Recovery of Hemlock Woolly Adelgid Predators in the High Country of Northwestern North Carolina, 2004-2008

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ABSTRACT

Three species of predatory beetles have been released to combat infestations of the hemlock woolly adelgid in the High Country region of northwestern North Carolina. They are the spring/summer predators *Sasajiscymnus tsugae* Sasaji (*St*), *Scymnus sinuanodulus* Yu and Yao (*Ss*), and the winter/fall predator *Laricobius nigrinus* Fender (*Ln*). A total of 890 adults of *St* have been released at three sites and adults were recovered from two of the three sites; one site was two years old. We also recovered *St* from a site where no releases were made by this group (Lees McRae Field Site). For *Ss*, 724 adults were released at three sites; within-season

recoveries were made at all three sites, but no F_1 adults have yet been found. For *L. nigrinus*, a total of 3,238 adults have been released at nine sites. Three of these sites are intensive study sites (Hemlock Hill, Holloway Mountain, and Lees-McRae Field). For Hemlock Hill, we have continuous adult recoveries in increasing numbers from 2004 to 2008 (establishment); adults have been found over 3/8th mile from the original release. The majority of beetle recoveries the first three years were in areas receiving winter light (southern facing coves or trees in the sun). HWA ovisacs with an *Ln* egg or larva at sampled sites ranges from 0 (River and Tate Field) to 31% (between release trees 9 and 10). Thirty one percent of HWA ovisacs with a *L. nigrinus* egg or larva translates to a predation rate of between 60 and 90 percent because a single larva consumes more than two ovisacs to complete development. The Holloway Mountain release site has establishment (F_3) and dispersal of *Ln* adults more than ¼ mile from the original release trees. Lees-McRae field release has F_2 beetles from the first wild-collected *Ln* (Oregon State University) release. We are achieving bracketing by having a spring/summer predator release with a fall/winter predator release at four sites and continuing strategic releases of beetles at ecologically sensitive areas, such as headwaters and other areas receiving adequate winter sunlight. We are cautiously optimistic that successful biocontrol of the HWA will occur in these release areas as we are seeing regrowth of hemlocks in the presence of predators at the three main release sites.

KEYWORDS

hemlock woolly adelgid, biological control, *Sasajiscymnus tsugae*, *Scymnus sinuanodulus*, *Laricobius nigrinus*

STUDY AREA

The High Country of northwestern North Carolina (Ashe. Avery, Alleghany, Mitchell, Yancy, Watauga, and Wilkes counties) is considered one of the most biologically diverse areas in the world. This area is rich in conifers and has native stands of both the Carolina and eastern hemlock. The High Country is also the headwaters for at least five major river systems—the New (both North and South forks), Watauga, Yadkin, Catawba, and French Broad rivers—making it an important source for trout and other riparian species. The hemlock woolly adelgid (HWA), *Adelges tsugae*, expanded its range into this area around year 2000; the High Country area is now considered generally infested.

In response to the threat to hemlock survival in this area, a cooperative effort between the USDA Forest Service, Virginia Tech University, Blue Ridge Resource Conservation and Development Council, Appalachian State University, and the author was implemented starting in 1999. Three species of adult predatory beetles of the HWA have been introduced during the course of these studies: the spring/summer predators *Sasajiscymnus tsugae* (*St*) (originally from Japan) and *Scymnus sinuanodulus* (*Ss*) (a Chinese HWA predator), and the fall/winter active native predator from the Pacific Northwest, *Laricobius nigrinus* (*Ln*) (Mausel 2007).

RELEASE OF *SASAJISCYMNUS TSUGAE*

Releases and recoveries of *St* adults are shown in Table 1. There have been at total of 890 adults released in three areas of the High Country. Recoveries of *St* beetles has occurred at three sites; one recovery is from a site where a release of beetles was made two years prior (Hattie Hill) and a second recovery of *St* beetles was made along the Elk River west of Banner Elk, though we have no record of releases made in this area. We are unsure whether this Elk River recovery is from dispersal or a release.

Table 1. Releases and recoveries of *St* beetles in the High Country of North Carolina, 2004-2007.

Release Date	Number/Whom	Release Site	No. Recovered	Date Recovered
April 2005	500/Graham	Hattie Hill (Bethel)	2	15 March 2007
April 2005	300/Graham	Grandfather Mountain	No sample	None
June 2006	90/RCM	Sugar Grove	2	April 2007
Unknown	0	Lees McRae Field (Elk River)	6	June 2006

RELEASE OF *SCYMNUS SINUANODULUS*

Releases of *Ss* adults are shown in Table 2. There have been a total of 724 adults of *Ss* released at three sites in the High Country. Within-season recoveries of *Ss* beetles have occurred at all three sites. Of note is the recovery of two *Ss* adults on the 25 November 2006 in Sugar Grove and a large number of adult *Ss* beetles found on both hemlocks and white pines at the Holloway Mountain release site. Monitoring has yet to find F_1 beetles.

Table 2. Release and recovery numbers for the Chinese HWA predator *Scymnus sinuanodulus*. All work with this predator has been cooperation with USDA Forest Service researcher Dr. Michael Montgomery.

Release Date	Number/Whom	Release Site	No. Recovered	Date Recovered
June-July 2006	228/RCM	Sugar Grove	10	July-November 2006
April 2005	400/MEM	Holloway Gap	63	April-October 2007
15 April 2007	96/RCM	Hemlock Hill	2	Late April 2007

RELEASE OF *LARICOBIUS NIGRINUS*

Cooperative work was performed with Virginia Tech on the three intensive study sites and six other release sites. Intensive study sites are: 1) Hemlock Hill (300 adults released 31 December 2003 and an augmentation of 300 beetles late March 2006); 2) Holloway Mountain (150 adults October 27, 2004, plus an augmentation of 240 adults late March 2006) and 3) Lees-McRae Field Research site (202 beetles from Oregon State University released December 2005/February 06). Adult beetles were recovered using beat-sheet sampling twice monthly from September to December and January to March of each year.

Larval sampling was by David Mausel and consisted of branch samples taken at mid- and upper-canopy of the 10 release trees

Release site #1: Hemlock Hill, Banner Elk

David Mausel, Ph.D., of Virginia Tech released 300 beetles (British Columbia strain) at Lees McRae College's Hemlock Hill, a significant area of old-growth hemlocks. Table 3 shows the recovery of *Ln* adults at the Hemlock Hill site post release. There was an exponential recovery by generation: three F_1 adults, 12 F_2 adults, 202 F_3 adults, and 103 F_4 adults (thus far: we will be sampling for winter 2008 numbers until March).

Table 3. Recovery of *Ln* adults by season and place at Hemlock Hill, 2004-2008. Larval numbers are from Mausel.

Season or Place	F_1 Adults ('04/'05)	F_2 Larvae (April '05)	F_2 Adults ('05/'06)	F_3 Larvae (April '06)	F_3 Adults ('06/'07)	F_4 Adults ('07/'08)
Fall	3		12		93	80
Winter	0	10	0	314	109	23
River	2		1		4	41
Ridge (Fall)	1		11		89	39

Release sites and dispersal patterns of *Laricobius nigrinus* at Hemlock Hill are shown in Figures 1 and 2. Once warmer weather or sunlight is present, dispersed adult beetles move into north-facing or shaded coves. In Figure 2, dispersal recoveries are shown in blue boxes: 1) mid-November of 2006 recovery of a single *L. nigrinus* adult on the main ridge of Hemlock Hill, nearly 1,000 feet from the nearest release tree; 2) March 2007 recovery of a single *L. nigrinus* adult more than 3/8ths mile from the closest release site; 3) December 2007, Luker and McDonald found two adults in same area as above; and 4) January 2008, Hamstead and McDonald recovered one *Ln* adult below Tate Field scoreboard, 200 yards beyond any prior known dispersal location.

The first two years post-release, we found beetles only on release trees; by the third year, we found abundant beetles in an areas that received abundant winter sunlight. Our survey data infer that beetles are more prevalent on south-facing aspects in winter months. This can help ensure success of beetle releases by strategically placing them in areas they prefer rather than northern aspects that receive no sun.

In order to determine predation rates of HWA ovisacs in the release area, HWA-infested branches were collected from February. to April. We focused on areas with high beetle recoveries (between release trees 9 and 10) as well as samples from the Elk River and Tate Field. Clipped branches were brought back to laboratory and ovisacs were dissected to determine presence of *Ln* egg/larva (Figure 3).

Release Site #2: Holloway Mountain

On 27 Oct 2004, 150 beetles were released on the north ridge of Grandfather Mountain at 3,6000 feet elevation; an additional 240 beetles were released on March 2006. In 2006, beetles were found 1/4 mile from the release site.

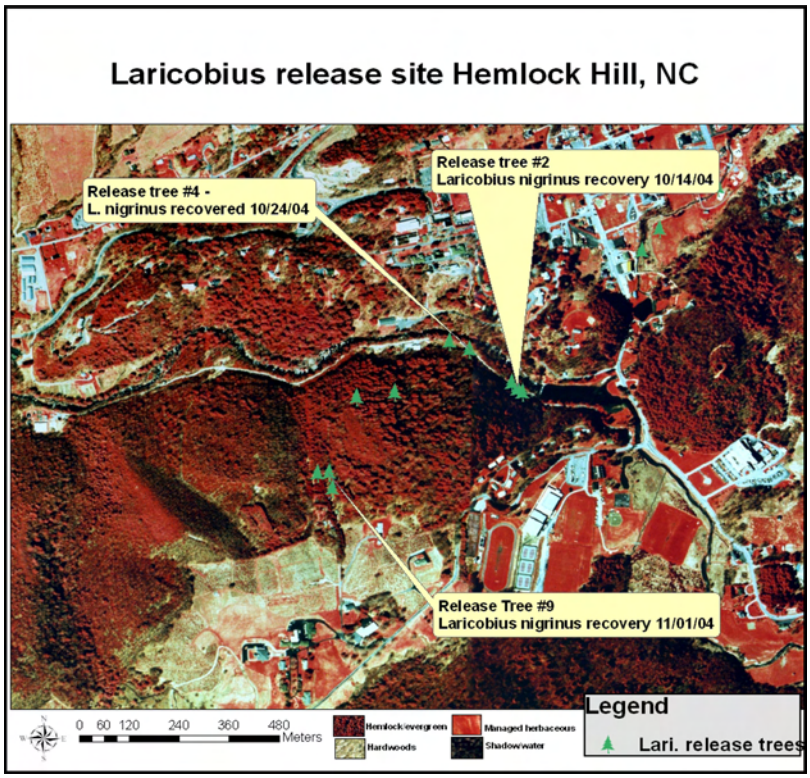

Figure 1. Release sites of *L. nigrinus* F_1 adults at Hemlock Hill. Compare this figure to the pattern of adult recoveries for F_2 to F_4 beetles in Figure 2. Infrared map courtesy of James Graham.

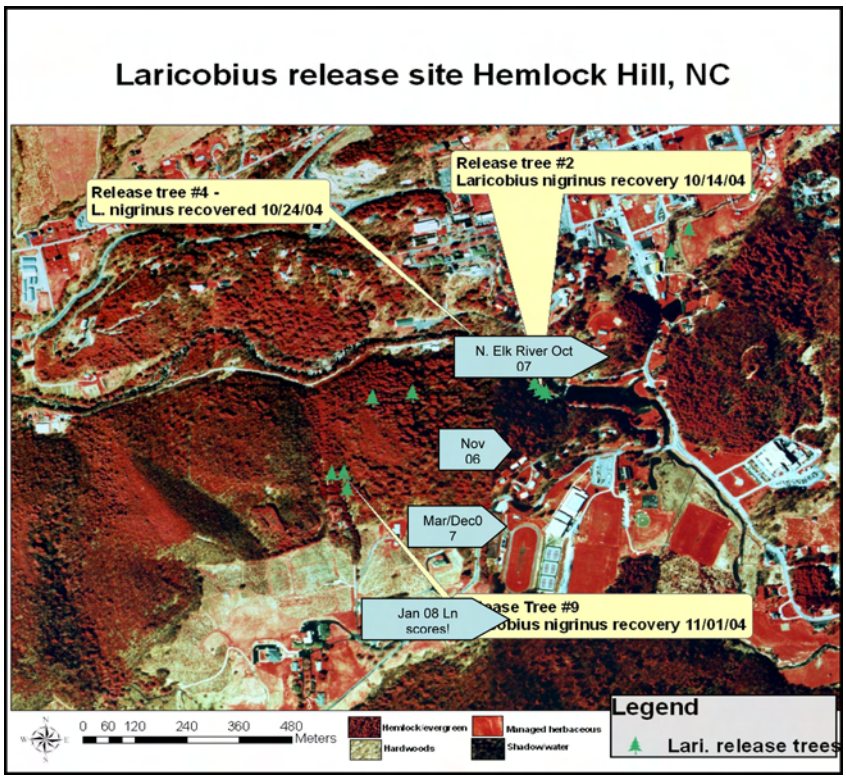

Figure 2. Pattern of dispersal of *Ln* adults from 2004 through 2008. Adults appear to be more prevalent on south-facing slopes during the coldest times of the year (December-February).

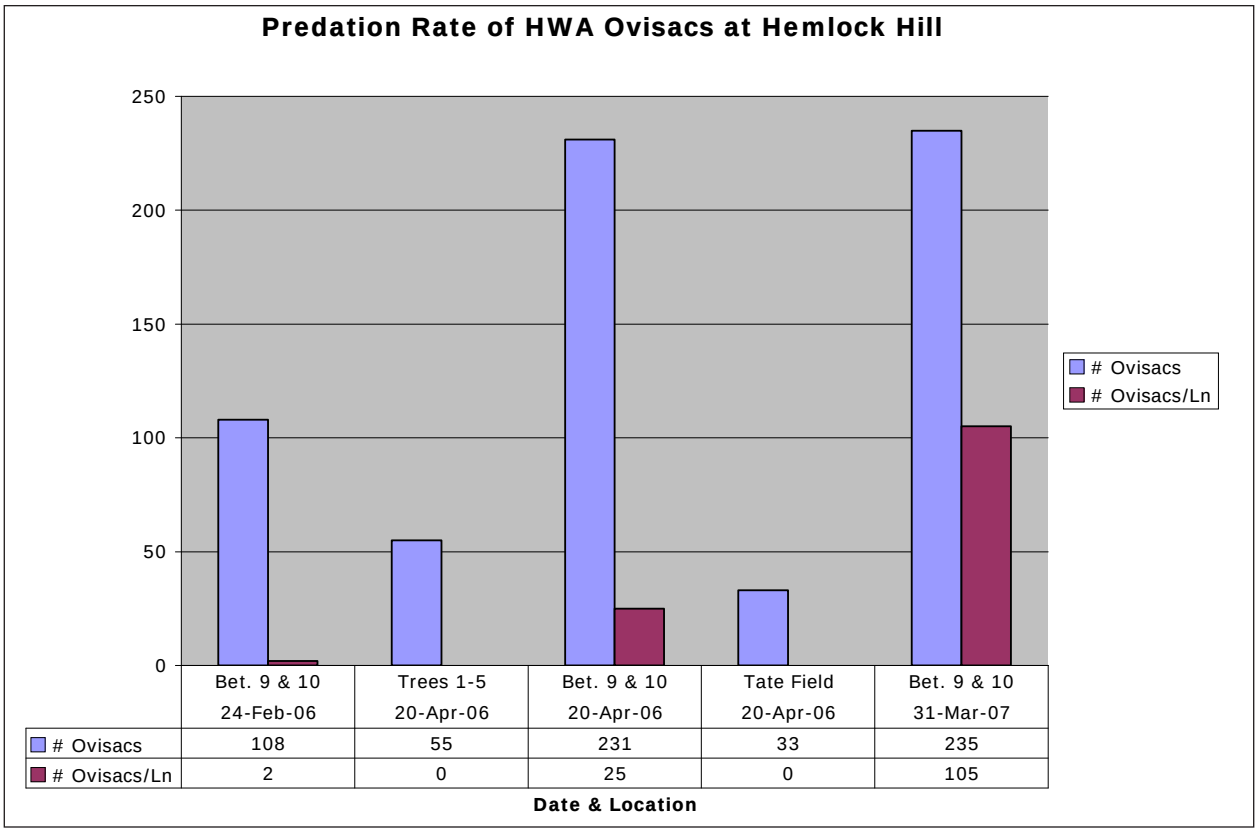

Figure 3. Predation rates of HWA by *L. nigrinus* through dissection of ovisacs. Ovisacs with a *Ln* egg or larva present were considered positive for predation. We found a 31% predation rate of ovisacs during late March 2007; HWA averages around 75 to 100 eggs per ovisac (smaller than western strain). It takes roughly 200-250 eggs for a *Ln* larvae to complete development: thus, 31% predation means that each larva eats an additional 2+ ovisacs, so the actual predation rate is between 60 to 90 percent after three years. Predation rates are approaching what is measured in the Pacific Northwest.

Table 4. Recovery of *Ln* adults at Holloway Mountain. Eight F_3 adults have been recovered during the '07/'08 season. This is the second site with establishment of *Ln* and dispersal of beetles more than ¼ mile from the original release trees.

F_1 Adults ('05/'06)	F_2 Adults ('06/'07)	F_3 Adults ('07/'08	F_1 Larvae (April '05)	F_3 Larvae (April '06)
1	9	8	2	24

Release site #3: Lees McRae Field Laboratory

Of 202 field adults received from Portland, Oregon, 100 were released 1 December 2005 (50 on each of two trees) and 102 adults were released on one tree 2 February 2006. Recoveries are presented in Table 5.

Table 5. Recovery of *Ln* adults at the Lees-McRae Field Laboratory site. Limited sampling at this site during fall of 2007 and winter of 2008.

F_1 Adults ('06/'07)	F_2 Adults ('07/'08)
6	1

Additional Release Sites

Additional releases of *Ln* adults in the High Country area are presented in Table 6.

Table 6. Additional releases of *L. nigrinus* adults in the High Country, 2005-2007. Additional resources to monitor these sites are needed.

Year of Release	Site	Release Date	*Ln* Total Number	*Ln* Source	F_1 Adults	F_2 Adults
2005	Sugar Grove	Dec.	146	WA Coll.	5	16
2006	Dugger Cr.	Nov. 06 +Jan. 07	1,100	WA Coll.	no sample	
2006	Simm's Cr.	March	200	WA Coll.	no sample	
2006	Hattie Hill	March	300	WA Coll.	2	
2006	Pensacola	March	100	WA Coll.	no sample	
2007	Beech Bog	Nov./Dec.	200	WA Coll.	no sample	
Totals			2,046		7	16

In addition to *Ln* adults, we also recovered adults of *L. rubidus* at most sites. We found *L. rubidus* on white pine saplings with pine bark adelgid, *Pineus strobi* (Hartig). The fewest *L. rubidus* were found at Hemlock Hill, and the most *L. rubidus* were found at Holloway Mountain. We are working with Virginia Tech and the USDA Forest Service to determine the impact, if any, of *L. rubidus* on HWA populations.

SUMMARY

Sasajiscymnus tsugae

- 890 *St* beetles were released at three sites (Hattie Hill, Grandfather Mountain, and Sugar Grove).
- Three sites showed positive for *St* (Hattie Hill, Sugar Grove, and Lees McRae Field); one site (Hattie Hill) two years old and another site (Lees McRae Field) has no record of *St* release.

Scymnus sinuanodulus

- 724 adults of the Chinese predator *Ss* were released at three sites (Sugar Grove, Holloway Mountain and Hemlock Hill).
- *Ss* adults were found during the season of release at all three sites.
- *Ss* adults also were found on pines, suggesting *Ss* feeding on pine bark adelgid.

Laricobius nigrinus

- Releases of adult *Ln* beetles starting in 2003 resulted in recovery of next-generation adults at five release sites: Hemlock Hill (F_4), Holloway Mountain (F_3), Lees McRae Field (F_2), Sugar Grove (F_2) and Hattie Hill (F_1). Four other release sites were not sampled.
- Both lab-reared beetles from Virginia Tech and field-collected adults from the West Coast have established or colonized hemlocks.
- Hemlock Hill (2003 release) results:
  - Exponential increase in adults each generation: F_1=3, F_2=12, F_3=202, F_4=103 (still sampling).
  - *Ln* adults dispersal over a ½-square-mile area.
  - More beetles present on sunny, south-facing aspects.
  - 31% of HWA ovisacs infested with *Ln* at the site between release trees 9 and 10; this translates to a 60 to 90 percent predation rate.
  - The site has the potential to be used as a nursery to provide beetles for distribution to other nearby areas.
  - We are seeing regrowth at Hemlock Hill, Holloway Mountain, and Lees-McRae field sites in the presence of predators.
  - Resource managers should make continued releases of all three predators a priority.

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REFERENCES

Mausel, D.L. 2007. Release and monitoring of *Laricobius nigrinus* (Coleoptera: Derodontidae) for biological control of the hemlock woolly adelgid in the eastern U.S. Ph.D. dissertation, Virginia Polytechnic Institute and State University, Department of Entomology. Blacksburg, VA. 161 p.

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Hemlock Woolly Adelgid

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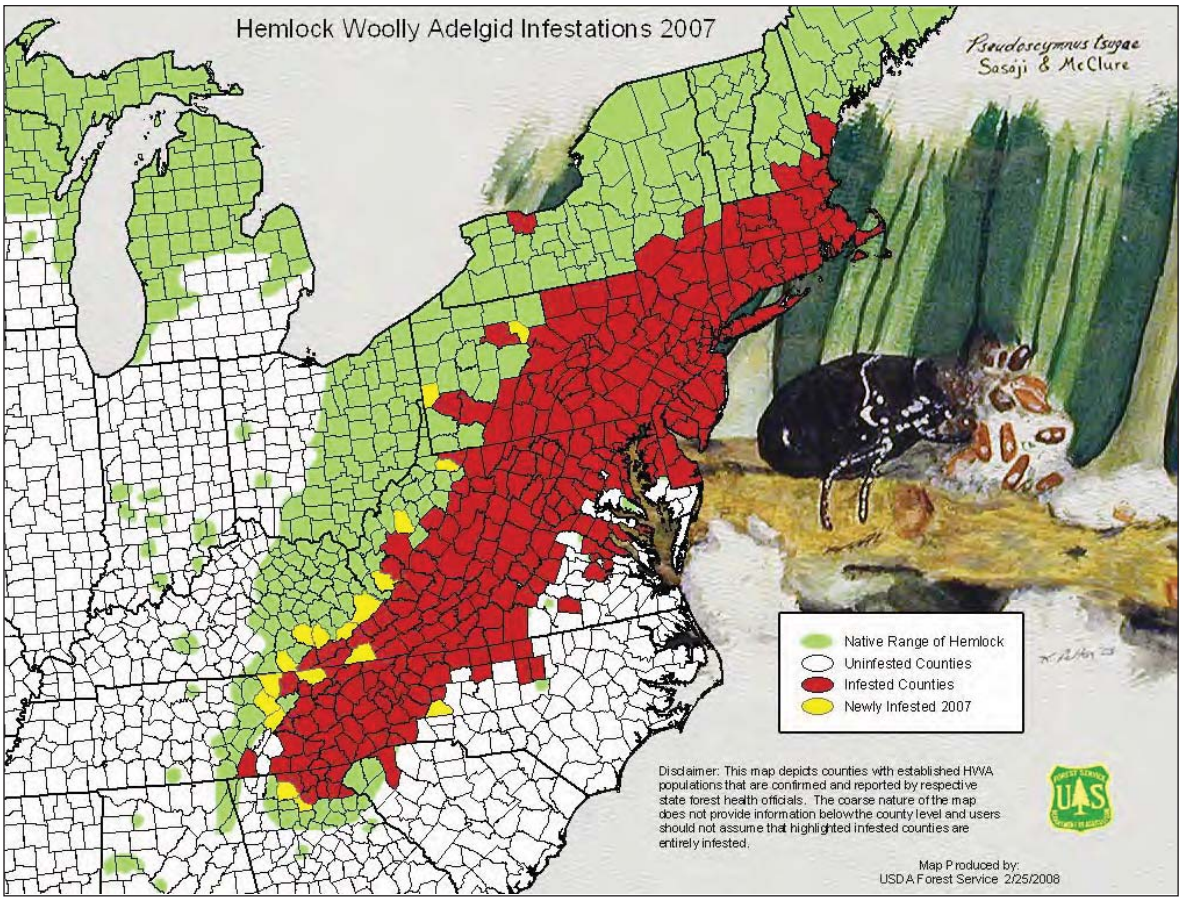

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