United States Department of Agriculture

Overview of the Forest Health Technology Enterprise Team Biological Control Program for Invasive Species - 1995 through 2017

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The Forest Health Technology Enterprise Team (FHTET) was created in 1995 by the Deputy Chief for State and Private Forestry, USDA, Forest Service, to develop and deliver technologies to protect and improve the health of American forests. FHTET became Forest Health Assessment and Applied Sciences Team (FHAAST) in 2016. This booklet was published by FHAAST as part of the technology transfer series.

http://www.fs.fed.us/foresthealth/technology/

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OVERVIEW OF THE FOREST HEALTH TECHNOLOGY ENTERPRISE TEAM BIOLOGICAL CONTROL PROGRAM FOR INVASIVE SPECIES – 1995 THROUGH 2016

BACKGROUND

The number of non-native (i.e., exotic, alien) plants and animals in the U.S. is estimated at 50,000; many provide enormous benefits and many others cause no problems, especially in agriculture. However, approximately 15 percent have been identified as having severe, unwanted economic costs.

In U.S. forests, about half of the 400 species of non-native insects and a relatively fewer number of non-native diseases are regarded as invasive pests, and 17 species are highly invasive due to severe economic and ecological impacts. Forest Health surveys in the northeastern U.S. indicated that more than 61% of forested acres have been damaged by non-native forest pests (insects and diseases).

Non-native invasive plants (i.e., noxious weeds) threaten the ecological integrity and biological diversity of forest and range ecosystems. Unfortunately, there are no accurate inventories of non-native invasive plants within the U.S. It is estimated that non-native invasive plants comprise 8 to 47 percent of the total flora of most states.

National impacts from non-native invasive species and the inadequacies of federal programs to address existing and potential threats were documented in a 1992 Office of Technology Assessment Report (OTA 1993). Subsequently, the role of the federal sector was addressed in Executive Order 13112, "Invasive Species," released in February 1999. This Executive Order defined the criteria for a species to be considered invasive, required federal agencies to prevent the introduction and spread of invasive species, and established the National Invasive Species Council to oversee implementation and prepare a National Invasive Species Management Plan that reviews current management programs and identifies how to minimize economic and ecological impacts by invasive species (completed on January 18, 2001). The Order also directed the Council to form a non-federal Invasive Species Advisory Committee (ISAC) to advise the Council on its work.

The risk of new introductions of invasive species into the U.S. will continue to increase due to increased interstate movement, either intentional or unintentional, and increased international trade. Continued spread of invasive species already established within the U.S. will require active management to reduce ecological, economic and social impacts and restoration of affected ecosystems.

ROLE OF THE U.S. DEPARTMENT OF AGRICULTURE AGENCIES

The Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine Division (PPQ), is the USDA agency authorized by the Plant Protection Act of 2000 and others to prevent the introduction of non-native invasive species into the U.S. This agency is also responsible for the detection and eradication of all non-native invasive species that are introduced into the U.S. However, other agencies, such as the Agricultural Research Service (ARS), Forest Service (FS), and agencies in the Department of the Interior (DOI), provide technical and financial assistance in APHIS's efforts to detect and manage non-native invasive species.

USDA Regulation 9500-10 stated the Secretary of Agriculture's direction pertaining to USDA leadership for non-native invasive species. It authorizes the Forest Service to directly respond, control, monitor, and conduct research on invasive species on approximately 190 million acres of National Forest System lands as well as providing technical and financial assistance for all of the nation's 731 million acres of forest lands, including urban lands; state, private, and tribal lands; and forested lands managed by other federal agencies. The goal of the Forest Service Invasive Species Program is to reduce, minimize or eliminate the potential for introduction, establishment, spread, and impact of invasive species across all landscapes and ownerships.

In 2013 the Forest Service developed a National Strategic Framework for Invasive Species Management (http://www.fs.fed.us/publications/invasive/invasive-framework-2013.pdf). This Framework supersedes the agency's 2004 Invasive Species Strategy and Implementation Plan. The Framework responds to a 2010 USDA Office of Inspector General audit of Forest Service invasive species programs by providing a consistent, agency-wide approach to the prevention, detection and control of invasive insects, pathogens, plants, wildlife and fish.
The Framework incorporates a new Invasive Species System Approach (ISSA), developed to provide a coordinated response to invasive species, both native and non-native, over time. The ISSA identifies four key program elements: (1) prevention, (2) detection, (3) control and management, and (4) restoration and rehabilitation. The agency has chartered national and regional Invasive Species Issue Teams (NISIT and RISITs, respectively) which are charged with assessing priorities, and coordinating activities across the Forest Service, and with Federal, State and local partners.

BIOLOGICAL CONTROL

Biological control—the reduction of an organism's population density through use of its natural enemies—has been recognized as being one of the most effective and cost-efficient longterm approaches for managing invasive species. Natural enemies (parasites, predators, herbivores, and pathogens) reduce the population of hosts; in turn, host abundance influences the population levels of natural enemies.

In natural ecosystems, the primary economically viable, environmentally sound and long-term sustainable management option over the entire invaded range of invasive species is classical bio-

logical control. It is the intentional introduction of non-native natural enemies for permanent establishment and long-term control of invasive species in the infested areas. It is a strategy that has been used extensively to control non-native invasive species. A review conducted on the outcome of 70 classical biological control programs, targeting both invasive insect and plant pests in wildlands worldwide, found that 62% of the insect pest control program using biological control organisms were successful in reducing damage below the impact threshold level, while only 27% of the invasive plant programs were considered successful (Van Driesche et al 2010).
It is a long-term process: successful classical biological control programs tend to average 10 years from the discovery and evaluation of natural enemies to their release and establishment in an infested area.

Existing biological control regulations are based mainly on the interpretation of five acts of legislation: 1) The Plant Quarantine Act of 1912, 2) The Federal Plant Pest Act of 1957, 3) The Federal Insecticide, Fungicide, and Rodenticide Act of 1947 (FIFRA), 4) The National Environmental Policy Act of 1969 (NEPA), and 5) The Endangered Species Act of 1973. These laws were not written with biological control agents in mind. Item 2 above is the law most often used for regulating classical biological control agents, though its purpose was to prevent the introduction of organisms that damage plants, not to provide a regulatory function for biological control agents.

One of the greatest challenges to biological control efforts is obtaining timely approval for importation and release of biological control agents. In general, there is poor communication by agencies about biological control applications, as well as the confusing and continually changing regulatory requirements. **There is a need to develop a process and standards that are efficient, and scientifically based for regulating biological control agents.**

FOREST HEALTH TECHNOLOGY ENTERPRISE TEAM

The Forest Health Technology Enterprise Team (FHTET) was created in 1995 by the Deputy Chief for State and Private Forestry to provide a focus within Forest Health Protection to develop and deliver technologies to protect and improve the health of America's forests. The FHTET Strategic Plan defines relationships with key cooperators and partners in three longterm strategic goals: 1) improve assessment of the health of America's forests, 2) protect and improve forest health through development and application of environmentally sound technologies, and 3) provide technical expertise and support to national programs. Goals 2 and 3, as well as the Forest Service strategy for dealing with invasive species, involved the need to develop biological controls as a central feature to an IPM approach to ecosystem restoration; therefore, biological control was identified as one of the major work emphasis areas within FHTET.

FHTET BIOLOGICAL CONTROL PROGRAM

The FHTET biological control program (FHTET-BC) is part of the broader Forest Service's National Strategic Framework for Invasive Species Management as well as regional

plans dealing with invasive species.
The focus of the FHTET-BC is to demonstrate a strong national leadership role in the development of biological control technology and its implementation as a viable component for integrated programs to manage invasive species (arthropods, plants, and diseases), and restore and rehabilitate habitats and ecosystems.

The FHTET-BC Program encompasses four program elements: 1) leadership and coordination, 2) communication, education, and public awareness via publications and sponsoring of symposia/meetings, 3) developing scientific information and technology for control and management (containing and reducing existing infestations), and 4) pilot or demonstration projects for established species and a rapid response for area-wide management of potential invasive species. Because invasive species are associated with disturbed habitats, rehabilitation and restoration (reclaiming native habitats and ecosystems) are the desired outcome of our efforts.

The FHTET-BC program benefits forest managers by providing assistance in:

- Increased awareness and use of biological control,
- More coordinated and focused funding for biological control,
- Technology transfer of up-to-date information on new invasive arthropod and plant species and natural enemies for new and established invasive species, and
- Recommendations on the restoration of native plant species.

The success of the FHTET-BC program is based on leveraging limited FHTET operational funds with Forest Health Protection, Vegetation Management and Protection Research funds and funds from state and local governments, universities, and industry cooperators.

FHTET-BC Program – 1995 through 1999

The initial five years (1995 through 1999) of the FHTET-BC Program were devoted to a comprehensive overview of the past history of biological control attempts for established invasive forest pests and documenting the recently introduced pests that were appropriate for biocontrol. These reviews were published as were the results of four sponsored meetings, all of which provided the initial basis for initiation of projects beyond 1999.

Projects

The extensive list of established invasive species introduced on forest and rangelands in the U.S. as well as potential non-native species required the FHTET-BC program to focus its resources on a few priority insect and plant species that appeared to have the greatest potential for biological control.

In the US, program staff focused on strengthening ongoing biocontrol programs for insect species established in limited geographical areas (i. e., hemlock woolly adelgid and beech scale) with the specific management objective of assisting in the search for and establishment of additional natural enemies for each selected invasive species. Also, we were requested to provide assistance internationally to assist in the development of biological control efforts for pink hibiscus mealy-

bug in Puerto Rico and Sirex woodwasp in several regions in Brazil. Non-native invasive plants were selected for biological control based on their invasiveness (e.g., preventing or depressing the regeneration of native species or out-competing native species after natural disturbance). An effort was initiated to develop a biological control program for mile-a-minute, which is an invasive weed from China and Japan that was rapidly spreading in forested areas in the Northeast. A major effort was initiated by numerous organizations to develop a biological control program for kudzu.

The overseas exploration efforts to locate natural enemies and conduct host range tests were co-ordinated through Forest Service International Programs. Gary Man (Asian Pacific Coordinator) was an active supporter of the classical biological control approach to managing invasive species and provided many opportunities in our search for natural enemies through his cost sharing and contacts in China.

Publications

1. Proceedings of the First Hemlock Woolly Adelgid Review. FHTET-1996-10.
2. Biological Control of Arthropod Pests of the Northeastern and North Central Forests in the U.S.: A Review and Recommendations. FHTET-1996-19.
3. Classical Biological Control of Pest Insects of Trees in the Southern U.S.: A Review and Recommendations. FHTET-1996-20.
4. Biological Control of Forest Pests in the Western U.S.: A Review and Recommendations. FHTET-1996-21.
5. Weed Biocontrol: Extended Abstracts from the 1997 Interagency Noxious Weed Symposium. FHTET-1998-12.
6. Training in the Control of *Sirex noctilio* by the Use of Natural Enemies (Portuguese and English). FHTET-1998-13.
7. Pink Hibiscus Mealybug (Spanish and English) Institute of Tropical Forestry. October 1998.
8. Biology and Biocontrol of Yellow Starthistle. FHTET-1998-17 (3rd ed. June 2009).
9. Host Specificity Testing of Exotic Arthropod Biological Control Agents - The Biological Basis of Host Range Testing, in Proceedings of the Xth International Symposium on the Biological Control of Weeds. FHTET-1999-01.

Symposia/Meetings (sponsored, co-sponsored)

1995 - First Hemlock Woolly Adelgid Review, Charlottesville, VA

1997 - "Biological Control in Natural Areas" at national meeting of the Entomological Society of America, Bozeman, MT

1997 - Oregon Department of Agriculture Interagency Noxious Weed Symposium, Corvallis, OR

1998 - Training in the Control of *Sirex noctilio*, Colombo, Brazil.

FHTET-BC Program – 2000 through 2004

The next five years (2000 through 2004) of the FHTET-BC Program focused on publishing documents, sponsoring meetings, continuing ongoing biological control projects, and initiating new projects to manage invasive species in forest ecosystems. One of the publications, *Biological Control of Invasive Plants in the Eastern U.S.*, was a book printed in 2002 dealing with a review of the history of biological control for 25 species of invasive plants in the eastern U.S.

Projects

Major progress was made in identifying and rearing natural enemies of hemlock woolly adelgid in US quarantine facilities, and then releasing and monitoring these natural enemies for establishment and impacts. Two species of coccinelids and a derodontid beetle were released in the U.S. for control of hemlock woolly adelgid. These natural enemies were recovered from hemlock woolly adelgid populations in China, Japan, and British Columbia, respectively. Natural enemies of pink hibiscus mealybug and Sirex woodwasp were released and established in Puerto Rico and Brazil, respectively. Classical biological control efforts were initiated for emerald ash borer, ambermarked birch leafminer, and elongate hemlock scale.

The mile-a-minute project continued with host range testing of potential natural enemies at the Chinese Academy of Sciences and at the University of Delaware.
A weevil from China, *Rhinoncomimus latipes*, that feeds on mile-a-minute was approved for release in the U.S. in 2003; releases of this weevil were made in New Jersey and Delaware in 2004. The weevil successfully established itself at all release sites.

Classical biological control efforts were initiated for non-native invasive plants: knotweeds, garlic mustard, and tree-of-heaven.

International Programs continued to provide much needed financial assistance in support of foreign exploration and host range testing at overseas institutions.

Publications

1. Guide to Common Natural Enemies of the Nantucket Pine Tip Moth. FHTET-2001-02.
2. Biological Control of Invasive Plants in the Eastern U.S. FHTET-2002-04.
3. Biology and Biological Control of Knapweeds. FHTET-2001-07. (Revised 3rd ed., 2011).
4. Proceedings of the First International Symposium on Biological Control of Arthropods. FHTET-2003-05.
5. Sampling Methods for Forest and Shade Tree Insects of North America Volume 1 - FHTET-2001-01 (2nd ed., April 2010)
6. Hemlock Woolly Adelgid. FHTET-2001-03. .
7. Invasive Plants of the Eastern United States – Identification, Biology and Control. FHTET-

2003-08. (CD ROM only) (3rd ed., 2005).

8. Emerald Ash Borer Research Review. FHTET-2004-02.
9. Biology and Biological Control of Purple Loosestrife. FHTET-2004-12. (revised 3rd ed, 2015).
10. Biological Control of Hemlock Woolly Adelgid. FHTET-2004-04.
11. Assessing Host Ranges for Parasitoids and Predators used for Classical Biological Control: a Guide to Best Practice. FHTET-2004-03.
12. Invasive plants of Asian Origin Established in the United States and Their Natural Enemies. Volume 1. FHTET-2004-05.
13. Emerald Ash Borer Research Review. FHTET-2004-15.

Symposia/Meetings

2002 – First International Symposium on Biocontrol of Arthropods–Honolulu, Hawaii
2002 – Second Hemlock Woolly Adelgid Review–New Brunswick, New Jersey
2003 – Emerald Ash Borer Research and Technology Development Meeting–Port Huron, Michigan
2004 – Emerald Ash Borer Research and Technology Development Meeting–Romulus, Michigan

Completed Projects - Insects

2004 – Our efforts on the pink hibiscus mealybug project in Puerto Rico ended with the establishment and distribution of parasitoids, but continued through APHIS.

FHTET-BC Program – 2005 through 2009

The program focus continued on publishing documents, sponsoring meetings, and ongoing biological control projects. Major progress was made in supporting the continued search for natural enemies as well as in rearing, host range testing, and release of additional natural enemies for the following invasive species: insects - emerald ash borer and hemlock woolly adelgid and *plants* - garlic mustard, knotweeds, mile-a-minute and tree of heaven.

In 2005, a new cooperative effort was initiated with the University of Massachusetts for biological control of the winter moth. The project focused on collecting parasitized winter moth larvae from Victoria, British Columbia. The recovered tachinid *Cyzanis albicans* was released in New England in 2005, with annual releases through 2009.

In 2007, our efforts on *Sirex* woodwasp in Brazil ended, but continued through FHP.

In 2007, a new cooperative effort was initiated with the Southern Research Station for Chinese privet. The project focused additional searches for natural enemies in China as well as host range testing and laboratory rearing of natural enemies already in laboratories in China. Efforts to locate parasitoids of beech scale were not successful despite extensive surveys in both the Caucasus Mountains proper and in the lesser Caucasus Mountains to the south.

In 2007, two workshops were conducted: the first workshop in China focused on cooperative efforts to use biocontrols to manage invasive species both in China and in the USA. The second workshop

was held in Mexico and focused on the use of biological controls for forest pests and a Spanish version of a biological control handbook (FHTET-2007-02) was distributed at the meeting. The handbook was subsequently made available to biological control scientists, pest managers, etc. throughout Spanish speaking countries.

In 2009, the following projects were completed: insects - ambermarked birch leafminer, beech scale, and elongate hemlock scale.

In 2009, a new cooperative effort was initiated with the University of California (Riverside) for biological control of the goldspotted oak borer.

Publications

1. Third Symposium on Hemlock Woolly Adelgid in the Eastern United States. FHTET-2005-01.
2. Proceedings of the Second International Symposium on Biological Control of Arthropods. Volumes 1 and 2. FHTET-2005-08.
3. Proceedings of the Garlic Mustard and Buckthorn Conference. FHTET-2005-09.
4. Biology and Biological Control of Dalmation and Yellow Toadflax. FHTET-2005-13. (revised 3rd ed, 2016).
5. Catalogue of Introductions of Pathogens and Nematodes for Classical Biological Control of In sects and Mites. FHTET-2005-05.
6. Invasive plants found in Asia and established in the United States and their natural enemies Volume 2. FHTET-2005-15.
7. Biology and Biological Control of Leafy Spurge. FHTET-2005-07. (2nd ed., June 2009).
8. Biological Control Agents of Noxious Weeds – Identification Cards. FHTET-2006-05.
9. Overview of Forest Health Technology Enterprise Team Biological Control Program for Invasive Species - 1995 through 2007 - FHTET-2006-18 (revised 2nd ed., 2015).
10. Emerald Ash Borer Research Review. FHTET-2005-16.

11. Parasitoids and Invertebrate Predators of Forest Pests in China (English and Chinese) – China Forestry Publishing House – February 2007.
12. *Aleiodes* Wasps of Eastern Forests: A Guide to Parasitoids and Associated Mummified Caterpill ars-FHTET-2006-08.
13. Rush Skeletonweed Management Plan for the Western U. S. FHTET-2009-03.
14. Biological Control of Pests and Weeds by Natural Enemies (In Spanish). FHTET-2007-02.
15. Biology and Biological Control of Common St. Johnswort. FHTET-2010-05.
16. Invasive Plants of the Western United States – Identification and Control. FHTET-2007.
17. Biology and Biological Control of Exotic True Thistles. FHTET-2007-05 (revised 3rd ed., April 2012).
18. Biology and Biological control of Mile-a-Minute Weed. FHTET-2008-10 (2nd ed., September 2009).
19. Noxious Weeds and Their Biocontrol Agents - Field Note Cards. FHTET-2007-01 (revised 2nd ed., 2012).

20. Third International Symposium on Biological Control of Arthropods FHTET-2008-06.
21. New Invaders of the Northwest. FHTET-2009-04.
22. Emerald Ash Borer and Asian Longhorned Beetle Research and Technology Development Meeting. FHTET-2007-04.
23. Emerald Ash Borer Research and Technology Development Meeting. FHTET-2008-07.
24. Emerald Ash Borer Research and Technology Development Meeting. FHTET-2010-01

Symposia/Meetings

2005 – Emerald Ash Borer Research and Technology Development Meeting – Pittsburgh, PA
2005 – Second International Symposium on Biocontrol of Arthropods - Davos, Switzerland
2005 – Third Symposium on Hemlock Woolly Adelgid in the Eastern USA – Asheville, NC
2006 - Emerald Ash Borer and Asian Longhorned Beetle Research and Technology Development Meeting (Oct. 31 - Nov. 1, 2006) Cincinnati, OH
2007 – Hemlock Woolly Adelgid Biological Control Working Group: January 2007, Annapolis, MD
2007 – International Workshop on Invasive Species of Forests (focus: biological control): September 2007, Beijing, China
2007 – International Workshop on Biological Control of Invasive Species of Forests, as part of a meeting of Mexican Entomological Societies: November 2007, Mexico City, Mexico
2008- Fourth symposium on Hemlock Woolly Adelgid in the Eastern U. S. (Feb. 12-14, 2008 Hartford, CT).
2008 - Hemlock Woolly Adelgid in the Eastern United States Symposia Proceedings 1995, 2002, 2005, 2008 CD-ROM - FHETET-2008-02.
2007 - Emerald Ash Borer Research and Technology Development Meeting – Pittsburgh, PA
2008 - Third International Symposium on Biological Control of Arthropods, Chile
2009 - Emerald Ash Borer Research and Technology Development Meeting July 2010

COMPLETED PROJECTS–INSECTS

Ambermarked birch leafminer (*Profenusa thomsoni*) (Hymenoptera: Tenthredinidae)

The ambermarked birch leafminer, a sawfly, was accidentally introduced from Europe to North America early in this century. It is a serious pest of native and introduced birches (*Betula* spp.) in western Canada and, in 1996, in the areas around Anchorage and Fairbanks, Alaska. Urban trees had a higher percentage of leaves mined than trees in forests due to an urban heat effect. FHTET funded a taxonomic review and development of a key to Nearctic *Lathrolestes* Forester with special reference to species attacking leaf mining Tenthredinid sawflies (Reshchikov et al 2010). A parasitic wasp, *Lathrolestes thomsoni* (the biocontrol agent, formerly misidentified as *L. luteolator)* was discovered attacking larval *Profenusa thomsoni* in Alberta, Canada, and dramatically reduced populations of the sawfly. *L. thomsoni* was determined to be an effective parasitoid and was mass reared and shipped from Canada to Alaska. From 2004 to 2009, a total of 3636 *L. thomsonii* parasitoids were released in Alaska. *L. thomsoni* wasps were recovered at all nine release sites, suggesting establishment of the parasitoid (Soper et al. 2015, Soper and Van Driesche 2014).

Two native parasitoids, *L. soperi* and *Aptesis segnis* were discovered parasitizing leafminers during the course of this study. In Anchorage, *A. segnis* caused an average of 26% parasitism, while parasitism by *L. soperi* ranged from 5% to 62% and parasitism by *L. thomsoni* ranged from 1% to 25%. Our efforts on ambermarked birch leafminer ended in 2009 although effectiveness and spread of these three species of parasitoids are being monitored through 2016 at all release sites by FHP-R-10.

Major cooperators: FHP R-10, Canadian Forest Service, University of Alberta, Alaska Department of Natural Resources, and the University of Massachusetts.

Beech scale (*Cryptococcus fagisuga*) (Homoptera: Eriococcidoe)

Beech scale invaded North America via Nova Scotia about 1890. It is now widespread in the eastern U.S. The beech scale attacks the bark of American beech, *Fagus grandifolia*, introducing a beech bark disease that has degraded 80% or more of the American beech over much of its range. This disease is a fungus complex consisting primarily of *Nectria coccinea* var. *faginata* and sometimes *N. galligena*. For beech scale, no parasitoids have ever been recorded in North America or Europe.

FHTET, in cooperation with the University of Massachusetts and CABI Bioscience, supported surveys in the UK and eastern Europe (Balkans) (2001 through 2003); China, Japan (2004 through 2006) and both the Caucasus Mountains proper - Georgia and Azerbaijan and in the lesser Caucasus Mountains to the south - southern Georgia, Armenia, parts of Turkey and Northern Iran. We did not locate any parasitoids, nor viable entomopathogens of the beech scale insect *C. fagisuga*. Also, a study was conducted of the endophytes within the stems of European beech (*F. sylvatica*) trees in UK ancient woodland sites to determine their roles in interacting with pathogenic fungi. Our efforts on beech scale ended in 2009 without the discovery of an effective natural enemy.

Major cooperators: CABI-Bioscience and the University of Massachusetts and Agricultural Univeristy of Georgia.

Elongate hemlock scale (*Fiorinia externa*) (Hemiptera: Diaspididae)

The elonglate hemlock scale (EHS) is indigenous to Japan and first reported in the U.S. in 1908 on Long Island, NY. The elongate hemlock scale is an invasive pest of hemlock, *Tsuga* spp., and other coniferous species of ornamental and forest trees. The principal host plants include Canadian or eastern hemlock, *T. canadensis*; fir, *Abies* spp.; and spruce, *Picea* spp. This pest occurs in Connecticut, Maryland, Massachusetts, New Jersey, New York, Ohio, Rhode Island, Virginia, North Carolina, and Tennessee.

Encarsia citrina is the principal parasitoid of elongate hemlock scale in eastern North America. FHTET assisted in conducting surveys in Japan for natural enemies of this pest with cooperation from The University of Massachusetts and the Osaka Museum in Japan. As a result, several species of parasitoids were identified, collected, and placed in quarantine facilities in the U.S. The outcome of host range testing of these species was not favorable; therefore a decision was made in 2009 to discontinue the search for additional natural enemies.

Major cooperators: University of Massachusetts, University of Tennessee, University of Maryland, University of Vermont, and the Osaka (Japan) Museum of Natural History, and Connecticut Agricultural Experiment Station.

FHTET-BC Program – 2010 through 2017

The program focus continued on publishing documents, sponsoring meetings and ongoing biological control projects. In 2010, the Biological Control of Non-native and Native Invasive Plants (BCIP) national program was initiated with requests for proposals and this program continued each year through 2016 (http://www.fs.fed.us/foresthealth/technology/biological_control_invasive_plants_2016.shtml).

In 2011, a new project as initiated to document the impacts of oriental bittersweet on floodplain forests.

In 2013, a new project was initiated to determine the feasibility for biological control of Japanese stiltgrass. Cooperative agreements were initiated with the University of Delaware, Chinese Academy of Sciences and Nanjing Agricultural University to prepare a risk assessment and draft host plant list, search for herbivores, and pathogens, respectively.

Publications

1. Biology and Biocontrol of Knapweeds - FHTET-2010-01
2. Natural Enemies of Invasive Knotweeds in the Pacific Northwest - FHTET-2010-02
3. Sampling Methods for Forest and Shade Tree Insects of North America Volume 2 - FHTET-2010-03
4. Utilizing Native Species in the Western United States - FHTET-2010-04 (2nd ed., 2012)
5. Biology and Biocontrol Common St. Johnswort - FHTET-2010-05
6. Fifth Symposium on Hemlock Woolly Adelgid in the Eastern United States - FHTET-2010-07
7. Rare, Declining and Poorly Known Butterflies and Moths (Lepidoptera) of Forests and Woodlands in the Eastern United States - FHTET-2011-01
8. Biology and Biocontrol of Tansy Ragwort - FHTET-2011-02
9. Proceedings of the International Symposia on Biological Control of Weeds DVD-ROM - Vol. I-XII 1969-2007 - FHTET-2011-03
10. Implementation and Status of Biological Control of the Hemlock Woolly Adelgid - FHTET-2011-04
11. Caterpillars on the Foliage of Conifers in the Northeastern United States (Revised) - FHTET-2011-07
12. Noxious Weeds and Their Biocontrol Agents - Field Note Cards - FHTET-2012-06
13. Forest Pest Insects in North America - A Photographic Guide - FHTET-2012-02
14. Biology and Biocontrol of Garlic Mustard - FHTET-2012-05
15. Proceedings of the XII International Symposium on the Biological Control of Weeds - FHTET-2012-07
16. The Use of Classical Biological Control to Preserve Forests in North America - FHTET-2013-02
17. Biological Control of Weeds –A World Catalog of Natural Enemies and Their Plants - FHTET-2014-04

18. Biology and Control of Hemlock Woolly Adelgid - FHTET-2014-05
19. Biology and Biological Control of Winter Moth - FHTET-2014-07
20. Field Guide for the Biological Control of Weeds in the Northwest - FHTET-2014-08
21. Biology and Biological Control of the Emerald Ash Borer - FHTET-2014-09
22. New Invaders of the Pacific Northwest - FHTET-2014-12 (revised 2nd ed., 2014)
23. New Invaders of the Southwest - FHTET- 2014-13
24. Biology and Biological Control of Mile-a-Minute Weed FHTET-2008-10 (Revised July 2015)
25. Biology and Biological Control of Purple Loosestrife FHTET-2015-03 (2nd ed. Sept. 2015)
26. Proceedings of the 2014 Emerald Ash Borer National Research and Technology Development Meeting FHTET-2015-07
27. Proceedings of the 2015 USDA Research Forum on Invasive Species FHTET-2015-09
28. Biology and Biological Control of Toadflax FHTET-2016-01 (3rd ed.)
29. A Review of Nontarget Effects of Insect Biocontrol Agents: Concepts and Examples FHTET-2016-02
30. Proceedings of the 3rd Northern Rockies Invasive Plants Council Conference FHTET-2016-03
31. Field Guide to Biological Control of Weeds in Eastern North America FHTET-2016-04
32. Biology and Biological Control of Rush Skeletonweed FHTET-2016-05
33. Classical Biological Control of Insects and Mites: A Worldwide Catalogue FHTET-2016-06
34. Overview of the FHTET Biological Control Program —1995-2016 FHTET-2016-07
35. Biology and Biological Control of Yellow Starthistle FHTET-2016-08
36. 2016 Proceedings of USDA Research Forum on Invasive Species FHTET-2016-09
37. Proceedings of 2016 Emerald Ash Borer National Research and Technology Development Meeting FHTET-2016-10
38. Biology and Biological Control of Scotch Broom and Common Gorse FHTET-2017-01
39. Suppressing Over-abundant Invasive Plants and Insects in Natural Areas by Use of Their Specialize Natural Enemies FHTET-2017-02
40. Biology and Biological Control of Knotweeds FHTET-2017-03
41. New Invaders of the Northeast and Northcentral United States FHTET-2017-04
42. New Invaders of the Southeast FHTET-2017-05
43. 2017 Proceedings of USDA Research Forum on Invasive Species FHTET-2017-06
44. Biology and Biological Control of Tree of Heaven FHTET-2017-07
45. Invasive Plant Publications (14) on flash drive FHTET-2017-08
46. Invasive Insect Publications (9) on flash drive FHTET-2017-09
47. Lepidoptera Publications (9) on flash drive FHTET-2017-10
48. Field Guide to Native Oak Species of Eastern North America FHTET-2003-01 (Reprinted Oct. 2017)

Symposia/Meetings

2010 Fifth Symposium on Hemlock Woolly Adelgid in the Eastern U.S.
2014 Emerald Ash borer Research and Technology Development Meeting, Columbus, OH

COMPLETED PROJECTS – INSECTS

Goldspotted Oak Borer (*Agrilus auroguttatus*) (Coleoptera: Buprestidae)

The goldspotted oak borer (GSOB) is an invasive pest of native oaks and first detected in southern California. It is indigenous to southern Arizona and northern Mexico where it is not considered a pest. In southern CA, GSOB aggressively attacks coast live oak, California black oak and canyon live oak. GSOB has killed at least 25,000 trees through larval feeding, primarily at the interface of the phloem and xylem.

In 2009, an effort was initiated to identify the locations of parasitoids with potential as biological control agents. The majority of known natural enemies associated with GSOB in its home range in AZ and Chiapas, Mexico are either generalist parasitoids or predators, and these are not suitable for use in a classical biological control program targeting GSOB because of their broad host ranges. Due to the inability to rear and thus determine the specificity of natural enemies attacking GSOB larvae and pupae, search efforts have focused on natural enemies attacking *A. auroguttatus* eggs.

A survey was conducted in AZ and CA for host specific egg parasitoids by deploying sentinel egg masses (more than 18,000 eggs). No egg parasitoids of GSOB were found in the native or introduced ranges of GSOB. A generalist egg parasitoid, *Trichogramma* sp. was found to attack *A. auroguttatus* eggs at very low levels (approximately 0.1%) during surveys conducted in AZ. Biological control may still be the most viable long-term management option for GSOB in southern CA. However, additional research on GSOB life history and population dynamics is needed before additional efforts for surveying natural enemies.

Major cooperators: University of California (Riverside), USDA - Forest Service - FHP, USDA - Forest Service Southwest Research Station

COMPLETED PROJECTS - PLANTS

Kudzu (*Pueraria montana* var. *lobata*)

Kudzu is an invasive climbing deciduous perennial vine capable of reaching lengths of 35 to 100 feet. Kudzu is easily identified when it grows in a large dense mat of vines, its usual growth form. It is found in open areas such as road sides, right-of-ways, forest edges, and old fields where it grows over, smothers, and kills all other vegetation, including trees. Kudzu is native to Asia and was first introduced into America in 1876 at the Philadelphia Centennial Exposition as a potential forage plant. Later, it was widely planted throughout the eastern United States to control erosion.

A major cooperative effort among numerous agencies was initiated to survey for potential natural enemies. Since 1997, a total of 116 phytophagous insect species in 31 families and 5 orders were collected from kudzu in China. Diseases of kudzu were also surveyed. Various leaf-feeding beetles and sawflies have been collected and evaluated for host range in China.

A proposed test list of plants was submitted to the TAG in 2004 detailing the breadth of the plant taxa that should be tested before a potential agent could be approved for use. Three of the most promising species of natural enemies were reared in quarantine facilities in the U.S. Unfortunately, all three of the species in quarantine also fed on soybean and/or hog-peanut. A host specific sawfly was recovered in China, but in extremely low numbers and a colony could not be maintained in quarantine. We have not been able to collect sufficient numbers of this sawfly to establish a lab colony. In 2009, classical biological control efforts for kudzu were discontinued.

Major cooperators: Forest Service (Rocky Mountain Research Station, Southern Research Station), International Programs, North Carolina Department of Agriculture, University of Delaware, University of Tokyo, Anhui Agricultural University, South China Agricultural University, and the Chinese Academy of Science.

Mile-a-minute (*Persicaria perfoliatum*)

Mile-a-minute is native to east Asia and was introduced several times into the United States. In the northeastern U S in the mid-1930s from Japan, pobably as seed unintentionally mixed in with holly seeds. Mile-a-minute is a vine that invades disturbed areas, such as fields, forest edges, roadsides, ditches, and stream banks, in the northeastern United States. The seed remains viable in the seed bank in the soil for six years. It's rapid growth allows it to cover existing vegetation and restrict light availability, which can lead to plant death and restrict establishment of new vegetation.

FHTET sponsored surveys for native natural enemies of mile-a-minute at several sites in five states. More than 1,500 arthropods, representing 100 insect species in 50 families and several orders, were recovered from mile-a-minute. All of the insects recovered from mile-a-minute were not causing any damage except for Japanese beetle adults that were feeding on the foliage.

Out of more than 150 natural enemies collected in China and Japan, a weevil, *Homorosoma chinensis* (Wagner), was determined to be the most promising biocontrol agent. FHTET funded a taxonomic review and revision of the weevil subfamily Ceutorhynchinae to confirm the taxonomy of *H. chinensis.* The weevil was designated *Rhinoncominus latipes* Korotyaev (Boris Korotyaev, Russian Academy of Sciences 2006). Extensive host range testing was conducted at the University of Delaware and the Chinese Academy of Sciences. The weevil was approved for release and released in 2004 in Delaware, New Jersey and West Virginia; the weevil has established populations at all release sites. The weevil is now established in 15 states and spreading rapidly.

Field collections of *R. latipes* geographic populations and mile-a-minute geographic populations in China were evaluated in common garden experiments for the performance of *R. latipes* populations. The completed assessment for the selection of appropriate *R. latipes* haplotypes in China or Japan for biocontrol of mile-a-minute in the U.S. indicated that the released population from Hunan province in China was the most damaging to mile-a-minute in the U. S. (Guo et al 2011).

Since 2003, the NJDA has mass reared *R. latipes* weevils under contract with the USDA (Forest Service and APHIS) and through 2014 reared a total of over 700,000 weevils.

FHTET funded 3-year study investigating integrated approach (Goldstein et al 2015 FHTET-2008-10, revised July 2015) to controlling mile-a-minute using the biocontrol weevil *R. latipes* and restoration planting using a native seed mix. Results suggested an additive effect of biocontrol and seeding in suppressing mile-a-minute. Seeded treatments also developed the highest native plant species richness and diversity, comprised of spontaneous recolonization in addition to species from the seed mix.

Several studies were conducted to prevent the invasive treadmill following biocontrol of mile-a-minute. The combination of biocontrol, pre-emergent herbicide, and revegetation with native

plants suppressed mile-a-minute, prevented invasion by Japanese stiltgrass, and increased the abundance of native plants.

In another study, viability of mile-a-minute seed in green fruits increased throughout the season, peaking before the first frost. So if necessary, to apply a physical or chemical control methods during the fruiting period, these methods should be applied as early in the season as possible, when immature fruits are less likely to contain viable seed.

Under open field conditions, *R. latipes* dispersed from, and did not feed on any nontarget plant species (including *Polygonum lapathifolia*, *P. punctata* and *P. virginiana*), even when the preferred host plant was killed or absent.

Mile-a-minute monitoring protocols were developed for spring mile-a-minute surveys and summer/fall weevil and plant surveys. These protocols were required for PIs recovering weevils from the NJDA.

Major cooperators: New Jersey Department of Agriculture, University of Delaware, Chinese Academy of Agricultural Sciences, University of Tokyo (Japan), Letterkenny Army Depot, and Codorus State Park (Pennsylvania).

Chinese privet - (*Ligustrum sinense*)

Chinese privet originated from China and was introduced into the U. S. in 1852 as an ornamental. By the 1990s, Chinese privet occurred on 2.9 million acres in the southeast. It is a shade tolerant, semi-evergreen shrub that forms dense thickets, shading or overcrowding native vegetation in forest understories and riparian areas. It is spread by seeds dispersed by birds and other animals as well as root sprouting.

In 2007, FHTET funds were used to expand the biocontrol component of an IPM program, including additional searches for natural enemies in China as well as host range testing and laboratory rearing of natural enemies already in laboratories in China. Host range testing was conducted in quarantine at the University of Georgia. Plots for monitoring Chinese privet have been established by the Southern Research Station. In 2014, a petition for field release of the lace bug (*Leptoypha hospita*) for control of Chinese privet in North America was submitted to TAG. By September 23, 2016, the TAG has not responded to the petition.

Cooperators: Chinese Academy of Science, Southern Research Station, University of Georgia

Oriental Bittersweet – *Celastrus orbiculatus*

Oriental bitterseet was introduced into the U.S. in the 1860s as an ornamental plant. This woody climbing vine grows on trees and shrubs in North America from the eastern Canadian provinces and Miane to Georgia and west to Iowa and Arkansas, often forming thick stands. It damages native plants by twining around them and killing them by restricting the flow of nutrients and water. Upon reaching the canopy, it overgrows the crowns of host trees , causes death from excessive shading or breakage, and often uproot trees because of its excessive weight. Despite the widespread impression and observation that oriental bittersweet has a negative impact on native trees and shrubs, there are no published reports that measure this impact.

In 2011, a new project "Impact of Oriental Bittersweet in Floodplain Forests" was initiated with The Nature Conservancy. This 5 year effort focused on 88 flooplain forest sites comprising 197 vegetation transects and 12, 656 permanently tagged trees distributed throught the Connecticut River Basin. In the CT and MA portions of the basin, oriental bittersweet is exceedingly widespread and abundant becoming less so going north through the NH and VT portions of the basin. These invasive vines are destroying about 0.33% of the floodplain trees per year. Although this rate seems modest, consider that the damage could be cumulative because the vines are often dense enough in the herb and shrub layer to prevent tree recruitment in gaps, then it would be an impact comparable to emerald ash borer in a couple of decades (Marks and Canham, 2015).

CONTINUING PROJECTS - INSECTS

Hemlock woolly adelgid (*Adelges tsugae*) (Homoptera: Adelgidae)

The hemlock woolly adelgid is native to Asia and western North America, and through DNA analysis the population invasive in eastern North America was determined to have originated in northern Japan. It has been present in the United States since 1924. It is a serious pest of eastern and Carolina hemlocks and first identified in eastern North America in 1953 or 1954. In the eastern United States, it is present from the Smoky Mountains north to the mid-Hudson River Valley and southern New England.

FHTET's cooperators surveyed for candidate biological control agents in Asia (China, Japan) and western North America. All adelgid species do not have recorded parasitoids and therefore the search for natural enemies focused on specialized predators. Predators that may prove useful include: *Laricobius nigrinus* (Inland and Coastal strains), *Sasajiscymnus tsugae*, *Laricobius osakensis*, *Scymnus sinuanodulus*, *Scymnus ningshanensis* and *Leucopis* spp. *L. nigrinus* has established at most of the release sites and is spreading throughout the range of eastern hemlock. A monitoring plan was developed for assessing establishment of efficacy of other predators at previous release sites. Also, a HWA Predator Release and Recovery database was established at VPI.

The fungus *Lecanicillium muscarium*, recovered from HWA populations in the eastern U. S. and in a commercial formulation used to treat greenhouse pests in Europe, is being evaluated along with other *Lecanicillium* spp. for efficacy in ground and aerial application trials.

Major cooperators: Virginia Polytechnic Institute and State University, University of Massachusetts, Forest Service–Forest Health Protection and Research and Development, Osaka (Japan) Museum of Natural History, Oregon State University, China State Forestry Administration, Chinese Academy of Agricultural Sciences, Beijing Academy of Agricultural and Forestry Sciences, and the Sichuan Academy of Forestry

Winter Moth (*Operophtera brumata*) (Lepidoptera: Geometridae)

The native range of winter moth covers most of Eurasia, including all of Europe and much of Russia, including the Russian Far East. Winter moth was introduced into Nova Scotia some time before 1950, Oregon in the 1950s, and into Vancouver Island in the 1970s. In the late 1990s, a new outbreak of winter moth was observed in eastern Massachusetts. Populations of this insect now extend from southeastern Maine to Long Island, NY.

Winter moth larvae are extremely polyphagous, feeding mainly on a large number of deciduos trees. The most preferred hosts are oaks. The winter moth is one of a group of species that feed in early spring and then pupate in the top layer of the soil or litter beginning in mid-May. The pupae remain in the soil or leaf litter until adult emergence in late autumn or early winter (e.g., northeastern U. S. in late November through early January). The female has vestigial wings and cannot fly.

Surveys for natural enemies of winter moth in its native range in France and Germany began in 1952. The tachinid, *Cyzanis albicans* and the ichneumonid *Agrypon flaveolatum* were the most abundantly collected parasitoids. *C. albicans* attacks its host by laying microtype eggs along the edges of partially defoliated leaves. The eggs are consumed by winter moth caterpillars. *C. albicans* was released in MA, RI, CT, ME, and NH.

As of 2014, *C. albicans* is established at eleven sites in the northeastern U. S., has achieved parasitism in excess of 20% at these sites, and appears to have lowered the density of winter moth at least one site.

Major cooperators: USDA-APHIS, University of Massachusetts.

Sirex Woodwasp (*Sirex noctilio*) (Hymenoptera: Siricidae)

Sirex noctilio is one of the top 10 most serious insects pest in the world. It is native to northern Africa, Asia and Europe where it is not a pest. *S. noctilio* was discovered in New York State in 2004 and in 2005 in Ontario, Canada. During egg laying, *S. noctilio* females inject a toxic mucus and a fungus into the bark of pine trees. The mucus kills the tree cells, the fungus feeds on the dead tree cells, and the larvae feed on the fungus.

Exploration for natural enemies indicated that the most effective species was a nematode, *Deladenus siricidicola*, which sterilizes female woodwasps. Three native hymenoptera parasitoids attack *S. noctilio* with *Ibalia leucospoides* the most abundant.

S. noctiilio and other *Sirex* spp. as well as their nematode and associated fungi are being evaluated for effectiveness in sterilizing *S. noctilio* females in the northeast prior to a mass rearing and release program. The Komona strain of the nematode is not effective in sterilizing female *Sirex noctilio* found in the northeast.

Major cooperators: Cornell University, Natural Resources Canada, University of Arkansas, University of Pretoria, South Africa, USDA-APHIS.

Emerald ash borer (*Agrilus planipennis*) (Coleoptera: Buprestidae)

In 2002, the emerald ash borer (EAB) was discovered in North America in southeastern Michigan and nearby Ontario, Canada. EAB was introduced from China during the 1990s. Its host range and distribution (in 21 states) coincides with that of *Fraxinus.*

The USDA Forest Service (FHTET), ARS and APHIS were part of a cooperative effort with the Chinese Academy of Forestry and others to find natural enemies of this pest in China. Three species of parasitoids (*Spathius agrili*, *Tetrastichus planipennisi*, and *Obius agrili*) have been collected in China, reared in quarantine facilities, approved for release and released in several states. All three species established although numbers of *S. agrili* are extremely low. An additional *Spathius* species *galinae* was discovered in Russia, approved for release in the U.S., and is being reared in quarantine facilities for release in 2015.

Major cooperators: USDA APHIS, Michigan State University, Chinese Academy of Forestry, and USDA Forest Service–Research and Development, USDA-ARS, University of Massachusetts.

CONTINUING PROJECTS - PLANTS

Garlic mustard (*Alliara petiolata*)

Garlic mustard is an invasive biennial plant introduced from Europe for medicinal use in the 1800s and first escaped in 1968 on Long Island, New York. Garlic mustard is one of the most serious invaders in forested areas of the Northeast and Midwest and is able to invade and dominate the understory of North American upland and floodplain forests, both in shaded areas and in open woods and savanna, and not just in disturbed areas. Since 2000, it has spread to more than 34 states in the US and 4 Canadian provinces.

Natural enemies collected in Europe are being evaluated in Europe and at the University of Minnesota quarantine facility for host range. The most promising herbivores are four species of weevils: *Ceutorhynchus constrictus*, *C. alliariae*, *C. scrobicollis*, and *C. roberti*. The individual and combined impact of these species can increase rosette mortality and decrease seed output, stem height, and overall performance of garlic mustard. The host range testing for *C. scobicollis* (a root crown feeder) is complete, and the petition for its release was being reviewed by the TAG. The release of *C. scrobicollis* is planned for 2017. Two of the other species of weevils are being reared in quarantine at the University of Minnesota and host range testing is ongoing.

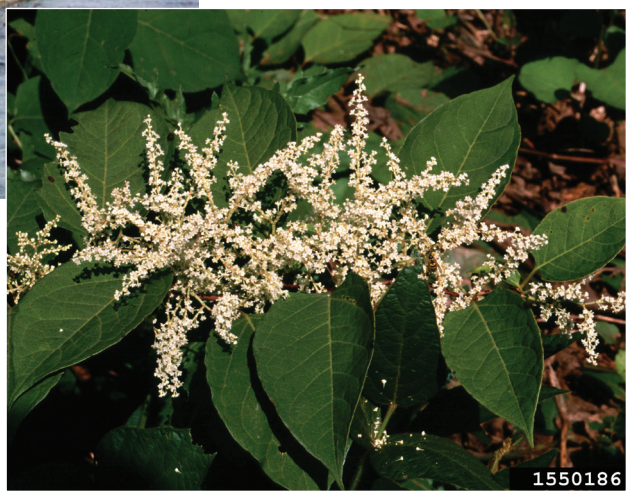
Major cooperators: University of Minnesota, CABI-Bioscience, and the New Jersey Department of Agriculture.

Japanese knotweed (*Fallopia japonica*)

Japanese knotweed was introduced from Asia to North America in the late 19th century. It is a dense growing shrub that reaches heights of up to 10 feet, spreads quickly, and forms dense thickets that exclude native species. It invades disturbed areas with high light, such as roadsides and stream banks. It is extremely difficult to eradicate due to its extensive rhizome system. The dense patches produce shade and displace other plant life and reduce wildlife habitat. The weed is having a major impact in riparian areas associated with salmon restoration. Japanese knotweed has spread through most of North America and has been observed as far north as Alaska.

Few natural enemies have been recovered from knotweed in the United States. In 2006, a limited survey for natural enemies of Japanese knotweed was initiated in China. Two herbivores causing extensive damage to knotweed were recovered, but not pursued after host range testing. In Japan, there are at least 12 species of insect herbivores commonly found on this plant and many more species recorded. Three insects and one pathogen were evaluated in quarantine facilities. The most promising natural enemy is a sap-sucking psyllid *Aphalara itadori* which is being reared in the quarantine facility at Oregon State University. This psyllid has received preliminary recommendation for release in the U. S.

Major cooperators: Oregon State University. University of Washington, CABI-Bioscience, Cornell University, Welsh Development Agency and the United Kingdom Environment Agency.



Tree-of-heaven - (*Ailanthus altissima*)

Tree-of-heaven, native to Asia, was first introduced into the United States in 1748 by a Pennsylvania gardener. It was a widely planted tree in cities because of its ability to grow in poor conditions. Tree of heaven is a fast growing tree with numerous wind dispersed lightweight seeds. It is extremely tolerant of poor soil conditions and thrives in disturbed forests or edges. Dense clonal thickets displace native species and can rapidly take over fields and meadows.

Surveys for natural enemies were conducted in China. Two species of weevils are important natural enemies of tree-of-heaven and have been damaging trees planted in cities as part of China's beautification program. One weevil, *Eucryptorrhynchus brandti*, is in quarantine at Virginia Polytechnic Institute and State University. Host range testing is complete and in 2014 a petition was submitted to TAG. Additional host range testing was recommended which was completed in 2016 and revised petition resubmitted to TAG.

An indigenous fungus, *Verticillium nonalfalafae* was recovered from tree-of-heaven and causing significant mortality at sites in PA, VA, and OH. Host range testing for *V. nonalfalafae* was completed and injections of this fungus have proved successful in killing tree of heaven. In 2015, a regional program to demonstrate the effectiveness of the fungus was proposed for the states of OH, PA, and VA.

Major cooperators: Penn Staate University. Virginia Polytechnic Institute and State University, West Virginia University, USDA- Forest Service-NRS and FHP, and USDA-APHIS.

NEW PROJECTS - PLANTS

Japanese stiltgrass (*Microstegium vimineum*)

Japanese stiltgrass is an annual grass that thrives in low-light conditions. It is one of the most aggressive weed invaders of the forest understory, with proven severe effects in reducing diversity of woodland herbaceous communities and inhibiting forest regeneration and succession. It was accidentally introduced into the U. S. from southeast Asia in the early 1900s. It is currently reported in 27 states and it is continuing to spread. Stiltgrass is spread by seeds dispersed by birds and other animals as well as root sprouting.

Japanese stiltgrass appears to be a good candidate for biological control as there are 16 species in the genus *Microstegium*, mostly tropical or subtropical, and all native to the Old World. There are no other species of *Microstegium* other than *M. vimineum* currently found in North America. In China, Japanese stiltgrass occurs in at least 15 provinces and 15 other species in the same genus are also found in China. So far there have been no systematic surveys for insects or pathogens feeding on the genus *Microstegium* in Asia.

An initial risk assessment and biological control feasibility study for Japanese stiltgrass is being prepared by Hough-Goldstein at the University of Delaware, Ding at the Chinese Academy of Sciences is surveying for potential herbivores, and Qiang at Nanjing Agricultural University is surveying for potential pathogens..

SUMMARY

There are numerous organizations and regulations in place to deal with non-native invasive species and much progress is being made in identification of introductive pathways, preparation of risk maps, and attempted prioritization of invasive species threatening North America.

The Forest Health Technology Enterprise Team biological control program for invasive species was initiated in 1995. From 1995 through 1999 the program was devoted to reviewing past history of biological control attempts for invasive forest pests and documenting which new pests were appropriate candidates for biocontrol. The program from 2000 through 2016 focused on publishing documents, sponsoring meetings, and providing funds critical to developing classical biological control programs for invasive insects and plants.

The release of the weevil, *Rhinoncominus latipes* for mile-a-minute has been a huge success, as the weevil has established overwintering populations at all release sites, spread to nearby sites, and impacted plant populations. Also, the New Jersey Department of Agriculture at their Phillip Alampi Biological Control Laboratory continues to rear the weevils for cooperators both within and outside the state of New Jersey. The collection of adults from field insectaries continues to provide weevils for release at additional sites.

The release of the parasitic wasp, *Lathrolestes thomsoni* for control of the ambermarked birch leafminer has been a success with populations established in most release sites in Alaska. Monitoring wasp and leafminer populations at release sites continued through 2016 to determine rates of parasitism.

The biological control projects for garlic mustard, Japanese knotweed, tree of heaven, and Chinese privet have resulted in petitions to the TAG for evaluation and recommendation to APHIS for release of the specific agents in the U. S. Unfortunately, recent USFWS (US Fish and Wildlife Service) Section 7 consultations have resulted in all petitions to be placed “on hold” until several issues can be resolved. If the current USFWS interpretations of Section 7 consultations persist, all releases of biological control agents will be stopped.

Our efforts for biological control of beech scale and kudzu have not been productive and were terminated. We never could locate any parasitoids for beech scale in spite of extensive surveys including remote areas not previously surveyed. We discovered several herbivores of kudzu, but all were not specific to kudzu and fed on soybeans and hog peanut.

Our 3 year (2014 - 2016) effort to determine the feasibility of developing a biological control for Japanese stiltgrass will probably require an additional year of survey for natural enemies and preliminary host testing in China. A list of plants for host range testing of potential natural enemies has been developed and submitted to the TAG for review/comment.

The release of the tachinid *Cyzanis albicans* for control of winter moth at various release sites in the northeastern U. S. has been successful with establishment at most release sites, parasitism in excess

of 20% and appears to have lowered the density of winter moth at least one site.

The biological control program for *Sires noctilio* is continuing with the focus on studies to determine the most effective nematodes and associated fungi for effectiveness in sterilizing *S. noctilio* females.

The biological control programs for emerald ash borer and hemlock woolly adelgid are ongoing and expanding into new geographical areas, with establishment of new species of parasitoids and predators, respectively. The biological control program for hemlock woolly adelgid has become one of the largest biological control programs for a forest pest since the gypsy moth program.

Despite the successes of the FHTET-BC program, there are some major challenges that must be addressed to ensure that the FHTET-BC program remains viable: 1) additional funding sources for identifying candidate biological control agents in their native range, undertaking foreign exploration, screening and post-release monitoring, 2) resolving difficulties in shipping live biological control agents from the countries of origin, 3) streamlining regulatory requirements and procedures including those of the originating foreign countries, which may differ from the receiving country, 4) obtaining timely approval for the importation and release of biological control agents, and 5) modification of the final stages of the biological control review process by APHIS-PPQ and USFWS.

REFERENCES

Goldstein, J., E. Lake, R. Reardon, and Y. Wu. 2015. Biology and Biological Control of Mile-a-Minute Weed. FHTET-2008-10 revised July 2015.

Guo, W., X. Li, X. Guo, and J. Ding. 2011. Effects of *Rhinoncominus latipes* on the growth and reproduction of *Persicaria perfoliata* an invasive plant in North America. Biocontrol Science and Technology 21(1): 35–45.

Korotyeav, B. 2006. A review of the weevil genus *Rhinoncomimus* Wagner (Coleoptera: Curculionidae:Ceutorhynchinae). Entomologische Abhandlungen 63 (1-2): 99–122.

Marks, C. and C. Canham. 2015. A quantitative framework for demographic trends in size-structured populations: analysis of threats to floodplain forest. Ecosphere 6: 1–18.

Office of Technology Assessment (OTA) 1993. Harmful non-indigenous species in the United States. United States Congress, Washington, D. C.

Pimental, David, Lori Lach, Rodolfo Zuniga, and Doug Morrison. 2000. Environmental and Economic Costs Associated with Non-Indigenous Species in the U. S. BioScience 50: 53.65.

Reshchikev, A., A. Soper and R. VanDriesche. 2010. Review and key to Nearctic *Lathrolestes* Forster. Zootasca 2614:1–17.

Soper. A., C. MacQuarrie, and R. VanDriesche. 2015. Introduction, establishment, and impact of *Lathrolestes thomsoni* for biological control of the ambermarked birch leafminer. Biological Control 83: 13–19.

Soper, A. and R. VanDriesche. 2014. Ambermarked birch leafminer. Chapter XX in VanDriesche and Reardon. The Use of Classical Biocontrol to Preserve Forests in North America. FHTET-2013-02.