SAES-422 Multistate Research Activity Accomplishments Report

submitted by Lisa Tewksbury February 18, 2019

Project No. NE1332

Project Title: Biological Control of Arthropod Pests and Weeds
Report Information:
Period the Report Covers: 03/2017-02/2018
Annual Meeting Date: March 19, 2018 in conjunction with the Eastern Branch ESA Meeting in Annapolis, MD

Participants (at Annual Meeting)

1.	Lisa Tewksbury	URI
2.	Joe Elkinton	U. Mass. Amherst
3.	Ann Hajek	Cornell Univ.
4.	Ellen Lake	USDA-ARS, Fort Lauderdale, FL
5.	Juli Gould	USDA - APHIS
6.	Robert Nowierski	USDA-CSREES-PAS
7.	Scott Salom	Virginia Tech.
8.	Moses T. Kairo	University of Maryland E. Shore
9.	Mauri Hickin	USDA-APHIS
10.	Art Agnello	Cornell Univ. – NYSAES
11.	Hannah Broadley	U. Mass. Amherst
12.	Theresa Murphy	USDA-APHIS

Brief Summary of Minutes of Annual Meeting

1) Officers. The business meeting was moderated by Lisa Tewksbury and Scott Salom. John Losey was not present, and Ann Hajek agreed to serve as Incoming Chair for 2018. John Losey will serve as chair in 2019.

2) Venue for next meeting. The first meeting of NE1832 (new project) will be held in conjunction with the **Entomological Society of America Eastern Branch - 2019 Meeting** from March 9-12, 2019 in Blacksburg, VA. NE1832 is planning to co-sponsor a symposium for that meeting entitled "**Biological Control of Invasive Organisms Affecting the Eastern Branch"** on March 10, 2019. Ann Hajek and Lisa Tewksbury are co-moderators of this symposium with Dalton Ludwick and Joe Kaiser.

3) Funding opportunities for biological control. Bob Nowierski, National Program Leader for Bio-Based Pest Management, USDA-National Institute of Food and Agriculture (NIFA), updated the group on funding opportunities that impact biological control at the national and regional levels. He gave a background of the Agriculture and Food Research Initiative (AFRI). He also summarized the current status of permitting for Biological Control of Weeds projects.

Symposium Program

As part of the ESA Eastern Branch Meeting in Annapolis MD, the regional project organized a symposium entitled "**Biocontrol of Introduced and Invasive Insect and Weed Pests of Forests/Woody plants**".

March 19th, 2018 8:00 A.M. - 12:00 P.M.
Moderators and Organizers: Lisa Tewksbury[1] lisat@uri.edu and Juli Gould[2] Juli.R.Gould@aphis.usda.gov, [1]Univ. of Rhode Island, Kingston, RI, [2]USDA-APHIS-PPQ, Science and Technology Lab, Buzzards Bay, MA

8:00 Introductory Remarks

8:10 Status of Biological Control Research for Tree of Heaven, *Ailanthus altissima*. **Scott M. Salom[1]**, salom@vt.edu, Tom McAvoy[1], tmcavoy@vt.edu, Rachel Brooks[1], rkbrooks@vt.edu, Kristen Wickert[2], klw5421@gmail.com, and Matt Kasson[2], mtkasson@mail.wvu.edu. [1]Virginia Tech, Blacksburg, VA., [2] West Virginia University, Morgantown, WV.

8:35 Biological Control of Mile-a-Minute Weed: Challenges, Accomplishments, and Lessons Learned. **Ellen C. Lake**[1], ellen.lake@ars.usda.gov, Judy Hough-Goldstein[2], jhough@udel.edu, and Richard Reardon[3], rreardon@fs.fed.us. [1]USDA-ARS Invasive Plant Research Laboratory, Fort Lauderdale, FL., [2]University of Delaware, Newark, DE, [3]USFS, Forest Health Assessment & Applied Science Team, Morgantown, WV.

9:00 Winter Moth in the Northeast and its Associated Parasitoids, Pathogens, and Predators. **Joe Elkinton**, elkinton@ent.umass.edu, and **Hannah Broadley**, hbroadley@cns.umass.edu, University of Massachusetts, Amherst, MA.

9:25 Update on Asian Longhorned Beetle Biological Control. **Theresa Murphy**, Theresa.C.**Murphy@aphis.usda.gov,** USDA-APHIS-PPQ, Science and Technology Lab, Buzzards Bay, MA

9:50 Break

10:05 Redistribution of *Trissolcus japonicus* for Use in the Biological Control of Brown Marmorated Stinkbug in New York State. **Peter Jentsch**, pjj5@cornell.edu, Art Agnello, ama4@cornell.edu, Tessa Grasswitz, tg359@cornell.edu, and Dana Acimovic, dda42@cornell.edu, Cornell University, Hudson Valley Research Lab, Highland, NY.

10:30 Spotted Lanternfly Biological Control. **Mauri Hickin, Mauri.L.Hickin@aphis.usda.gov,** USDA-APHIS-PPQ, Science and Technology Lab, Buzzards Bay, MA.

10:55 On the Horizon: Biological Control of Swallow-worts. **Lisa Tewksbury**, lisat@uri.edu, Richard Casagrande, casa@uri.edu, University of Rhode Island, Kingston, RI.

11:20 Ecology and Biological Control of the Viburnum Leaf Beetle *Pyrrhalta viburni*, **Gaylord Desurmont**, gdesurmont@ars-ebcl.or, EBCL USDA ARS

11:45 Concluding remarks

Accomplishments

Goal 1 (Conservation of existing natural enemies)

No reports for this goal included.

Goal 2 (Augmentation programs)

Objective 1. To release and evaluate augmentative biological control agents and educate the public about their role in pest management. (Mark Mayer, NJ Dept of Agriculture; M. Hoffmann, Cornell University)

Phillip Alampi Beneficial Insect Laboratory (PABIL). A total of 30,700 *Rhinoncomimus latipes* weevils were shipped to cooperators in Massachusetts, Pennsylvania, West Virginia, Maryland, Connecticut, Rhode Island, New York City, Virginia, and North Carolina under the terms of a USDA/APHIS/PPQ rearing agreement. In addition, 7,700 were purchased by private property owners and 5,500 adults were released on mile-a-minute weed in New Jersey to augment existing populations.

Mexican bean beetle populations were low but there were some problems on organic farms and in community gardens. A total of 226,500 *Pediobius foveolatus* adults were released during the 2016 field season in soybean fields, in community gardens and on organic farms. There were some rearing issues with the Mexican bean beetle colony due to pesticide-contaminated seed that was used early on to rear them. The first instar larvae dropped off the plants and did not survive. Once this was discovered, the rearing staff switched to the old seed and there were no further problems although the parasite production was affected. Some *P. foveolatus* were also provided to out-of-state organic farmers.

Surveys for *Laricobius nigrinus* beetles on hemlock woolly adelgid have shown that they have dispersed 33 miles into Pennsylvania and are throughout the Delaware Water Gap NRA, a length of 34 miles, wherever there are adelgids present. The beetles have been recovered twelve miles into NJ and were recovered in five new sites in 2016. *L. nigrinus* has been recovered in a total of 193 sites in New Jersey and Northwestern Pennsylvania as of 2016.

Overall this season, a total of 6,250 *Cybocephalus nipponicus* (Coleoptera: Nitidulidae) have been released for control of elongate hemlock scale and 4,700 beetles were released on euonymus scale.

A total of 2,875 *Peristenus relictus* were released in NJ with 3,300 shipped to cooperators. Additionally, 2,050 *Peristenus digoneutis* were shipped to cooperators. These parasitoids are parasitic on *Lygus* sp.

PABIL reared and supplied federal and state investigators with *Halyomorpha halys* adults, nymphs, and egg masses for ongoing laboratory and field studies. *Trissolcus japonicus* was recovered at two sites in NJ.

Objective 1. Augmentation programs involving repeated rearing and release. (Michael Hoffmann, Cornell University) For a third season of experimentation, there continued to be no discernible difference in fruit damage between vines receiving releases of the parasitoid *Trichogramma ostriniae* and those not receiving releases. This strongly suggests that *T. ostriniae* will do little to prevent berry moth damage and thus this particular parasitoid does not appear to be a good candidate for berry moth control.

Objective 2. To investigate potential new biological control projects for the northeast.

(Michael Hoffmann, Cornell University) Introduction of new natural enemies against invasive pests: Results with *T. ostriniae* strongly suggest that over a distance of millimeters to centimeters, either sight or random encounter are substantially more important than smell, but that there probably is some small interaction with olfactory cues. This suggests that attempts to manipulate efficacy by manipulating volatiles may not work well, but that suitable target pests may be those that have eggs that are more visually apparent to the parasitoid, either because of size, contrast, odor, or an interaction of the factors. Results from releases in beans and corn suggest that efficacy in corn is greater than that in beans. Additionally, *T. ostriniae* were sent to a cooperator in Nebraska who determined that there is dispersal in beans but dispersal in beans is not as great as in corn. This implies that for *T. ostriniae* to be useful for controlling western bean cutworm in beans, higher rates of release will be necessary.

(John Losey, Cornell University) OUTPUTS: Working in conjunction with the citizen science program, the Lost Ladybug Project (www.lostladybug.org), substantial progress has been made in determining the causes and consequences of the decline of several native coccinellid species in North America especially in regard to their interaction with invasive species. In Roy et. al. (2016) we worked with a large international team to investigate and report on the biology of the coccinellid species that has risen to unprecedented global dominance, *Harmonia axyridis*. Drilling down into a specific aspect of *H. axyridis* biology, we reported on the susceptibility of this species to parasites (Halewaters et al. 2016). This research has important implications as any factor leading to a decline for the dominant species could cause a substantial decrease in pest suppression. In Dienbrock et al. (2016), we examined specific impacts of introduced coccinellids on native species. Finally, in DiTommaso et al. (2016) we went beyond documenting composition shifts and investigation of causes to present a broad management strategy for weeds that could greatly facilitate the services insects provide, including biological control.

OUTCOMES: Based primarily on data from the Lost Ladybug Project, the North American native coccinellid species, *Coccinella novemnotata* was listed as endangered at a national scale in Canada and we consulted directly on the development of a conservation plan for the Province of Ontario. As the invasive coccinellid *Harmonia axyridis* continues to increase its density and dominance and susceptibility to parasites have been demonstrated, conservation of other species is vital if we do not want a gap in biological control services, placing food production at risk. This is a global issue for biological control with potentially profound implications for our region. To organize at a larger scale, I submitted a proposal to the IUCN to form a specialist group to evaluate native coccinellid species and to coordinate conservation efforts.

Objective 3. To examine the effects of exotic species on ecosystem function and conserve existing natural enemies (Ann Hajek, Cornell University)

The Hajek laboratory has been studying how the invasive Eurasian woodwasp, *Sirex noctilio* and its associated fungal symbionts and parasitic nematodes are impacting native siricid communities. We found that when it occurs in the same trees as the native wood boring beetle *Serropalpus substriatus*, the parasitic nematodes thought to have been introduced with *S. noctilio* were parasitizing this native beetle, but at very low levels. Parasitism levels were too low to evaluate potential impacts on the biology and ecology of this beetle. To further evaluate the potential for non-target impacts of this *S. noctilio*-parasitic nematode (*Deladenus siricidicola*, non-sterilizing strain), studies were conducted to demonstrate that it would use the same fungus (when in its mycophagous phase) as the strain of *D. siricidicola* sold for biological control (Kamona). We think this indicates that non-targets also associated with these fungi would have the greatest chance for contacting this nematode.

We also tested whether the gypsy moth fungal pathogen *Entomophaga maimaiga* would have the side-effect of infecting nun moth (*Lymantria monacha*) larvae in Europe. If there was infection in this non-target, this could provide control of a pest both in Europe and if this species invaded North America. With optimal conditions during laboratory and field studies, we found minimal levels of infection.

Objective 4. To release and evaluate augmentative biological control agents (Ann Hajek, Cornell University)

The Hajek laboratory conducted trials with microsclerotia of the entomopathogenic fungus *Metarhizium brunneum* F52, against adults of the invasive Asian longhorned beetle, *Anoplophora glabripennis*. We found that 3 carriers that could be used to formulate this fungus did not change the impact of the fungus. When microsclerotia were formulated with hydromulch and a sticker and applied to forest trees, we found that over time production of infective conidia increased, peaking at 4 weeks. Periods with greater rainfall had greater conidial production and infection of Asian longhorned beetles. We also studied whether mating and aging impacted susceptibility of Asian longhorned beetle adults to *M. brunneum*. There was increased susceptibility of mature male beetles that were mated versus unmated (compared with young or old). Young unmated male beetles were more susceptible than mature or unmated old beetles. Basically, we did not see a strong pattern of immunosenescence that we had predicted for these beetles with long-lived adults. Joanna Fisher also investigated the impacts of imidacloprid and starvation on immune responses to *M. brunneum* in Asian longhorned beetle adults. There was synergy between the fungus and pesticide that was not completely due to starvation, as the immune response was depressed when beetles were treated with imidacloprid but not when they were starved.

The *Sirex*-parasitic nematode *Deladenus siricidicola* Kamona strain, sold for biological control, was tested in experimental trials against *Sirex noctilio* in northeastern North America.

Goal 3 (Classical Biological Control)

Objective 5. To catalogue of pathogens and nematodes introduced for classical biological control around the world (Ann Hajek, Cornell Univ.)

A catalogue of pathogens and nematodes introduced for classical biological control around the world was updated and republished. With a group of authors from many countries, we summarized current knowledge about the environmental safety of classical biological control (paper in *Biol Invasions*), both synthesizing the past literature and discussing the present practices that ensure environmental safety of this practice.

Objective 6. Impact assessment of *Laricobius nigrinus* (Coleoptera: Derodontidae), a predator of hemlock woolly adelgid (Scott Salom, Virginia Tech. and Joe Elkinton, Univ. Massachussetts)

Relevance: *Laricobius nigrinus* (Ln) (Coleoptera: Derodontidae) is a predator of hemlock woolly adelgid (HWA), *Adelges tsugae* (Hemiptera: Adelgidae). We are currently trying to control HWA through several different methods, including through the use of predators such as *L. nigrinus*. Releases of this predator began in 2003; now, over a decade has passed since these initial releases, and this has allowed sufficient time for Ln to establish at these field sites and for us to assess efficacy of this small beetle as a predator for control of HWA.

Response: We set up nine field sites in six different states, from as far north as New Jersey and as far south as Georgia. This spans plant hardiness zones 6a – 7a. The field sites were chosen based on high densities of HWA, recovery of Ln, and Ln releases at least four years prior to the start of the study. Exclusion cages studies were set up to assess the impact that Ln was having on sistens and their progrediens eggs.

Emerging Results 2014-2016: This is the first large scale effort carried out to assess the potential efficacy of *L. nigrinus* on HWA populations. After two years, we have shown that there is significant disturbance to HWA ovisacs, containing adults and eggs on branches exposed to predators compared to branches where cages excluded the predators. At some sites the impact was > 80 %, at others it was significant but at a lower level, and at a few there was no impact. There was also a relationship between presence of *L. nigrinus* collected off of the branches and disruption of ovisacs which equates with HWA mortality. This is the first large-scale effort to quantify the impact of this predator on the winter generation of HWA. Work will continue for the next 2 years to try to quantify the impact on a 2nd spring/summer generation of HWA.

Objective 7. Release and colonization of *Laricobius osakensis*, a predator of hemlock woolly adelgid (Scott Salom, Virginia Tech.)

In 2010, following four years in quarantine, USDA, APHIS PPQ found that *Laricobius osakensis* Montgomery and Shiyake (Coleoptera: Derodontidae), a biological control agent for the hemlock woolly adelgid, was not a significant risk to the environment, and it was removed from quarantine. After rearing at Virginia Tech led to the production of a sufficient number of adults, release of the northern strain began in 2012. Rearing of the southern strain at the University of Tennessee led to its release beginning in 2013. By 2015, a total of 9,528 northern strain adult beetles were released at 12 locations (mostly VA, but also in WV, MD, PA, and OH) and 1,973 southern strain adult beetles have been released at three locations (all in TN). Additionally, eggs/larvae were released at a few locations during the spring of 2013 and 2014.

The 2015-2016 field season yielded 5 adult recoveries, 4 from Hungry Mother State Park, and 1 from the Cherokee National Forest in TN. Spring larval collections yielded 88 larvae from several sites. After running a genetic analysis on the larvae recovered, it was found that 14 were *L. osakensis*, 22 were *L. nigrinus*, 41 were *L. rubidus*, and 11 were undetermined. That means a total of 19 *L. osakensis* were collected in the 2015-2016 field season. Such low recovery numbers can be attributed to the extremely low winter temperatures in the January 2014 and February 2015, which resulted in a decrease in adelgid density. Low adelgid numbers make it difficult for *L. osakensis* to colonize and resulted in low recovery numbers. It is expected that as the winter temperatures become closer to the long-term average, the HWA numbers will rebound, and as a result the numbers of *L. osakensis* recovered will increase.

Objective 8. Biological studies and evaluation of *Scymnus coniferarum*, a predator of hemlock woolly adelgid from western North America (Scott Salom, Virginia Tech.)

A small, native lady beetle, *Scymnus (Pullus) coniferarum*, (Coleoptera: Coccinellidae) that was found on hemlock woolly adelgid (HWA) in the western United States is known to prey on adelgids on pine and hemlock, but no other insect groups. In the 125 years since the discovery of *S. coniferarum* in the western United States, there have been no reports of it causing harmful effects to plants, animals or humans, other than adelgids. Currently, no predators of consequence are effectively impacting the HWA progrediens generation. The presence of *S. coniferarum* in the spring, when progrediens are present, motivated a group of researchers to pursue further study of this insect. Subsequently, an Environmental Assessment was submitted to USDA, APHIS to consider issuing permits for interstate movement of this insect and to provide a "Categorical Exclusion" to allow for its release in eastern U.S. states impacted by hemlock woolly adelgid.

Without adequate knowledge of this insect in its native habitat, we studied the life history of *S. coniferarum* and associated adelgid prey species in the western U.S. To relate seasonal abundance of *S. coniferarum* and HWA and other adelgid species, we sampled six sites near Tacoma, WA twice monthly, for one full year (Oct 2015 – Nov 2016). These sites were a mixture of pure hemlock stands, pure conifer stands (most commonly including shore pine, Douglas-fir, and western white pine), and mixed stands of hemlock and other native conifers.

In beat sheet sampling, *S. coniferarum* was collected from all *P. contorta* and *P. monticola* host trees. These results indicate that *S. coniferarum* is likely a predator of adelgids on *P. pini, P. strobi,* and *A. tsugae* in the western United States. In the sampling that has occurred between October 24, 2015 and November 20, 2016, a total of 215 adult *S. coniferarum* were recovered. 119 *S. coniferarum* were collected from *P. contorta*, 54 from *P. monticola*, 42 from *T. heterophylla* and 0 *S. coniferarum* were collected from *P. menziesii.* It seems that *S. coniferarum* feeds on multiple adelgid species throughout the year within its native range. High densities of adult *S. coniferarum* beetles were collected on adelgid-infested *P. contorta* and *P. monticola* between February and April 2016, and again in July and August. *S. coniferarum* were found feeding on adults and eggs of *Pineus pini* (pine woolly aphid) on *P. contorta*, and *Pineus strobi* (pine bark adelgid) on *P. monticola* for the first time in the western U.S. These conifer sample trees are often nearby western hemlock stands, which suggests *S. coniferarum* feeds on a number of adelgid species for optimal fitness. Due to the behavior of these phylogenetically similar species, and because *A. tsugae* aestivates from June-October in the Pacific Northwest and southwest Virginia, we believe that *S. coniferarum* feeds on multiple adelgid species throughout the year within its native range.

Objective 9. To develop a biological control program for exotic *Phragmites australis* (B. Blossey, Cornell Univ., L. Tewksbury, URI):

Bernd Blossey's lab conducted vegetation sampling of all long term Phragmites plots. In 2017 we visited all sites in both May and August/September. In early May 2017 we were able to find the vast majority of quadrats since markers were either in place and visible, had fallen to the ground (potential frost upheaval) or were obscured by years of tall decomposing materials (see Figs. 1, 5, 8). We placed existing markers upright, replaced PVC stakes as necessary and flagged quadrats for easier relocation in fall 2017. In September 2017 we collected vegetation data including *Phragmites* stem density and estimated percent cover, and recorded presence and estimated percent cover of all plant species rooted within each quadrat. One site, Martens marsh, was accidentally mowed in September 2017 by a DEC contractor. When the contractor realized the existence of quadrats markers, mowing was stopped saving a few quadrats. We were able to relocate all quadrats at this location due to the ability to find transects and remaining stakes in the ground, so we re-established this site. We further discussed with DEC personnel the continued "safety" of the site since they scheduled herbicide treatment for Martens marsh later in fall 2017. We came to an agreement to allow this research and potential biocontrol agent release at this location and we established a buffer zone to avoid accidental treatment of the site.

Native *Phragmites* is considered increasingly rare in the US, particularly in the East where introduced *P. australis* is expanding its range locally and regionally. However, native *P. australis americanus* seems to hold its own at the sites we monitored.

Work at CABI Switzerland focused on maintaining and increasing the captive colony and providing eggs, and for the first time pupae for work at URI. We mainly reared pupae of the two noctuid moths *A. neurica* and *A. geminipuncta* and sent 80 pupae of *A. neurica* and 60 pupae of *A. geminipuncta* to URI. In addition, we shipped 60 pupae (Fig. CD) of *A. neurica* and 50 pupae of *A. geminipuncta* to Dr. Robert Bourchier (Agriculture and Agri-Food Canada, Lethbridge), for analysis of their pheromones (please note that Agri-Foods Canada is independently supporting part of the CABI work program). Shipping pupae was experimental but was very successful with good survival and establishment rates at URI (see below). This allows for a different release procedure than previously anticipated. Release of moths will be easier than release of eggs or early emerging larvae that are rather delicate and would be more elaborate. We will experiment with different release techniques once we obtain release permits. In addition, if work by our Canadian counterparts to assess and identify pheromones is successful, it will faciliate later monitoring of insect establishment using pheromone traps.

In addition, by intensifying our care for the larval rearing, we were able to avoid the high mortality observed for *A. geminipuncta* in 2016 (Fig. 13). We used the remaining moths that emerged from our larval rearing and that were not sent to North America to produce over 3000 eggs of *A. neurica* and slightly over 700 eggs of *A. geminipuncta*. These eggs are being kept in a wooden shelter at ambient temperatures and will be available for additional work in 2018.

On 14 June 2017 URI received 82 *A. neurica* pupae and 60 *A. geminipuncta* pupae from Patrick Haefliger at CABI Switzerland. Survival of pupae during shipments was excellent and emergence for *A. neurica* was 93.4% and 90% for *A. geminipuncta* (Table 3). There was a large difference in sex ration with almost twice as many females emerging for *A. neurica* while males and females emerged in almost a 1:1 ratio in *A. geminipuncta*. Despite identical set-up, we had a much better success in obtaining large quantities of eggs (total and per female) for *A. neurica* than for *A. geminipuncta* (Table 3), and we are unable to explain these differences at the present time. This is even more surprising given that we used similar procedures as is in place at CABI. We will experiment with different set ups in 2018 varying the number of stems, times between stem changes etc. since total number of eggs obtained per female at CABI is typically >100/female.

We are repeating an overwintering experiment that was conducted using southern US climate conditions to address the potential for these moths to survive under those climate conditions using increased replication. This will not only allow us to further assess the potential for the moths to colonize areas in the Mississippi Delta (see Task 2.3), but also allow us to make recommendations for the potential of *A. neurica* and *A. geminipuncta* to colonize areas in the southern and southeastern US that are currently experiencing rapid *P. australis* invasions. Such areas may not be suitable for insect releases, at least not for the two species currently under consideration.

In order to determine if it is possible for *Archanara* eggs to hatch under Florida conditions and utilize Type I *Phragmites* in Florida, we set up an egg hatch experiment to compare egg hatch under Florida temperature/photoperiod with egg hatch under Switzerland temperature/photoperiod. On the first of November we set up 100 *A. neurica* and 100 *A. geminipuncta* eggs in one growth chamber set to temperature and photoperiod conditions of Fort Pierce, Florida, and 100 of each species were placed in a second growth chamber, set to the conditions of Basel, Switzerland. The temperature and photoperiod data used to set the two chambers twice each week will be averaged from data taken from The Weather Underground (www.wunderground.com). We will record egg hatch in the spring. The remaining eggs are kept under Switzerland conditions. They will be kept at 4°C until needed for larval rearing in the spring.

Objective 10. To develop a biological control program for swallow-worts in North America (R. Casagrande, L. Tewksbury URI)

We continue to maintain a colony of *Hypena opulenta*, the biological control agent for invasive swallow-wort species (Vincetoxicum spp.) in the University of Rhode Island containment facility and improve mass rearing techniques. The first U.S. releases of *H. opulenta* were made in the fall of 2017 in RI and MA.

Objective 11. To establish and evaluate biological control agents for garlic mustard (*Alliaria petiolata*) (B. Blossey, Cornell University)

No longer an active objective since garlic mustard is not the driver in ecosystem deterioration. Deer are.

Objective 12. To establish and evaluate natural enemies of the winter moth (J. Elkinton, UMASS)

Additional projects at URI (L. Tewksbury, R. Casagrande). We released over 5,000 *Rhinoncomimus latipes* weevils for mile-a-minute control in three new sites in RI in 2017. We released 2,355 *Larinus obtusus* for control of black knapweed at five sites in RI. All sites are monitored to evaluate the efficacy of the biocontrol agents. We continued to monitor the establishment and spread of lily leaf beetle parasitoids. We conducted preliminary experiments with *Lilioceris cheni*, the agent released against air potato in Florida to determine the possible impact of parasitoids released against *L. lilii* in the Northeast. Preliminary tests with *Tetrastichus setifer* and *Diaparsis jucunda* showed no attack of *L. cheni*, but this needs to be repeated with larger sample sizes. We also collaborate with Joe Elkinton from the University of Massachusetts to release and monitor the establishment of *Cyzenis albicans*, the biocontrol agent for winter moth.

We maintain a URI biological control website to provide information on our classical biological control projects, and R. Casagrande and L. Tewksbury give many presentations in RI and in the Northeast about classical biological control.

Goal 4 (Evaluation and Education)

Objective 13. To provide web-based information for growers, landscape managers, educators, and students on biological control programs (J. Losey, Cornell University)

OUTPUTS

Educational outreach includes our successful Lost Ladybug Project citizen science program, through which the public can gather information and participate via our project website (www.lostladybug.org), Facebook page activities, and other social media. The public also receives notices and information surrounding educational offerings through public events and programming with school, youth and community groups.

A wide range of individuals have been trained and are developing their skills through participation in Lost Ladybug Project web-based outreach: undergraduate students, extension and teaching specialists, 4H youth educators, parents, classroom teachers, environmental educators, graduate students, and faculty members.

OUTCOMES

Our successful citizen science program has reached a total of over 1,350,00 (up from cumulative totals of 1,200,000 in 2015, 1,000,000 in 2014, 700,000 in 2013 and 400,000 in 2012) people through our project website (www.lostladybug.org), Facebook page activities, and other social media; an estimated total of 65,000 (up from 58,000 in 2015, 50,000 in 2014, 40,000 in 2013 and 25,000 in 2012) people have participated in programs and event activities of the project; and over 13,200 (up from 12,500 in 2015, 11,500 in 2014,10,000 in 2013 and 8,000 in 2012) total people have submitted ladybug images, as individuals, families, or other groups.

Over 38,000 (up from 34,000 in 2015, 27,000 in 2014, and 22,000 in 2013) images of ladybugs have been submitted to the Lost Ladybug database by citizen scientists from every state. Participation also includes email questions and requests for materials, Lost Ladybug Project Facebook “Likes” at 8,660 (up from 8,078 in 2015, 7,800 in 2014 and 6,700 in 2013, and 1,000 in 2012) and Facebook conversation/question activity. Because this is a public project with free materials on the internet, some people and organizations interact with us while others use our materials but have little or no contact.

In 2016, several targeted Facebook notices were used for public education and to invite LLP participation in new initiatives. The largest post: 23,410 people were reached, 122 people responded electronically, 66 people wrote comments and questions, 160 people wrote messages for more information, and 295 people shared the post with others.

IMPACTS

We continue to have consistent website and social media visits by the public as well as participation via web-based photo submissions and attendance at events.

Our online program provides the tools for other educators and researchers to participate and to hone and expand their skills. On our website, participants are assisted through email communication and posted content to increase their information and skills for the project. On the Lost Ladybug Project Facebook page, we provide informative posts and answer questions from participants to increase proficiency in everything from specific project skills through understanding biodiversity and rare species information.

Objective 14. To publish the results of biological control research in refereed journals, books, and proceedings. (See list of new publications below)

Abram, Paul K., Kim A. Hoelmer, Angelita Acebes-Doria, Heather Andrews, Elizabeth H. Beers, J. Christopher Bergh, Ric Bessin, David Biddinger, Paul Botch, Matthew L. Buffington, Mary L. Cornelius, Elena Costi, Ernest S. Delfosse, Christine Dieckhoff, Rachelyn Dobson, Zachary Donais, Matthew Grieshop, George Hamilton, Tim Haye, Christopher Hedstrom & 29 others. 2017. Indigenous arthropod natural enemies of the invasive brown marmorated stink bug in North America and Europe. Journal of Pest Science. 90(4): 1009-1020.

Bittner, T., Hajek, A.E., Haavik, L.J., Allison, J.D., and Nahrung, H. 2017. Multiple introductions of *Sirex noctilio* (Hymenoptera: Siricidae) in northeastern North America based on microsatellite genotypes, and implications for biological control. Biological Invasions 19(5) DOI 10.1007/s10530-016-1365-1.

Bittner, T.D., Hajek, A.E., Liebhold, A.S., Thistle, H. 2017. Modification of a pollen trap design to capture airborne conidia of *Entomophaga maimaiga* and detection by quantitative PCR. Applied & Environmental Microbiology 83: 1-11.

Broadley, H.J., E.A. Kelly, J.S. Elkinton, R. Kula, and G.J. Boettner. 2018. Identification and impact of hyperparasitoids and predators affecting *Cyzenis albicans* (Tachinidae), a recently introduced biological control agent of winter moth (*Operophtera brumata* L.) in the northeastern U.S.A. Biological Control 121:99-108.

Casagrande, R.A., P. Häfliger, H.L. Hinz, L. Tewksbury, and B. Blossey. 2017. Grasses as appropriate targets in weed biocontrol: is the common reed, *Phragmites australis*, an anomaly? BioControl DOI: 10.1007/s10526-018-9871-y

Duan, JJ, LS Bauer, and RG. Van Driesche. 2017. Emerald ash borer biocontrol in ash saplings: the potential for early stage recovery of North American ash trees. Forest Ecology and Management 394:64-72.

Duan, J.J, L.S. Bauer, R.G. Van Driesche, and J.R. Gould. 2018. Progress and Challenges of Protecting North American Ash Trees from the Emerald Ash Borer Using Biological Control. Forests. 9(3), 142. doi:10.3390/f9030142.

Elkinton, J., G. Boettner. 2017. Winter Moth Biological Control Report 2017. Dept. of Environmental Conservation, University of Massachusetts.

Gardescu, S., A.E. Hajek, T.A. Goble and M.A. Jackson. 2017. *Metarhizium* microsclerotia and hydrogel versus hydromulch: testing fungal formulations against Asian longhorned beetles.

Golec, J.R., J.J. Duan and J. Hough-Goldstein. 2017. Influence of Temperature on the Reproductive and Developmental Biology of *Ontsira mellipes* (Hymenoptera: Braconidae): Implications for Biological Control of the Asian Longhorned Beetle (Coleoptera: Cerambycidae). Environmental Entomology 46(4):978-987.

Grab, H., B. Danforth, K. Poveda, G.M. Loeb. 2018. Landscape simplification reduces classical biological control and crop yield. Ecological Applications. 28(2):2-8.

Hajek, A.E., D.C. Harris, and T.D. Bittner. 2018. Symbiont spillover from invasive to native woodwasps. Microb. Ecol. 75(1):7-9.

Hajek, A.E. and J. Eilenberg. 2018. Natural Enemies: An Introduction to Biological Control. 2nd edition. Cambridge University Press, Cambridge, UK.

Hajek, A.E., L.F. Solter, J.V. Maddox, W.F. Huang, A.S. Estep, G. Krawczyk, D.C. Weber, K.A. Hoelmer, N.D. Sanscrainte, J.J. Becnel. 2017. *Nosema maddoxi* sp. nov. (Microsporidia, Nosematidae), a widespread pathogen of the green stink bug *Chinavia hilaris* (Say) and the brown marmorated stink bug *Halyomorpha halys* (Stål). Journal of Eukaryotic Microbiology DOI: 10.1111/jeu.12475

Hudson, W., C. Detweiler, M. Mayer, G. Robbins, A. Lovero and J. Beetle. 2017. *Rhinoncomimus latipes* (Coleoptera: Curculionindae) As A Biological Control Agent For Mile-a-minute, *Persicaria perfoliata* in New Jersey. Annual Report.

Kenis, M., B.P. Hurley, A.E. Hajek, M.J.W. Cock. 2017. Classical biological control of insect pests of trees: facts and figures. Biological Invasions. DOI: 10.1007/s10530-017-1414-4

Mausel, D. L., L. T. Kok, and S. M. Salom. 2017. Numerical response and impact of *Laricobius nigrinus* (Coleoptera: Derodontidae) on *Adelges tsugae* (Hemiptera: Adelgidae) in their native range. Environ. Entomol. 46: 544-551. doi:10.1093/ee/nvx078

Murphy, T.C., R.G. Van Driesche, J.R. Gould, and J.S. Elkinton. 2017. Can *Spathius galinae* attack emerald ash borer larvae feeding in large ash trees?

Tewksbury, L., R.A. Casagrande, N. Cappuccino and M. Kenis. 2017. Establishment of parasitoids of the lily leaf beetle (Coleoptera: Chrysomelidae) in North America. Environmental Entomology. 46(2): 226-236. https://doi.org/10.1093/ee/nvx049

Williams, D.W., Hajek, A.E. 2017. Biological control of *Sirex noctilio* (Hymenoptera: Siricidae) in the northeastern United States using an exotic parasitic nematode. Biological Control 107: 77–86. DOI: 10.1016/j.biocontrol.2017.01.008