Pesticides, Predators, and Patch Cuts: Persistent Peril or Possible Promise for the Prized Eastern Hemlock?

Albert (Bud) Mayfield
Research Entomologist
USDA Forest Service
Southern Research Station

Save Georgia's Hemlocks, Ellijay GA, 5 June 2016

Eastern and Carolina Hemlock

Tsuga canadensis, T. caroliniana

- Eastern: Long-lived, shade tolerant, “foundation species”, unique riparian communities
- Carolina: Ridges, rocky outcroppings, very narrow distribution in S. Appalachians

BATTLING A GIANT KILLER

The iconic eastern hemlock is under siege from a tiny invasive insect

By **Gabriel Popkin** *in Highlands, North Carolina; photography by* **Katherine Taylor**

On a frigid morning this past March, arborist Will Blozan snuck behind a small church here and headed down into a gorge thick with rhododendron. He crashed through the shrubs until he spotted the gorge's treasure: the world's largest known living eastern hemlock tree, known as the Cheoah.

In 2006, Blozan had climbed the nearly 50-meter-tall giant and calculated that it contained 44.29 cubic meters of wood—then a record. Blozan would later discover two even larger hemlocks in the nearby Great Smoky Mountains National Park. Both of those champions, however, are now dead.

So are millions of other hemlocks across eastern North America. They've been reduced to leafless gray skeletons by the hemlock woolly adelgid (*Adelges tsugae*), a tiny sap-sucking insect about the size of a pinhead. Originally from Japan, the adelgid has spread from Georgia to Maine in recent decades, entering new hemlock stands every year. Left unchecked, it kills nearly every tree it attacks. Paradoxically, large, seemingly vigorous trees like the Cheoah often go fastest.

For years, forest managers have been in a fierce fight against the park, "are in intensive care." Like the family of a gravely ill patient, ecologists are also preparing for the possibility that these efforts will fail, and the eastern forest will lose one of its defining species.

TSUGA CANADENSIS is one of eastern North America's largest native conifers. It has been called the "redwood of the east" and the "queen of the conifers." A healthy tree resembles an evergreen waterfall; overlapping layers of short, downy needles cascade from the crown almost to the ground.

Biologists believe the species diverged

Distinctive tufts help protect adult hemlock woolly adelgids. The insects stay put once they start feeding on hemlock needles.

branches, creating a thick canopy that blocks up to 99% of sunlight. Few plants grow in the gloom, but a hemlock seedling can bide its time for decades or more, waiting for a sunlit opening. Hundreds of species of insects, mites, and spiders appear to live primarily or exclusively in hemlock forests, and some aquatic invertebrates eat the hemlock needles that fall into mountain streams. Many migratory birds seek out the trees.

The oldest known specimen was 555 years old when dendrochronologist Edward Cook measured it in 1991; just four other eastern tree species are known to live longer. "There's no tree, certainly in the east, that has anything like that kind of complete control" over its environment, says David Foster, an ecologist and director of the Harvard Forest in Petersham, Massachusetts.

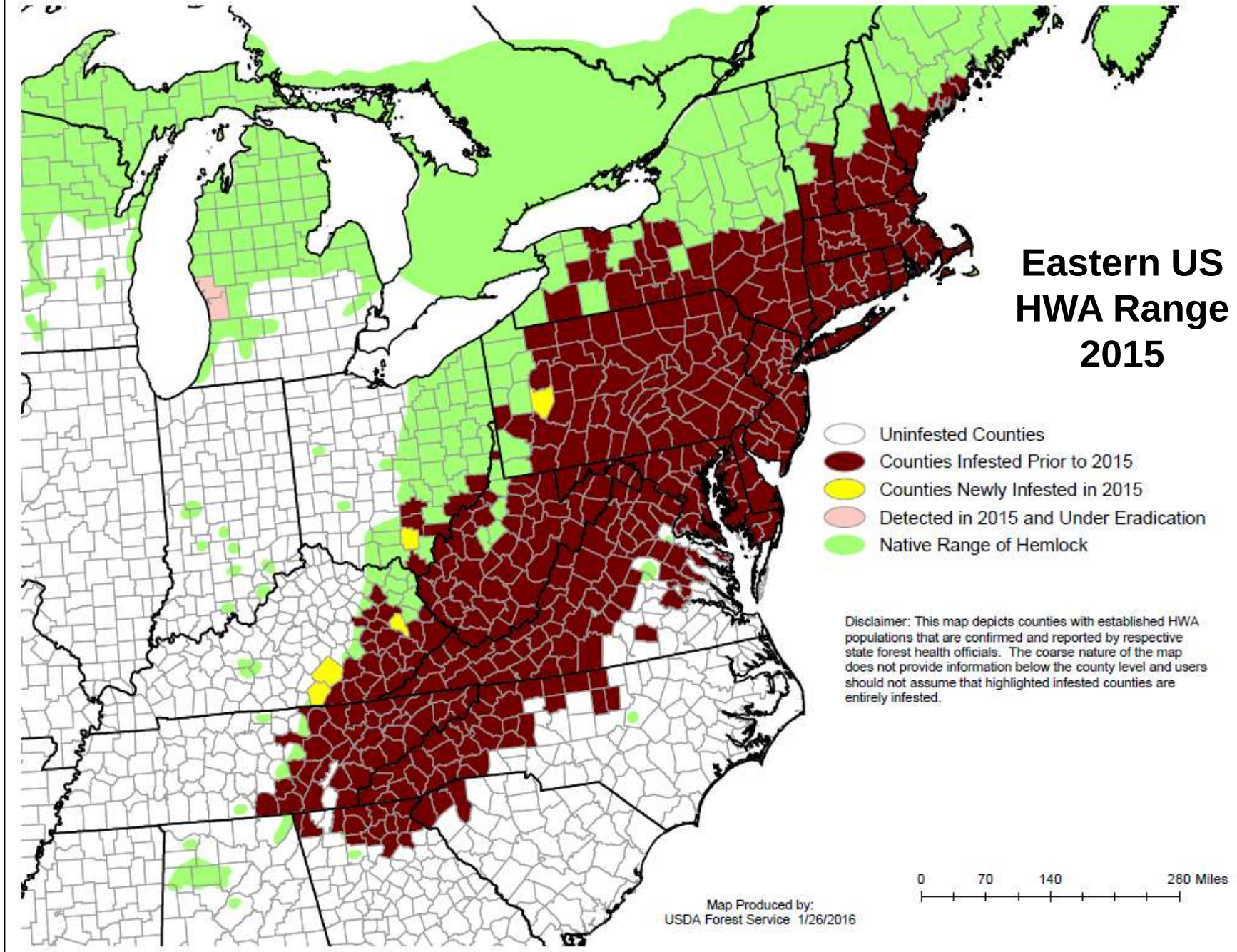
THE HEMLOCK'S MIGHTY GRIP is now being loosened by the diminutive *A. tsugae*. Hemlock woolly adelgids "are bizarre little things," says entomologist Lynne Rieske-Kinney of the University of Kentucky in Lexington. An adult is about a millimeter long, with a threadlike proboscis that can be three times as long as its body. They can easily catch a ride to new trees on the wind or on birds and

Science Magazine, August 2015

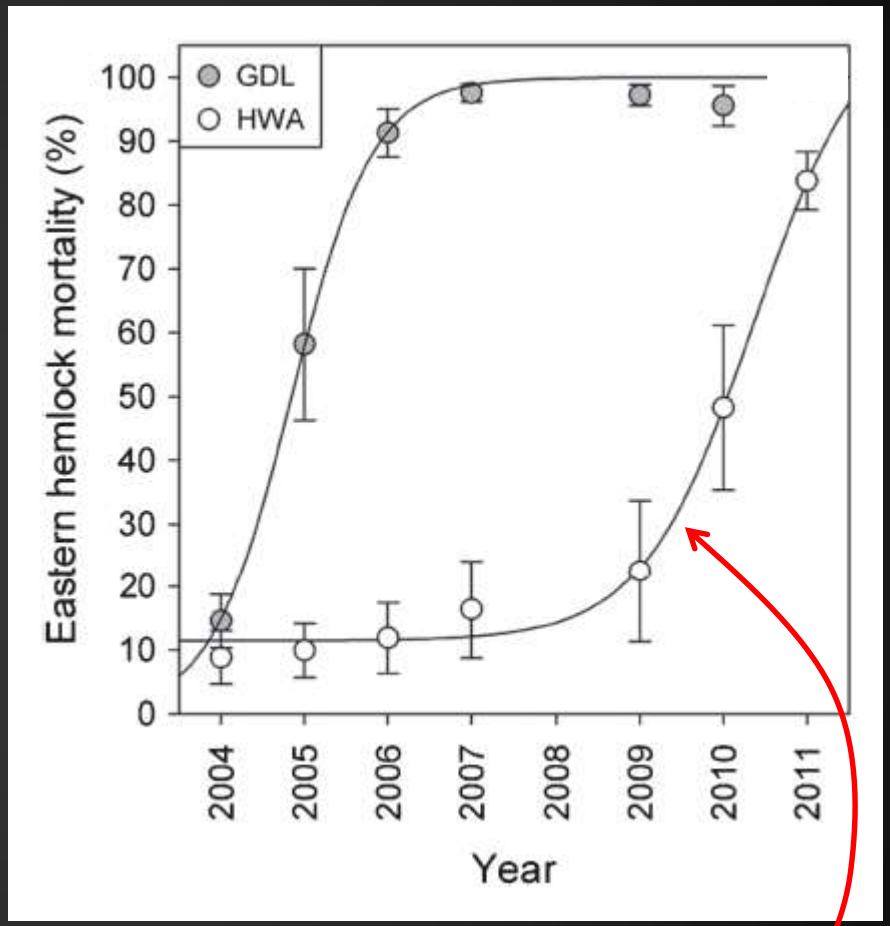
Hemlock Woolly Adelgid

Adelges tsugae

- Native to Asia and western North Am.
- Introduced to eastern U.S. from Japan
- Two asexual generations per year
- Depletes carbohydrates in ray parenchema


Eastern US
HWA Range
2015
Uninfested Counties
Counties Infested Prior to 2015
Counties Newly Infested in 2015
Detected in 2015 and Under Eradication
Native Range of Hemlock
Disclaimer: This map depicts counties with established HWA populations that are confirmed and reported by respective state forest health officials. The coarse nature of the map does not provide information below the county level and users should not assume that highlighted infested counties are entirely infested.
0
70
140
280 Miles
Map Produced by:
USDA Forest Service 1/26/2016

Rapid hemlock mortality in S. Appalachians



Coweeta Watershed, NC
90% hemlock mortality in 7 yrs

Source: Ford et al. 2012. Oikos 121: 523

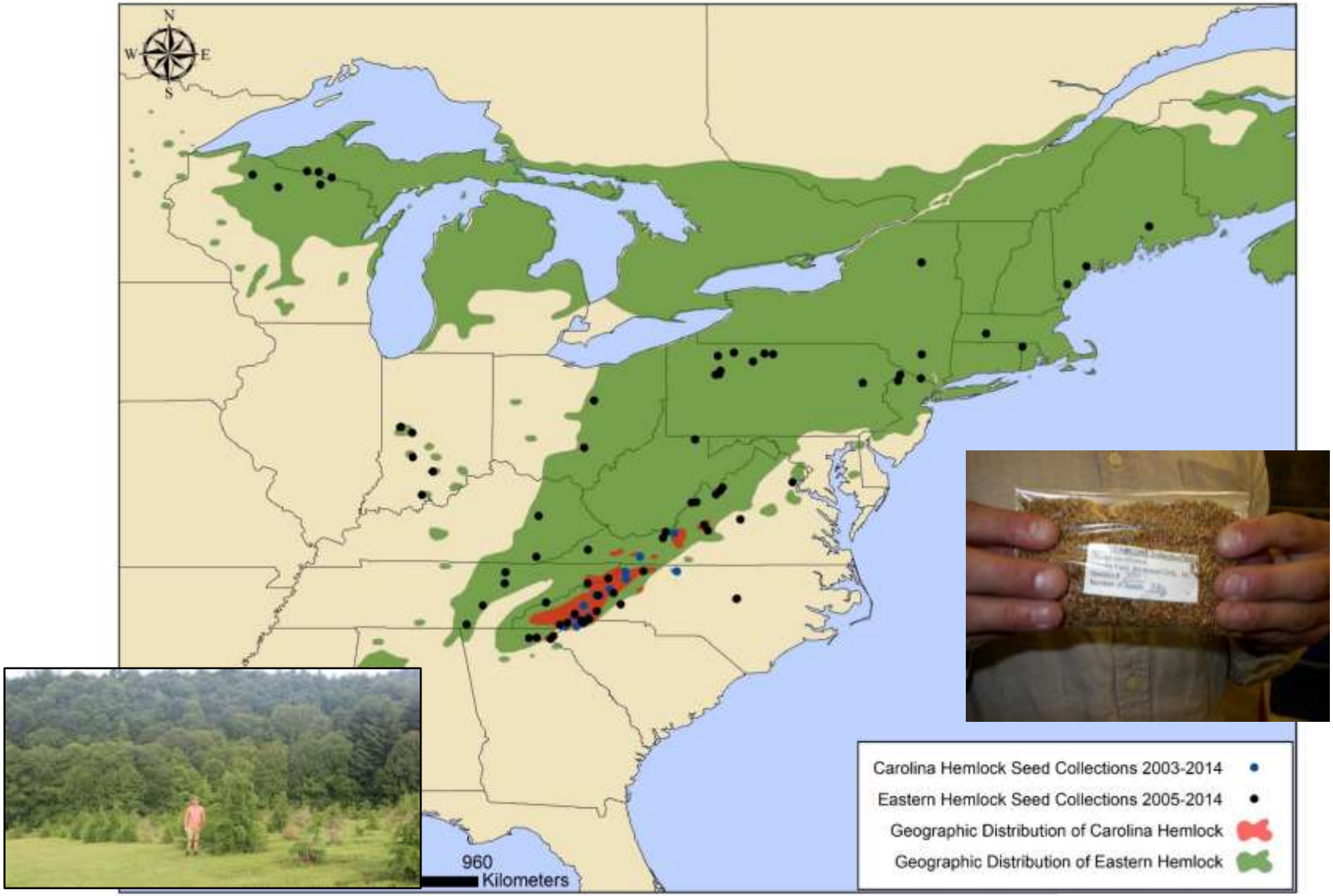

Coors
LIGHT

Hemlock Woolly Adelgid Toolbox

- **Genetic Resource Conservation**
  - *In situ* - hemlock conservation areas protected with chemical and biological controls established on National Forests
  - *Ex situ* - genetically representative and adaptable seed samples conserved in seed banks & seed orchards
- **Host Plant Resistance**
  - hybridization of HWA susceptible hemlocks with resistant hemlock species
  - low frequency resistance in generally susceptible species
  - transgenic resistance
- **Chemical Control**
  - soaps, oils, systemics, foliar sprays, soil injections, stem applications
  - for HWA management on high-value trees in ornamental settings, recreation areas
- **Biological Control**
  - predators from the native range of HWA
  - *Sasajiscymnus* sp., *Scymnus* spp., *Laricobius* spp., *Leucopis* sp.
  - for HWA management in forest settings
- **Silviculture**
  - manipulation of forest stands to reduce HWA susceptibility
  - restoring forest stands with new species
  - **restoring hemlock to degraded habitats**

Slide by Robert Jetton

Eastern and Carolina Hemlock Seed Collections



Slide by Robert Jetton

Pesticides and Predators?

Chemical Control of HWA

- Effective, fast, short-term protection for indiv. trees
- Systemic neo-nicotinoids
  - Imidacloprid
    - Olefin metabolite
  - Dinotefuran
- Applied tree-by-tree
- Impractical on forest-wide scale, not persistent
- Environmental and economic limitations

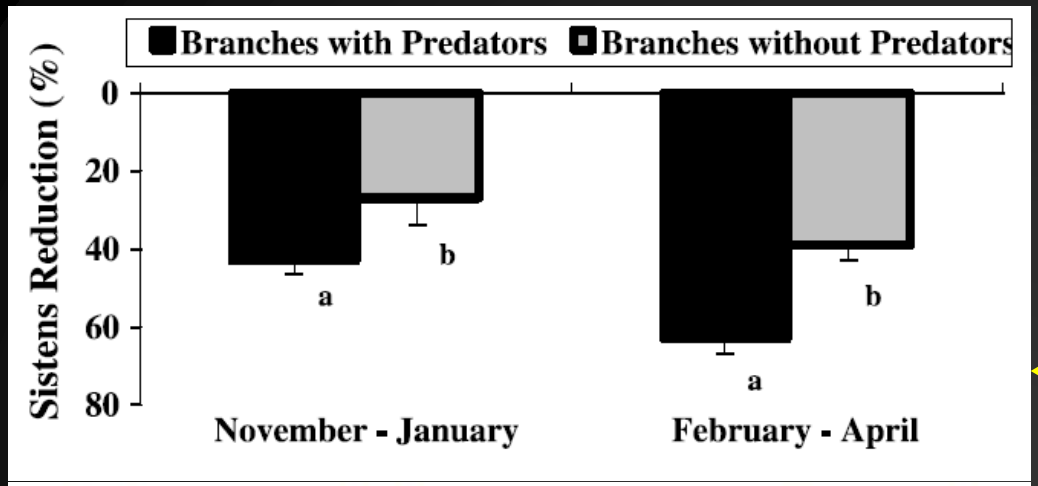
Biological Control of HWA

Predators from HWA native range

- Ladybird beetles (Coccinellidae)
  - *Sasajiscymnus tsugae*
  - *Scymnus coniferarum*
  - *Scymnus camptodromus*

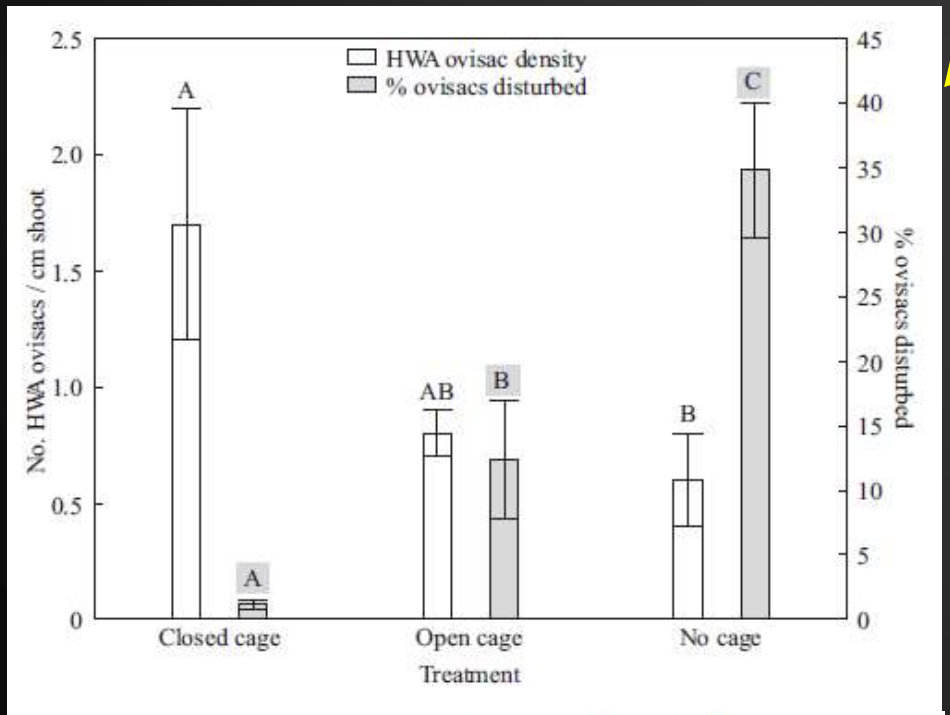

- Tooth-necked fungus beetles (Derodontidae)
  - *Laricobius nigrinus*
  - *Laricobius osakenis*


- Silver flies (Derodontidae)
  - *Leucopis argenticollis*
  - *Leucopis piniperda*

A. B. Lamb et al. / Biological Control 32 (2005) 200–207

Laricobius nigrinus published field studies documenting *L. nigrinus* impact on HWA sistens density



D.L. Mausel et al. Environ. Entomol. 37(6): 1498–1507 (2008)

Banner Elk NC (2005-2014)

Photos: R. McDonald

Cooperative *Ln* Impact Assessment Project

U. Tenn, U. Mass, Va. Tech, USFS

Delaware Water Gap	NJ
Rocky Gap	MD
James River S.P.	VA
Kentland	VA
A.M. School, Celo	NC
Bio Control Demo (GRSM)	TN
Blackberry Farm, Walland	TN
Elkmont (GRSM)	TN
Chatt. Nat. Forest	GA

Hemlock decline can outpace predator proliferation

300 *L. nigrinus* released
12 Jan & 13 Mar 2005

Beetles established,
tree died w/in 5 years

Photos by D.L. Mausel and G.A. Davis

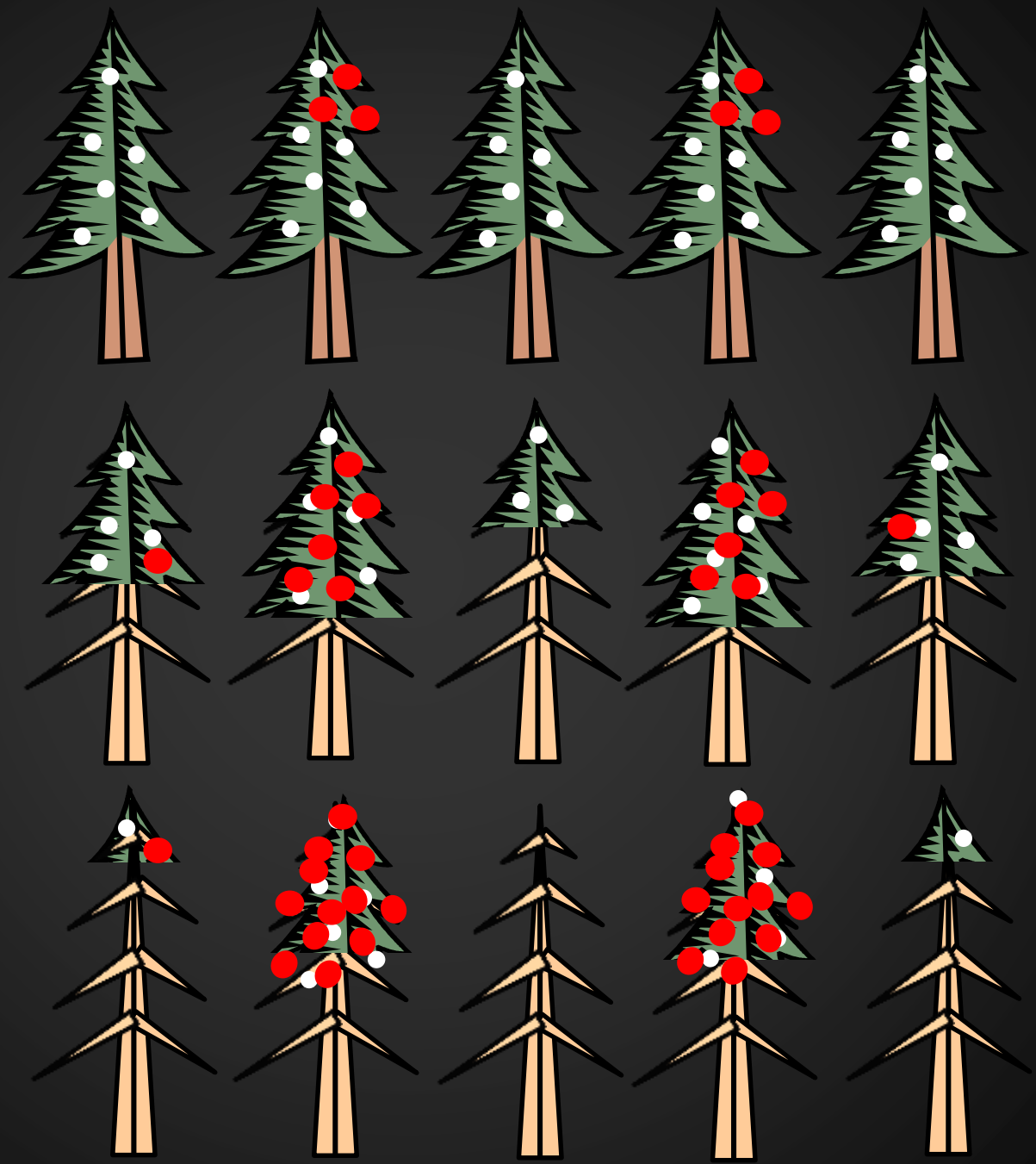
Source: U.S. Forest Service Pub. FHTET-2011-04

Standard Release Scenario
(hypothetical)

Legend:

= HWA

= Predator



Chemical & Biological Control of HWA

Chemical Control

Fast

but

Doesn't persist

+

Biological Control

Persists

but

Isn't Fast

Can these strategies be integrated in a way that capitalizes on the strengths and helps offset the weaknesses of each?

Integrated Chem-Bio Scenario
(hypothetical)

Legend:

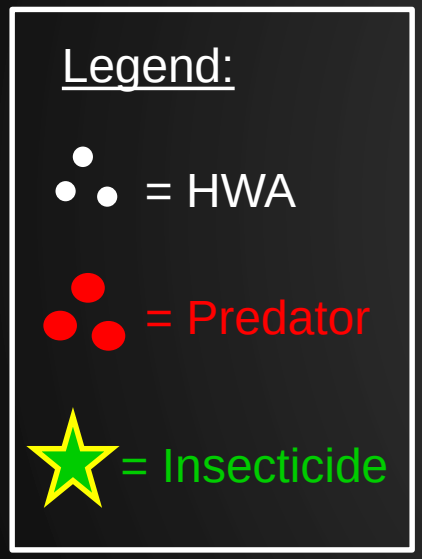
= HWA

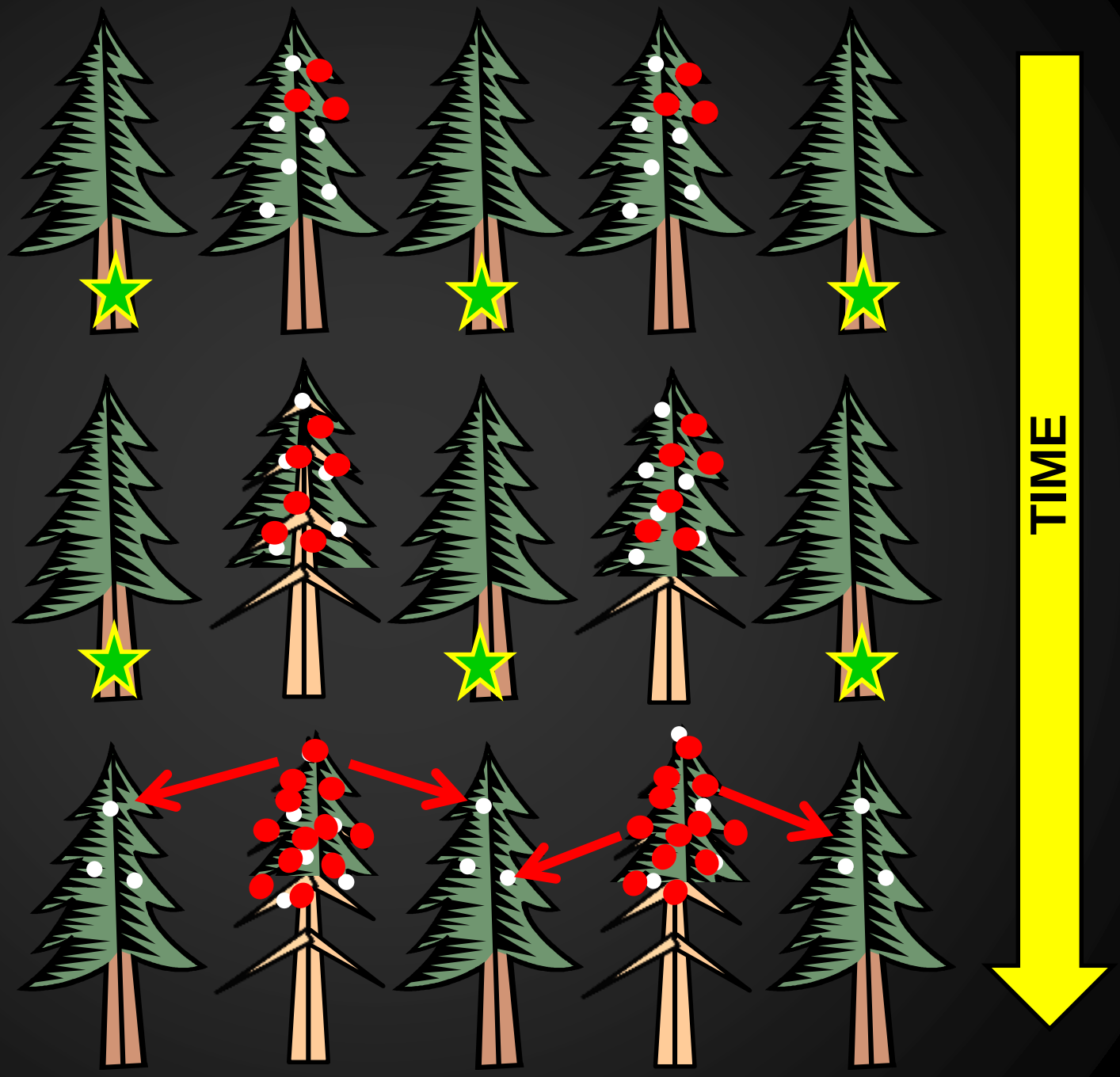
= Predator

= Insecticide

TIME

Integrated Chem-Bio Scenario
(hypothetical)





Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

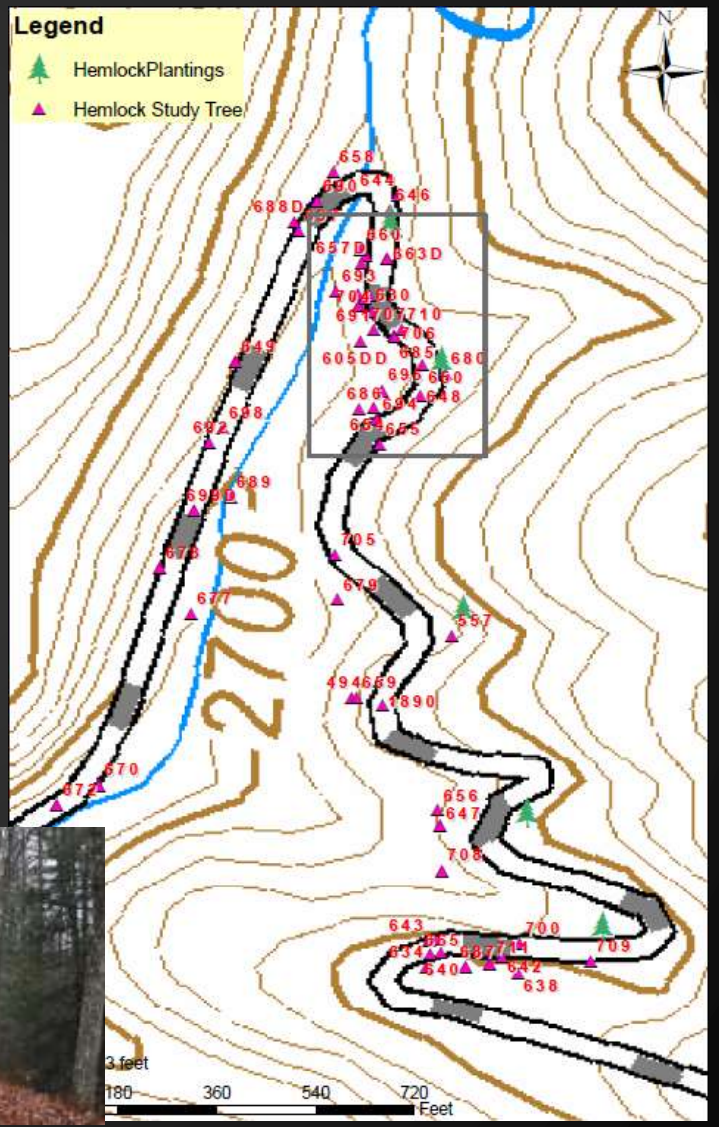
Establishment, hybridization and impact of *Laricobius* predators on insecticide-treated hemlocks: Exploring integrated management of the hemlock woolly adelgid

Albert E. Mayfield III [a,*], Barbara C. Reynolds [b], Carla I. Coots [c], Nathan P. Havill [d], Cavell Brownie [e], Andrew R. Tait [b], James L. Hanula [f], Shimat V. Joseph [g,1], Ashley B. Galloway [c,2]

Mayfield et al 2015. For. Ecol. Manage. 335: 1-10

Chem-Bio Integration Site, Chattahoochee NF, Georgia

- **CHEM:** low-rate imidacloprid (2006)
  - 60 trees, soil injection
    - 25% label rate (n=20)
    - 10% label rate (n=20)
    - 0% control (n=20)



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  - Crown health (new growth, dead tips)
  - Insecticide, metabolite residues (LC/MS/MS)
  - Laricobius populations (adults, larvae)

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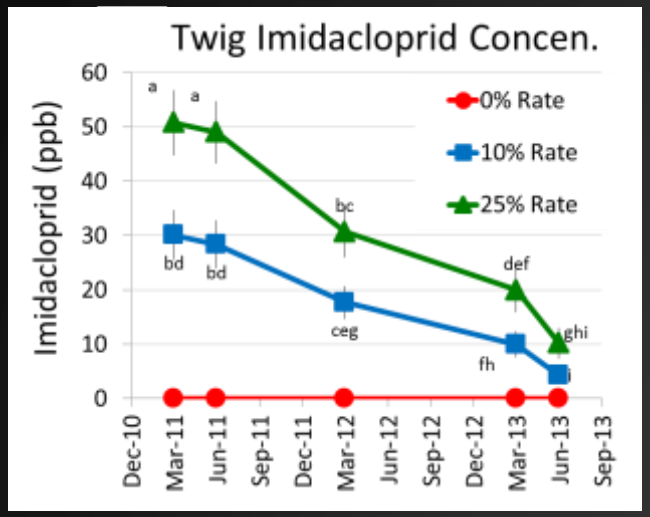
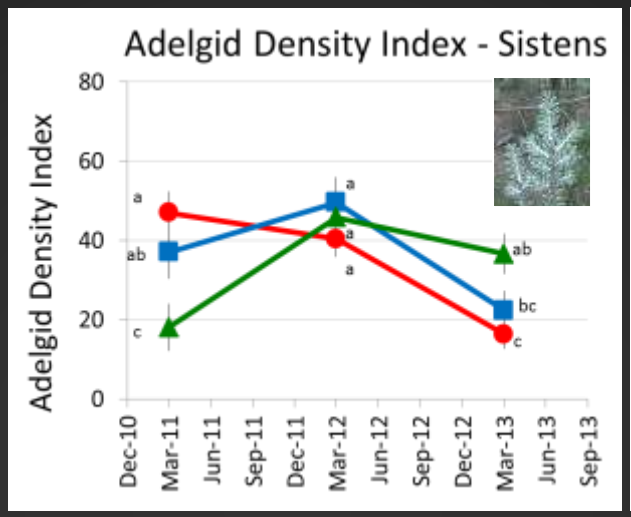
  - Insecticide, metabolite residues (LC/MS/MS)
  - Laricobius populations (adults, larvae)
- Predator exclusion study (2013)

Results: After 5-7 years post treatment, partial-dose trees:

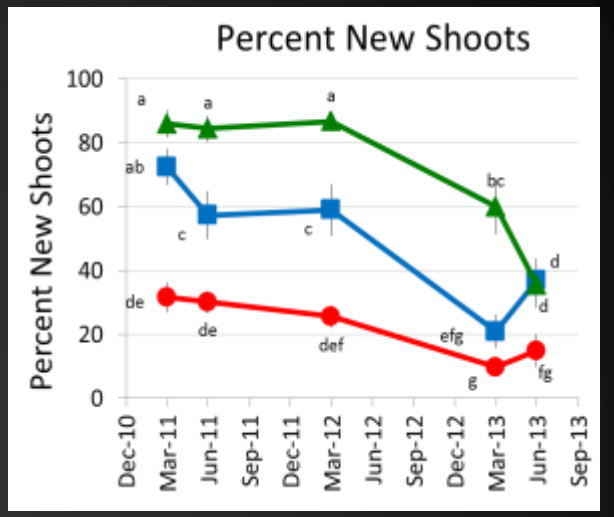
lost chemical protection…



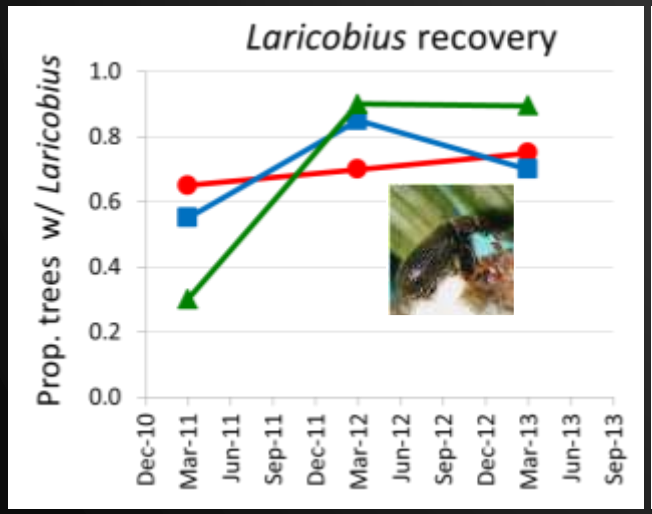
had more HWA…



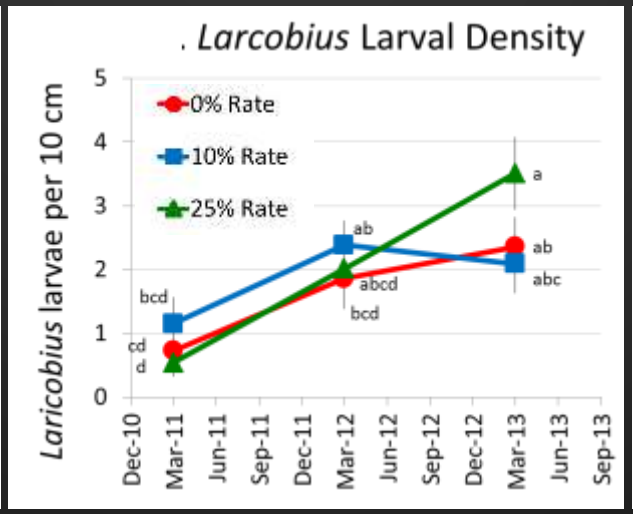
and better crown health…



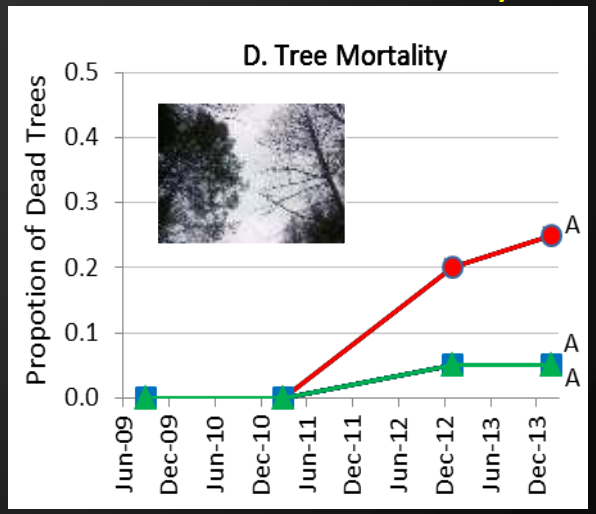
increased pred. frequency…



high predator density…

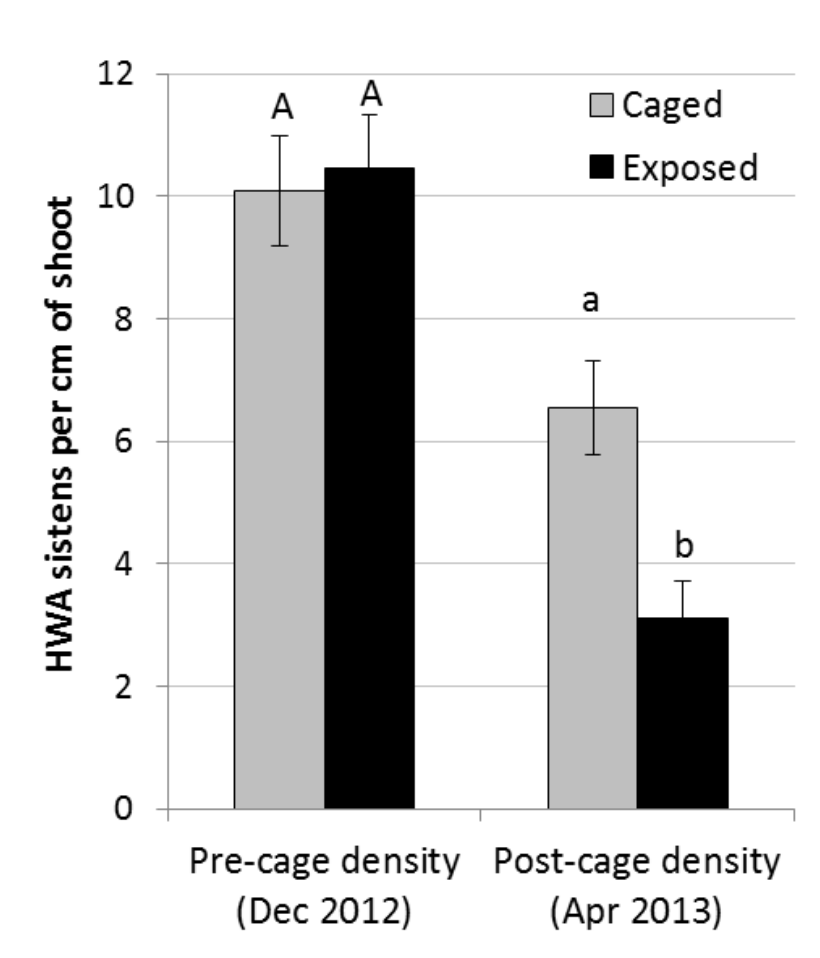


and low tree mortality



Mayfield et al 2015. For. Ecol. Manage. 335: 1-10

What is the impact of *Laricobius* predators on HWA populations on mature hemlocks in the forest?



Mean April HWA density on caged shoots was 2x that of exposed shoots

For. Ecol. Manage. 335: 1-10 (2015)

<u>Take home</u>: Strategic use of insecticide application may enhance biological control
by buying trees time while predators proliferate

- Applications in:
  - Stand management
  - Predator field insectaries

Laricobius osakensis

CompassLive
Southern Research Station

First Release in the Carolinas of New Hemlock Woolly Adelgid Predator

by Bryan Mudder, SRS Forestry Technician
Posted on January 13, 2016 by Zoe Hoyle

Bryan Mudder releasing biocontrol beetles on infested eastern hemlock tree at Bent Creek Experimental Forest

On Friday last week, U.S. Forest Service scientists with the Southern Research Station and Forest Health Protection released just over 1200 *Laricobius osakensis* beetles on eastern hemlock trees in North and South Carolina. Reared at University of Tennessee Knoxville's Lindsay Young Beneficial Insects Lab, the predator beetles are natural enemies of the hemlock woolly adelgid, an invasive insect that kills hemlo

Laricobius osake
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reduce populati
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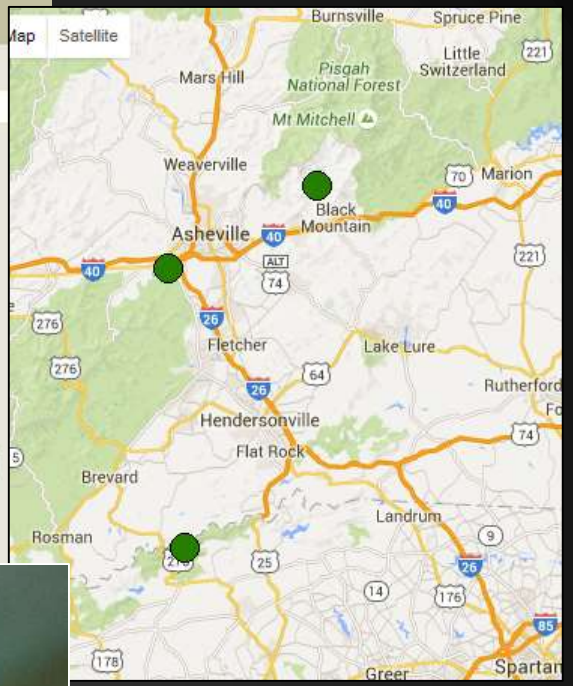
Laricobius osake
endemic to the
coevolved with
and Black Mour
Saluda River in South Carolina, were the first releases of *L. osakensis* in these states.



What makes a good hemlock field insectary?

Healthy hemlock trees in and around stand
Healthy adelgid population
Easy-to-reach branches and needles
Long-term management plan
Introduce and establish predators

Laricobius osakensis insectary, Bent Creek Pisgah NF, NC

Laricobius osakensis insectary, South Saluda River, SC

Thin from below, allow overstory to establish
Carve walkways inside stand
Adelgid just now infesting

First Releases of Western US Silver Flies (Diptera: Chamaemyiidae) for Biological Control of Hemlock Woolly Adelgid in the East

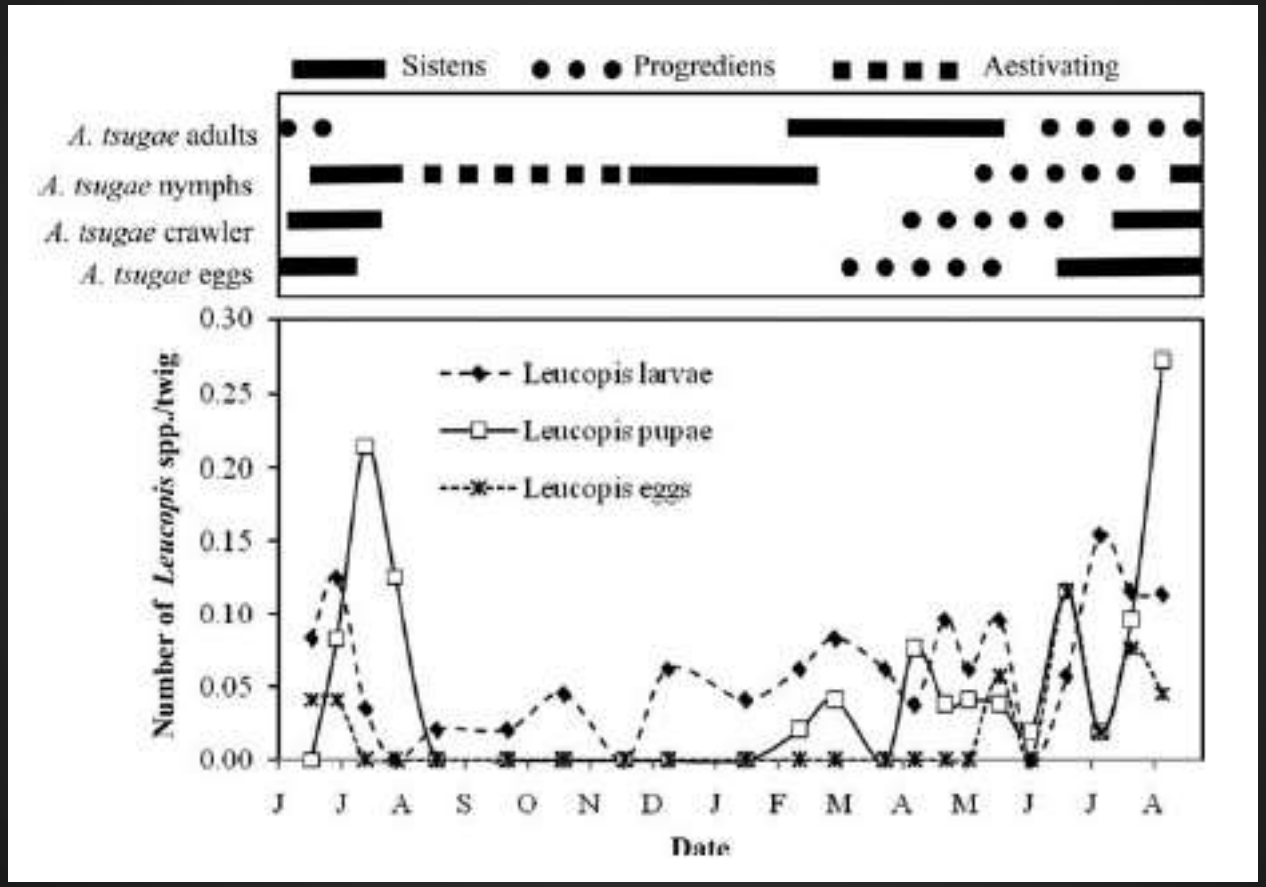
Darrell W. Ross[1], Arielle L. Arsenault-Benoit[2], Nathan P. Havill[3], Albert E. Mayfield[4], Kimberly F. Wallin[2,5], Mark C. Whitmore[6], and Stephen D. Gaimari[7]

[1]Oregon State University, Department of Forest Ecosystems and Society, Corvallis, OR; [2]University of Vermont, Rubenstein School of Environment and Natural Resources, Burlington, VT; [3]USDA Forest Service, Northern Research Station, Hamden, CT; [4]USDA Forest Service, Southern Research Station, Asheville, NC; [5]USDA Forest Service, Northern Research Station, Burlington, VT; [6]Cornell University, Department of Natural Resources, Ithaca, NY; [7]California Department of Food and Agriculture, Sacramento, CA

Silver Flies (Chamaemyiidae)

- Predators of adelgids, aphids, scale insects, and their relatives
- Some spp. successful biocontrol agents of pine adelgids in HI and Chile
- *Leucopis argenticollis* and *L. piniperda*
  - Adelgid specialists found consistently with HWA in Western US
  - Same species present in Eastern US on pine adelgids, but not HWA
- Use western *Leucopis* populations to enhance eastern HWA biocontrol
  - Feeds on both sistens and progrediens generations

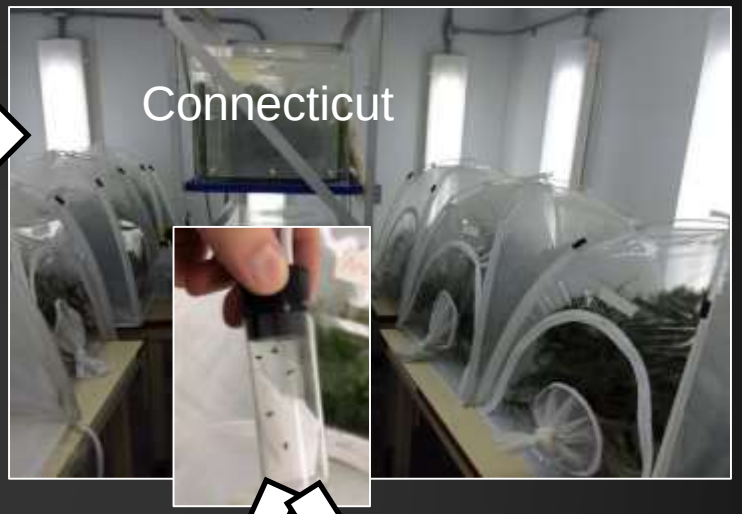
Leucopis activity well synchronized with HWA in the West



Grubin, S.M. et al. 2011. *Environ. Entomol. 40:* 1410-1416.

Leucopis study site Cumberland Plateau

Western *Leucopis* releases in East (Apr-May 2015)



Spring 2015 Leucopis Releases
Enclosed branch treatments:

1) Low density *Leucopis* (2F:2M)
2) High density *Leucopis* (6F:4M)
3) Control, enclosed branch with no *Leucopis*
4) Control, non-enclosed branch control with no added *Leucopis*

Leucopis work in Eastern US in 2016

- University of Vermont student Kyle Motley (w/ Kimberly Wallin)
  - Behavioral studies, additional caged field releases and assessment of open releases

Patchcuts and Plantings?

A Shady Situation

??????

Photo: A. Mayfield USFS

Silvicultural release: field gap study

Experimental Design

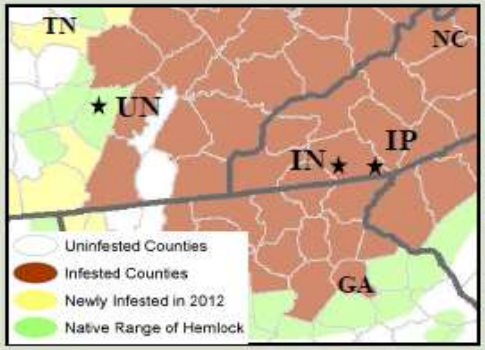
Three sites:

HWA Infested Forest (IN)

HWA Infested Forest + Biological Control (IP)

Non-HWA Infested Forest (UN)

10 trees per site received gap (n=5)or no-gap (n=5) treatment



Selected sites with similar climate & elevation : Bledsoe State Forest, TN = uninfested (UN); Coweeta, NC = HWA infested (IN) & no predator beetles; Blue Valley, NC = HWA infested & predator beetles (IP)

Before gap creation (IN site)

After gap creation (IN site)

IP site had ca. 10,000 predator beetles (*Sasajiscymnus tsugae*, ST) released at 4 locations in April/May 2005. In early June 2014, 520 additional ST were released on study trees.

Chelcy Miniat[1], David Zeitlow[1], Steven T. Brantley[2], Albert Mayfield[3], Rusty Rhea[4], Robert Jetton[5], and Paul Arnold[6] [1] Coweeta Hydrologic Laboratory, USDA Forest Service; [2] Joseph W. Jones Ecological Research Center; [3] USDA Forest Service; [4] Forest Health Protection, USDA Forest Service; [5] Camcore, Department of Forestry and Environmental Resources, North Carolina State University; [6] Department of Biology, Young Harris College

Silvicultural and Integrated Management Strategies for Restoring Hemlock to Degraded Southern Appalachian Forests

Robert M. Jetton[1], Andrew R. Tait[1,2],
& Albert E. (Bud) Mayfield III[2] and W. Andrew Whittier[1]
[1]Camcore, Department of Forestry & Environmental Resources, NC State University
[2]Southern Research Station, USDA Forest Service

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Global partners for the future of our forests

NC STATE UNIVERSITY

FOREST SERVICE
US
DEPARTMENT OF AGRICULTURE

SRS
SOUTHERN
Research Station

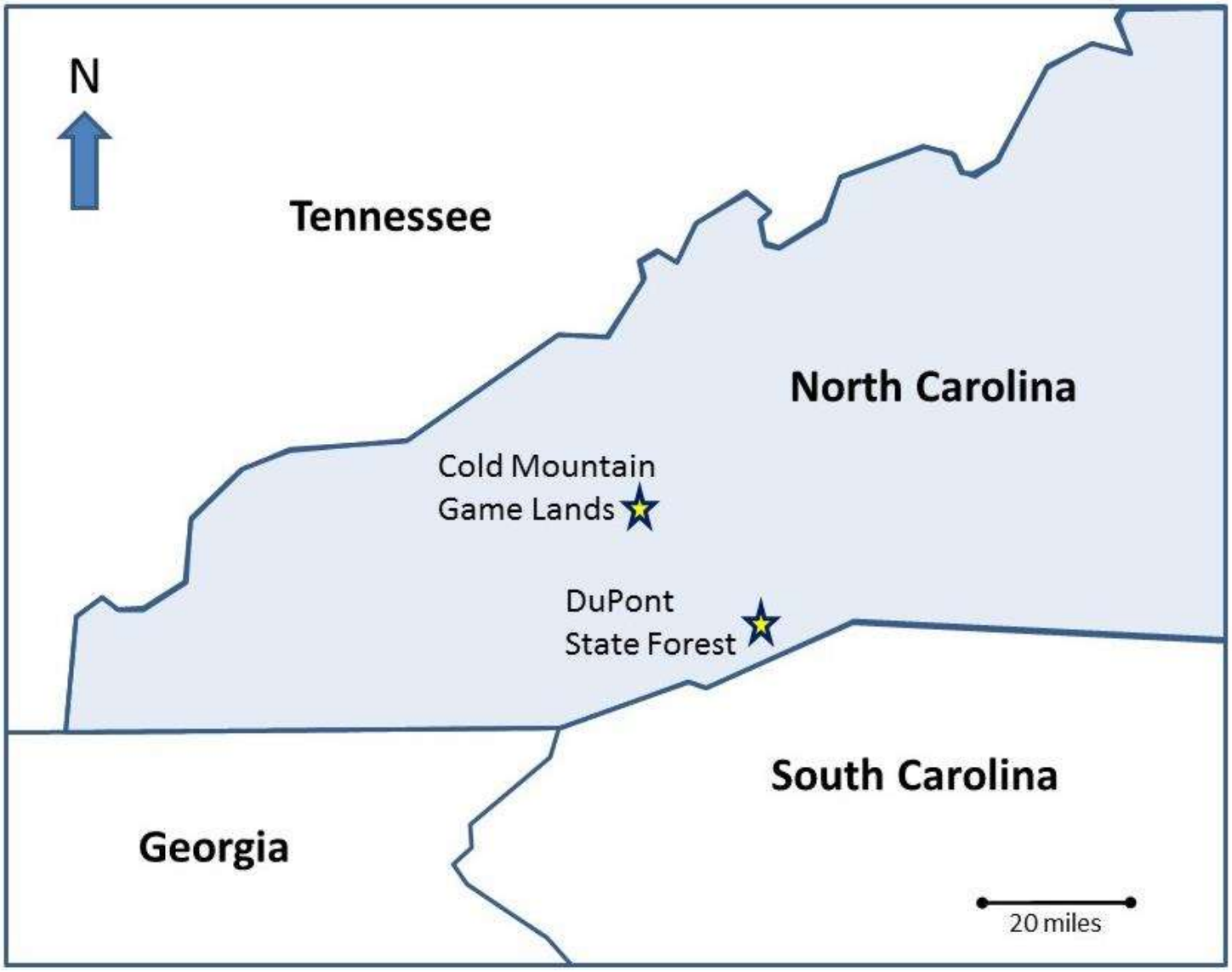
Project Objectives

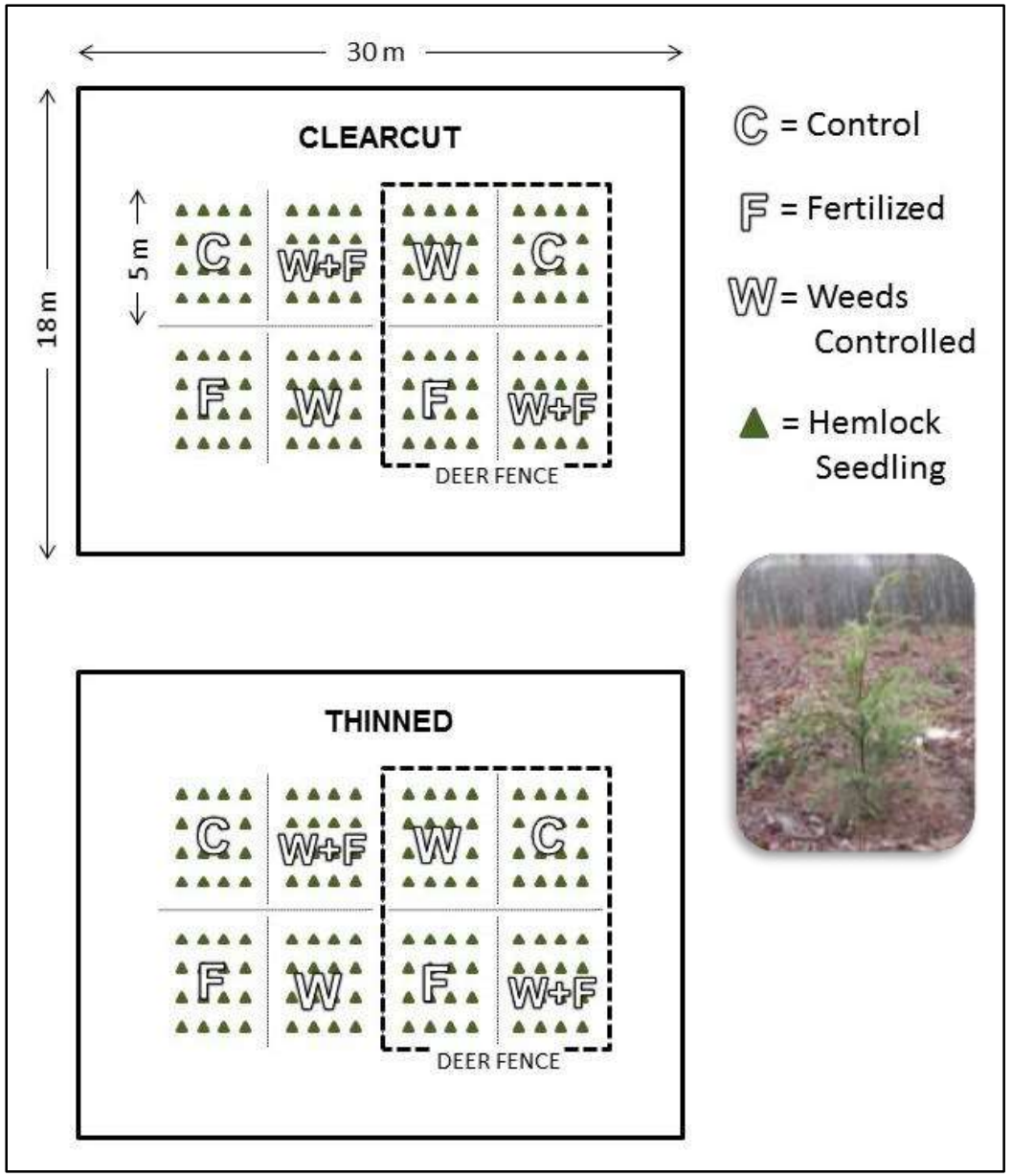
Determine HOW to re-introduce hemlock on the landscape BEFORE a resistant host is available

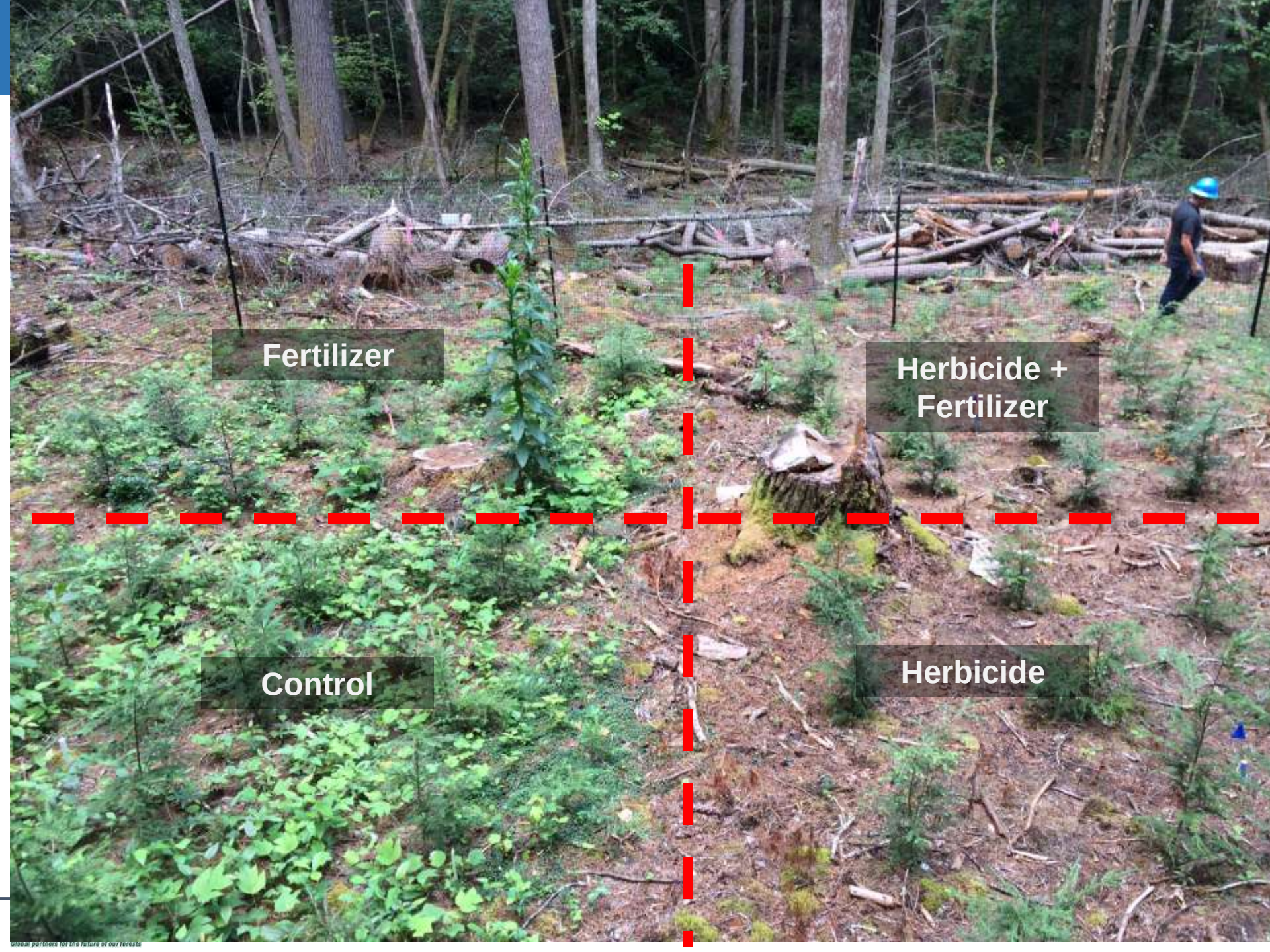
- **Phase 1:** Evaluate effects of
  - canopy structure
  - deer exclusion
  - fertilization
  - competition control

  on the establishment, survival, and growth of planted EH seedlings.
- **Phase 2:** Optimize integrated biological/chemical control strategy on Phase 1 plots. Establish new, local-source EH and CH (and mixed species plots.

Phase 1 Methods




30 m
18 m
5 m
CLEARCUT
C
W+F
W
C
F
W
F
W+F
DEER FENCE
THINNED
C
W+F
W
C
F
W
F
W+F
DEER FENCE
C = Control
F = Fertilized
W = Weeds Controlled
▲ = Hemlock Seedling


Fertilizer
Herbicide + Fertilizer
Control
Herbicide

In Closing

- Biological and chemical control can be integrated to prolong crown health while predators establish.
- New biological control predators are in initial stages of release and assessment.
  - Exploration for additional agents not planned.
- Sunlight on young hemlocks may improve their success in the face of HWA.
  - Field insectaries may need mix of sun and shade.
- Research on the restoration of hemlock seeks to integrate multiple tactics including silviculture.

In Closing

- Despite peril of hemlock, all hope is not lost
- Integrating multiple tools is key to success

Thanks!

Bud Mayfield
amayfield02@fs.fed.us

Photo courtesy of Bryan Mudder

Photo courtesy of Mac Stone