9. Implement and evaluate habitat modification, horticultural practices, and pest suppression tactics to conserve natural enemy activity.***

Conservation biocontrol field evaluations assessing the efficacy of flowering plants (e.g., alyssum) for natural enemies (both parasitoids and generalist predators [especially hover flies]) attacking sap sucking pests, including Asian citrus psyllid, infesting citrus was supposed to have started in summer 2020. These field studies didn’t start because of COVID-19 work restrictions. Experiments were conducted using marigolds and alyssum in association with saffron plantings to determine their attractiveness to natural enemies. The plants survived well in the plants despite severe drought conditions. Many types of predators were observed on the habitat plants. Because saffron blooms late in Vermont, no thrips were attracted, but honey bees were abundant demonstrating the value of this crop for supporting pollinators. The percentage of fractional green canopy cover (percent FGCC) in the saffron beds will be measured annually every July. Results will provide insights into the effect of habitat plants on insect pests on saffron and demonstrate the attractiveness of different flowering plants to beneficials.

Since 2018, studies have been evaluating the use of summer trap crops in California pistachio orchards to attract plant bugs, *Leptoglossus zonatus,* away from the crop canopy while young nuts are more vulnerable to bug damage. In parallel, studies have been assessing the impact of these trap crops on supporting and improving biological control activity of the key *L. zonatus* egg parasitoid *Gryon pennsylvanicum* (Scelionidae).

Three sites infested with Russian knapweed were established to test the efficacy of mowing to increase the availability of suitable host material associated with late summer southern monsoon rains. Three plots in NW, NC, and SC New Mexico were established in May 2018. Limited regrowth occurred in July and August 2018 and 2019 with monsoon rains occurring at only one site. The others had almost no regrowth after mowing.

**Goal C: Augment Natural Enemies to Increase Biological Control Efficacy.**

***Objective 10. Assess biological characteristics of natural enemies.***

In 2018, an adventive population of the exotic parasitoid wasp, *Trissolcus japonicus* was discovered in Michigan. It is considered the most promising biological control agent against the brown marmorated stink bug (*Halyomorpha halys*). In 2020, augmentative releases of this wasp took place at 8 field sites in eastern Michigan. A total of 3,200 adult wasps were released. *Trissolcus japonicus* was recaptured at 3 sites, indicating reproduction in the field. There was also one recapture in 2020 from a field site where *T. japonicus* was released in 2019 indicating overwintering success.

Two resident parasitoid species that attack spotted wing drosophila were released in cane berry fields in the central coast of California; approximately 200,000 parasitoids were released over three months.

Research determined the survival rate, longevity, and fecundity under various development temperatures for *Gryon gonikopalense* in host eggs of *Bagrada hilaris* in controlled conditions

Studies are attempting to characterize the volatile organic compounds from Russian knapweed found at different sites in New Mexico and determining which bioactive compounds influence the behavior of adult gall midges and wasps.

Investigations are underway for the chemical searching cues for *Trichogramma papilionis*. Related work looked at the effects of colony founder size on *T. papilionis* fitness. Results showed that *T. papilionis* is attracted to volatile compounds released from sunn hemp leaves when eggs of *Helicoverpa zea* are laid on them. Other work demonstrated short-distance attraction to a specific blend of compounds identified, in olfactometer and greenhouse studies.

Hawaii has a multitude of scolytine (Coleoptera: Curculionidae: Scolitinae) pests including *Hypothenemus hampei*, coffee berry borer, which is a coffee pest of coffee, *Hypothenemus obscurus,* tropical nut borer, a significant pest of macadamia nut, and *Xylosandrus compactus*, black twig borer, a pest of many tropical and ornamental crops. The flat bark beetles, *Carthartus quadricollis* (Coleoptera: Silvanidae)and *Leptophloeus* sp. (Coleoptera; Laemophloeidae), are known to predate on coffee berry borer and tropical nut borer but their natural history (feeding habits, reproduction and movement) are poorly understood. Studies were conducted using molecular, field and laboratory assays to examine 1) flat bark beetle reproduction and movement in coffee and the broader agricultural landscape, 2) establishment of augmentative releases for biological control, and 3) predation rates on *H. hampei*, and, *H.* *obscurus* and *X.* *compactus*. Various life stages of *Cathartus quadricollis* and *Leptophloeus* sp. were found in seven different plant species common to the agricultural landscape around coffee farms, suggesting these predators are feeding and reproducing on theses hosts. Molecular analysis indicated that *C. quadricollis* and *Leptophloeus* sp. predated on *H. hampei, H. obscurus* and *X. compactus* in coffee, macadamia nut, and mixed coffee-macadamia nut farms.Laboratory reared predators were discovered near release sites on coffee farms at 1, 2, and 7 weeks after augmentative releases. Predation of *Cathartus quadricollis* on *H. hampei* eggs placed inside artificial coffee berries in coffee farms was about 40 percent. Flat bark beetle predators are significant natural enemies of scolytine pests in Hawaii and have excellent potential for augmentative releases.

***Objective 11. Develop procedures for rearing, storing, quality control and release of natural enemies, and conduct experimental releases to assess feasibility.***

Evaluation of rearing methods for the Guineagrass stem-borer, *Buakea kaueae* has been conducted. The project was, so far, unsuccessful in rearing this specialist herbivore insect.

A project evaluated membranes for artificial rearing of cattle fever ticks. It was able to rear unfed nymphs to the engorged nymphal stage.

Researchers conducted a study on the impact of rearing on an alternative host on the host specificity of *Psyttalia ponerophaga* for biological control of *Bactrocera oleae*.

Experiments were performed to optimize cold storage conditions on survival and parasitism rate of *Gryon gonikopalense* in host eggs of *Bagrada hilaris* in controlled conditions

Mass-rearing methods for a parasitoid, *Anagrus daanei*, to be used against the Virginia creeper leafhopper (Cicadellidae: *Erythroneura ziczac*), were developed. More than 30,000 parasitoids were successfully produced and reared.

Evaluations of inundative “bioherbicide” releases against leafy spurge continued.

Techniques to utilize plant volatile organic compounds (VOCs) as a tool in host plant finding (yellow starthistle) and acceptance continues. VOCs are collected in situ from bolting leaf tissue and from flowering stems of both yellow starthistle (YST) and Malta starthistle (MST) using a portable volatile collection system. Gas chromatography-mass spectrometry (GC-MS) is used to analyze VOC profiles of YST and MST. A y-tube olfactometer is used to conduct behavioral bioassays on existing and potential agents. Airflow is maintained at 400 ml/min using a flowmeters on each arm of the olfactometer. At the end of each arm, a 1 μl aliquot of eluted VOCs is placed on filter paper as an odor source. As techniques are improved we should be able to help determine issues associated with host plant acceptance and variability in site establishment.

The square-necked grain beetle, *Cathartus quadricollis*, is a predator of the coffee berry borer, *Hypothenemus hampei*, in coffee and a stored product pest. Field tests were conducted to identify the best lure and trap types based on captures of adult beetles. The aggregation pheromone Quadrilure composed of the EZ isomer was significantly more attractive than the pure E blend, and the EZ blend was used in all further attractant tests. A membrane-type release device was superior to a red septa, gray septa or vial in attracting *C. quadricollis*. Either an aggregation pheromone used alone or in combination with a fungal odor blend were attractive but the fungal blend resulted in higher bycatch. Black sticky traps caught more *C. quadricollis* than blue, green, red, yellow, white, or clear sticky traps. A predator breeding station consisting of a screened and sheltered enclosure, a pheromone-fungal odor blend lure released from a membrane-type release device, and food (250 g, cracked corn to cornmeal [4:1]), was developed to augment predator numbers in coffee fields. During a 7-month field test, wild *C. quadricollis* were attracted to breeding stations where they reproduced and multiplied on the provided food and dispersed back into coffee. In laboratory tests, stocking the breeding station with 100 *C.* *quadricollis* resulted in production and dispersal of about 10,000 adults per station during 4 months at 25oC. In field tests using the *C. quadricollis* aggregation pheromone to naturally stock breeding stations for 1 month followed by rearing in the laboratory, about 3,000 adults per station were produced and dispersed over a 5-month period. Breeding stations have the capacity to greatly multiply the coffee berry borer predator *C. quadricollis* in Hawaii coffee fields.

***Objective 12. Implement augmentation programs and evaluate efficacy of natural enemies.***

Many results have been reported under other objectives. A few examples follow:

Lab trials were conducted to assess the efficacy of a commercially available soil-dwelling predatory mite (*Stratiolaelaps scimitus*) to suppress bulb mite populations. Three different predator/prey ratios (1:5, 1:10 and 1:15) with five *S. scimitus* to 25, 50 and 75 *R. robini*. were evaluated. Predation was assessed after 48 hours. The trial was conducted based on a completely random design (CRD) and the experiment was replicated six times on different dates. Results showed the 1:5 predator to prey ratio yielded mortality of 72.5%, which was significantly greater than the other treatments (1:10: 51.8%; 1:15: 38.2%) and controls (4.4-8.0%). Future experiments will replicate the laboratory trials in soil in the laboratory with this rate. These trials will also offer options for managing mites in other crops, such as onions and garlic.

Augmentation of entomopathogenic nematodes for eradication of cattle fever ticks on infested wildlife is in implementation mode in Texas.

**Goal D: Evaluate Environmental and Economic Impacts and Raise Public Awareness of Biological Control.**

***Objective 13. Evaluate the environmental and economic impacts of biological control agents.***

Many results have been reported under other objectives. One example follows:

A synthesis based on classical biological control of 43 insect pests in food, feed and fiber crops in the Asia-Pacific region of the world showed on-farm, annually-accruing benefits of US$ 14.6 – 19.5 billion. In addition, biological control has promoted rural growth and prosperity even in marginal, poorly endowed, non-rice environments. The magnitude of this benefit is on par with that derived from the Green Revolution for rice production.

***Objective 14. Develop and implement outreach activities for biological control programs.***

Over this review period a total of three semitechnical/scholarly articles (e.g., Citrograph, CAPCA Adviser) on ACP, Argentine ant, and South American palm weevil were published in this review period. Updates were posted to www.biocontrol.ucr.edu and www.cisr.ucr.edu A total of 20 extension talks covering ACP biocontrol, conservation biocontrol and IPM, management of Argentine ant, BMSB invasion ecology and biocontrol, and SAPW invasion ecology and management were given. Approximately 20 media interviews to newspapers (e.g., New York Times, Press Enterprise, San Bernardino Sun), radio, Podcasts, and various trade (e.g., Ag. Alert, Western Farm Press) and popular magazines (e.g., Sunset) were given on aspects of the work reported on here.

The annual APHIS-PPQ workshop normally held at the University of Guam in March was cancelled due to Covid-19 restrictions on travel and local quarantine requirements.

As part of a funded NSF project modules are being developed 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 are developing 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. Ideas for outreach are being vetted through a broad group of local teachers, and extension researchers at UC Riverside and Texas A&M University. A PowerPoint presentation has been developed with audio, on biodiversity of parasitic Hymenoptera that we have been able to get introduced into high school curriculums on ecology. Investigators are currently in the process of developing a web page that can deliver all of the products. They are also working with Master Gardeners to develop modules and information appropriate for their clientele.

**2020 Impacts**

Control of invasive Argentine ants increases natural enemy impacts on sap sucking pests in citrus by more than 90% and colonies of some pest species are completely eliminated.

Biocontrol of Asian citrus psyllid has resulted in a >70% reduction in pest numbers in urban citrus in southern California. Two studies over two different time periods have been completed and locations and both have produced similar findings.

Five years ago W-4185 project members released the first biological control agent to be used in North America against hoarycress. Over the past five years, projects have provided over 165,000 *Aulacidea acroptilonica* adults for redistribution. Gall wasps were utilized for research releases, but the majority of adults were sent to county, federal, and state cooperators in ten counties located Montana, and tribal lands (Crow, Northern Cheyenne, Ft. Belknap, Chippewa Cree, and Confederated Salish and Kootenai tribes). Consignments were also made to USDA-APHIS PPQ & CPHST, BLM, New Mexico State University, University of Wyoming, Washington State University, Wyoming Weed & Pest, Department of Agriculture in California, Oregon and Nevada, and the Nez Perce Biocontrol Center, and the biocontrol program at Whitehall High School, MT. We also released the gall mite *Aceria drabae* in Montana in 2019 and 2020, and had recovery of the mite at both of the 2019 releases.

*Orcytes nudivirus* is currently being disseminated throughout Guam and its impact monitored. New strains of *O. nudivirus* are being sought from coconut rhinoceros beetle infested countries in the Western Pacific Region.

New pest control technologies (new insecticides, new Bt crops) need to be proactively assessed to determine compatibility with existing biological control services. The economic value of biological control is immense and additional efforts should balance the cost of more complete assessments with the need to implement biological control more widely and inform policy makers of its value.

A method of rearing bulb mites in the laboratory has been developed and published. This information will be of use to other scientists who are working on this pest, and who need to rear them for their biological control research.

Multiple presentations and factsheets were prepared and given on the value of habitat plantings, reaching at least 1,000 growers, many of whom have adopted this practice which benefits the environment by supporting beneficial arthropods.

*Gryon gonikopalense*, a host specific egg parasitoid of the cole crop pest, *Bagrada hilaris,* is an ideal biological control agent as its impact prevents any major damage to the host plants. The development cycle of the egg parasitoid is perfectly synchronized with its host. The parasitoid is able to attack a high percentage of host eggs on various species. The parasitoid is effective at low host density, and targets eggs that are dominantly buried below-ground by the *Bagrada hilaris* females. The parasitoid is an invaluable tool for pest containment

The microbiome study of *Arytinnis hakani* revealed the absence of phytopathogenic bacteria and thus ensures that this biocontrol agent will not vector plant diseases if released.

Research on the realized impact of *Aprostocetus celtidis* in the field, its host specificity and its relatedness to parasitoids collected from *Xanthogaleruca luteola* in the field helps evaluating the potential of this biological control agent against *Pyrrhalta viburni*.

Evaluation of host specificity of *Psyttalia ponerophaga* for biological control of the olive fly, *Bactrocera oleae,* helps evaluating the potential of this biological control agent against *Pyrrhalta viburni*.

Study of the impact of rearing on an alternative host on the host specificity of *Psyttalia ponerophaga* showed the safety of rearing this parasitoid on the alternative host *Ceratitis capitata*.

*Aphthona* flea beetles redistributed on all significant leafy spurge populations in New Mexico have reduced densities to non-economic levels throughout the state.

Russian knapweed gall wasp, *Aulacidea acroptilonica,* continues to establish much better than Russian knapweed gall midge, *Jaapiella ivannikovi,* under hot and dry conditions*.*

*Mecinus janthiformis* flea beetles have been released on all known populations of Dalmatian toadflax in New Mexico.

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. This research is providing a better understanding of the wasp parasitoids attacking several pest groups in California including the Citrus Peelminer, Citrus Leafminer, sharpshooter parasitoids and the Asian Citrus psyllid. 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.

Common mullein is an invasive weed in the USA that causes economic and ecological damage in pastures, rangeland, and disturbed and natural areas, especially in California and Hawaii, from sea level to more than 13,000 ft elevation. ARS researchers in Sidney, MT, using molecular tools, have determined that the invasion is mostly dominated by a single genotype that exists across the western states, with origins of Belgium and Germany. This information helps land managers protect against development of herbicide resistance in the invasion, and helps researchers ensure that future biological control agents will have highest control efficacy against the most common genotypes.

**2020 Publications**

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**W4185 Target Pest Groups for 2020**

**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) Unspecified species

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 (Sternorrynchus) Hemiptera:

(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.

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) *Phytomyza gymnostoma* (22) Unspecified species

**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*

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

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) Unspecified other species.