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Proposed Field Release of *Laricobius osakensis* (Coleoptera: Derodontidae), a Predatory Beetle for Biological Control of Hemlock Woolly Adelgid (*Adelges tsugae*), in the Continental United States

Environmental Assessment, December 2009

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I. Background and Introduction

The hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand) is an introduced insect pest destructive to forest and ornamental hemlock trees (*Tsuga* spp.) in the eastern United States. The adelgid feeds at the bases of needles, causing them to dry out and resulting in needle loss. This prevents trees from producing new buds for the next year's growth, and leads to branch dieback and often eventual death of the tree. Heavy infestations have killed trees in as little as four years, but some survive longer with only a sparse amount of foliage at the very top of the crown (McClure et al. 2001). HWA has become a very important pest of eastern hemlock, *Tsuga canadensis*, and Carolina hemlock, *T. caroliniana* in the eastern United States because of the damage and mortality to trees ranging from landscape shrubs to old, large, forest trees. This pest has impacted federal parks, recreation areas, and forests; state-managed forest lands; commercial and private landowners; and urban and suburban communities.

The first report of HWA in eastern United States came from the Virginia Department of Agriculture and Consumer Services in 1951 on planted eastern hemlock in Richmond, VA (Stoetzel 2002). HWA now infests 18 states and it is estimated that approximately 40 percent of the *T. canadensis* range and 100 percent of the *T. caroliniana* range within the United States is infested (Tighe et al. 2005). Because HWA is adapted to high elevations in Japan where winter temperatures commonly drop below -35°C (-63°F), it should continue to spread in eastern North America until it occupies the entire range of *T. canadensis* (see Appendix 1).

HWA infestation is fatal to eastern hemlocks of all ages, regardless of health prior to infestation (McClure 1990), with tree mortality occurring between four and ten or more years after infestation, depending on environmental conditions (Orwig and Foster 1998, McClure et al. 2001). Modes of dispersal for HWA include birds, deer, humans (via movement of nursery stock), or wind (McClure 1990, McClure et al. 2001).

Existing management options for HWA are ineffective, expensive, temporary, or have nontarget impacts. For these reasons, forest managers and the United States Department of Agriculture (USDA) Forest Service have sought to identify an effective, host specific biological control organism and release it into the environment for the control of HWA.

II. Purpose and Need for the Proposed Action

The USDA Animal and Plant Health Inspection Service (APHIS) is proposing to issue permits for the release of a predatory beetle, *Laricobius. osakensis* (Coleoptera: Derodontidae). The agent would be used by the applicant for the biological control of HWA in the continental United States. Before permits are issued for release of *L. osakensis*, APHIS must analyze the potential impacts of the release of this agent into the continental United States.

The applicant's purpose for releasing *L. osakensis* is to reduce the populations and the severity of infestations of HWA where it occurs in the United States. The HWA is a nonnative invasive pest in eastern North America on eastern hemlock and Carolina hemlock causing damage and mortality to the trees.

This environmental assessment[1] (EA) has been prepared, consistent with USDA, APHIS' National Environmental Policy Act (NEPA) implementing procedures (Title 7 of the Code of Federal Regulations (CFR), part 372). It examines the potential effects on the quality of the human environment that may be associated with the release of *L. osakensis* to control infestations of HWA within the continental United States. This EA considers the potential effects of the proposed action and its alternatives, including no action

III. Alternatives

This section will explain the two alternatives available to APHIS: no action, and the action to issue permits for environmental release of *L. osakensis*. Although APHIS's alternatives are limited to a decision on whether to issue permits for release of *L. osakensis*, other methods available for control of HWA are also described. These control methods are not decisions to be made by APHIS and are likely to continue whether or not permits are issued for environmental release of *L. osakensis*. These are methods presently being used to control HWA by public and private entities.

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[1] Regulations implementing the National Environmental Policy Act of 1969 (42 United States Code 4321 *et seq.*) provide that an environmental assessment "[shall include brief discussions of the need for the proposal, of alternatives as required by section 102(2)(E), of the environmental impacts of the proposed action and alternatives, and a listing of agencies and persons consulted." 40 CFR § 1508.9.

A third alternative was considered, but will not be analyzed further. Under this third alternative, APHIS would have issued permits for the field release of *L. osakensis,* but the permits would contain special provisions or requirements concerning release procedures or mitigating measures. Due to the small size of *L. osakensis,* and the probability that it may disperse on its own after release, mitigating measures for containment or retrieval would not be feasible. No issues have been raised that would indicate that special provisions or requirements are necessary.

A. No Action alternative

Under the “No Action” alternative, APHIS would not issue permits for the field release of *L. osakensis,* so the release of this agent would not take place in the United States.

The following methods are presently being used to control HWA, and these methods will continue under the no action alternative and will likely continue even if permits are issued for release of *L. osakensis*.

1. Chemical control

Hemlock woolly adelgid infested hemlocks in the urban environment can be chemically controlled by thoroughly spraying infested trees with an application of insecticidal soap, horticultural oil, or any one of numerous other insecticides specifically labeled for this use. Oil and soap have been commonly used and are highly effective in killing adelgids but two spray treatments each year are usually necessary (McClure et al. 2001) and not economically practical on larger scales. For example, the hydraulic application equipment required to spray larger trees cannot be used in rural forest situations without adequate access roads.

More recently, systemic treatments of the insecticide imidacloprid, using either soil drench, soil injection or trunk injection techniques have been frequently adopted, with combinations of soil and trunk injections being most effective over both short and long term (Doccola et al. 2008). The soil or truck injection techniques do not require large equipment and applications of imidacloprid have been performed on specific high value forested sites in many areas.

An integrated approach in the Great Smokey Mountain National Park was employed on approximately 2,700 combined acres using foliar applications in developed areas (roads, campgrounds picnic areas, and drench applications in undeveloped sites, applied based on a priority system including site and infestation factors (Johnson et al. 2008).

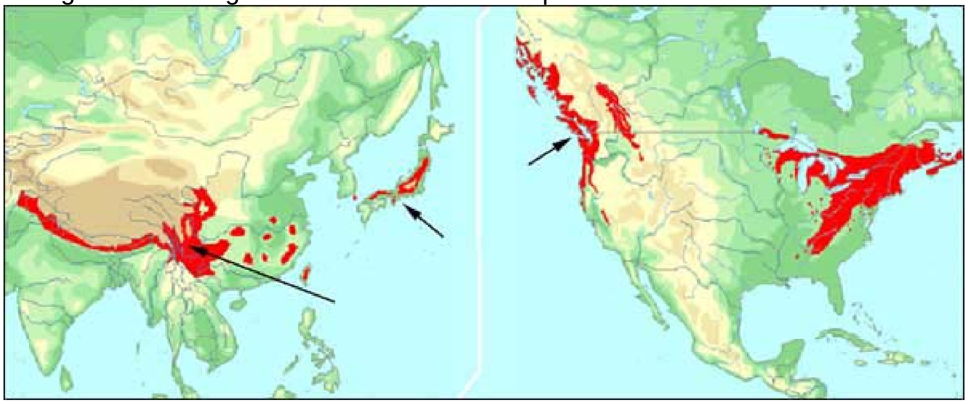
2. Silvicultural control

Silviculture involves the management of forest areas or stands using techniques aimed at controlling the establishment, growth, composition, and quality of trees and other forest vegetation for certain objectives such as timber, wildlife, or other ecological attributes. Hemlocks are slow growing and their value is mainly environmental and not economic. Thus, for most hemlock stands, silvicultural objectives are designed to ensure long term health of the associated ecological aspects of the site rather than for the production of timber. With essentially no ability to control the various modes of HWA dispersal, infestation cannot be prevented. Furthermore, HWA feeds on all ages of hemlock trees, and virtually all trees are susceptible to damage by the insect, regardless of age or site condition category. Therefore the options for using silvicultural techniques to specifically mitigate HWA infestations are limited. Silviculture for HWA simply emphasizes good tree care, in as much as it can be accomplished, by maintaining healthy trees on individual sites.

3. Biological control

Biological control efforts against HWA began in the early 1990's. Typically, searches for natural enemies begin with seeking available and new parasitoids (organisms that are parasitic on just one host, eventually killing it as the parasitoid completes development). However, there were no parasitoids known worldwide, and in eastern United States, only generalist predators were observed to feed on HWA, and there were occasional fungal infections, also by non-specific species. Foreign exploration for natural enemies of HWA began in 1992 in Japan), then continued in China in 1995, and included western Canada starting in 1997 (Cheah et al. 2004) as depicted in Figure 1 below.

Figure 1 Worldwide occurrence of Hemlock (red) with arrows showing where biological control agents were collected for importation to the United States.



More than 60 species of lady beetles (Coccinellidae) were eventually collected in China (Yu and Montgomery 2008), with most being in the subfamily Scymninae, the largest subfamily of lady beetles. These predatory beetles are quite small (less than 3 millimeters) and are "specialized predators" in that they attack only certain groups of sucking insects (Homoptera) such as scales, aphids, mealybugs - and adelgids. This group of tiny lady beetles contains the genera *Sasajiscymnus* and *Scymnus*. Both genera are found naturally only in Asia. *Sasajiscymnus tsugae* (Sasaji and McClure) (formerly *Pseudoscymnus tsugae*) (Coleoptera: Coccinellidae) was collected in Japan, and three species of *Scymnus* were brought to the United States from China. The *Scymnus* species were studied in quarantine and proved to be very specialized adelgid predators – the adults fed on aphids to some extent but otherwise they fed on all stages of adelgids (such as HWA) and the larvae could not survive unless fed adelgid eggs (Cheah et al. 2004).

L. nigrinus, from the beetle family Derodontidae, was collected in western Canada. This is also a very small predatory beetle that appears to be a specialized predator.

L. nigrinus, *Sasajiscymnus tsugae*, and *Scymnus sinuanodulus* have been released at numerous locations in eastern United States starting with *S. tsugae* in 1995, and after 2000 for the other two species. Establishment has been achieved by all three species, although establishment and build-up of *S. tsugae* has been very limited despite the release of over two million individuals of different stages (Salom et al. 2008). The degree to which these predators will suppress HWA populations has yet to be determined, however, since the majority of releases have been relatively recent (during just the last 5 years).

Other biological control efforts include additional species of predatory beetles, and are in various stages of evaluation and research. Current efforts also include the development of effective fungus-based pesticide formulations using *Lecanicillium muscarium* (formally *Vericillium lecanii*) and *Beauveria bassiana* (Cheah et al. 2004, Gouli et al. 2008).

B. Second Alternative: Issue permits for environmental release of *Laricobius osakensis*

Under this alternative, APHIS would issue permits for the field release of *L. osakensis*. These permits would contain no special provisions or requirements concerning release procedures or mitigating measures.

1. Description and Taxonomy of *Laricobius osakensis*

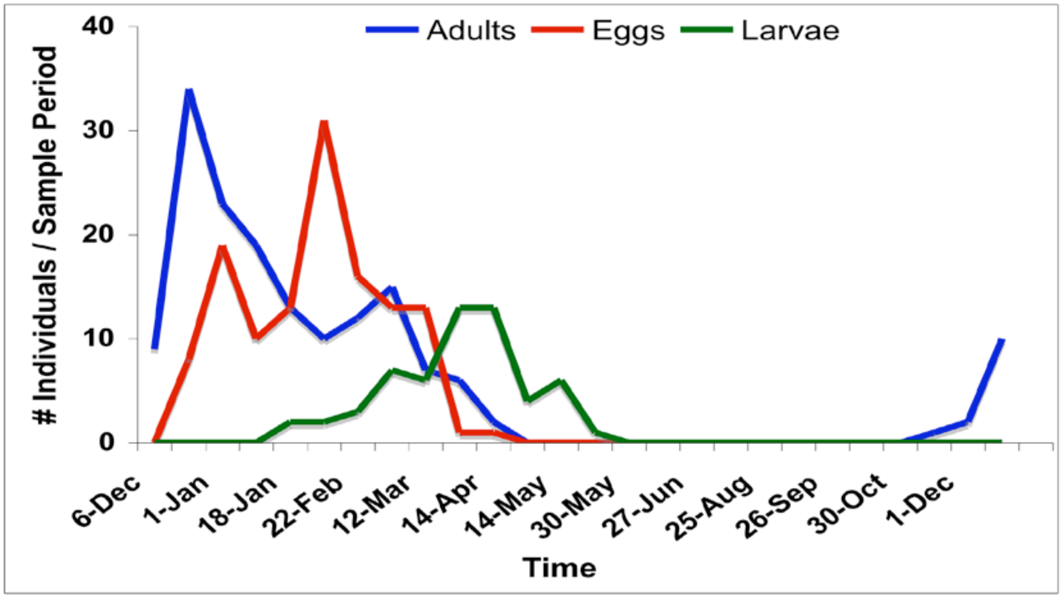
Laricobius osakensis Montgomery and Shiyake is a newly described species (see Montgomery et al. *in press*, for additional information). Traditional morphological and molecular techniques have been used to identify *L. osakensis*. Voucher specimens are currently located at the Osaka Museum of Natural History in Osaka, Japan, the USDA Forest Service, Northern Research Station in Hamden, CT, and the Beneficial Insects Quarantine Laboratory at Virginia Tech in Blacksburg, VA.

2. Life history

Based on weekly field sampling that has been conducted for the past year in Japan, adults emerge from the ground in the fall and go to hemlock trees. Adults feed on HWA throughout the fall and winter months. Egg laying begins in December and continues through March. Larvae are active and feeding on HWA eggs from January through April. As prepupae, they drop to the ground, and bury into the soil for pupation. As adults, they enter diapause (dormancy) for the summer months.

The life histories of *L. osakensis* and HWA are synchronized, although HWA has two generations per year and *L. osakensis* just one. The life history of HWA is characterized by the aestivation (summer dormancy) of the first stage nymphs during the summer (approximately June through September), with growth resuming in the fall, and continuing through winter and spring. HWA eggs are present typically from March into May and again in June (McClure et al. 2001). *Laricobius* larvae are likewise present during late February through May (see Figure 2). Larval development is completed and adults emerge by June, but the adults go into a period of dormancy during the summer as well, then resume activity and feed during the fall and winter on all stages of HWA which are present.

Figure 2 Summarized presence of *L. osakensis* life stages from sampling HWA-infested hemlock in the Osaka region of Japan 2007 and 2008.



3. Native geographical range

L. osakensis has been recorded from only eight of Japan's 72 prefectures (provinces). It has been collected from well below 34° N latitude to just above 36° in Japan and at altitudes ranging from 300 to almost 7000 ft. Given the latitudes and altitudes from which this species has been recorded, it is predicted that it will survive throughout most of the HWA-infested range of *Tsuga* spp. in the eastern United States. Furthermore, lab rearing indicates that *L. osakensis* is capable of surviving very low temperatures; as it lays eggs at 0°C and continues to feed at -7°C (A. Lamb, personal observation).

4. Impact on HWA

HWA is not a pest in the areas of Japan where *L. osakensis* has been collected. As explained below, *L. osakensis* has an observable direct effect on the target host *A. tsugae*. Exclusion cages deployed throughout the winter months in Japan show a large decrease of HWA on branches exposed to *L. osakensis* compared to caged branches where HWA remained, but predators were excluded. A field study was conducted during the winter months in Japan at three locations with sufficient HWA populations. The stage and number of adelgids, as well as dead adelgids and the cause of death was recorded (i.e., caused by a chewing insect, sucking insect, fungus, or during aestivation). During that time, *L. osakensis* was the only predator present on the hemlock trees, and predator abundance was positively correlated to percent mortality on a site by site basis (Lamb et al. 2008). In the lab, *L. osakensis* appears to feed more voraciously on HWA than *L. nigrinus*, and also larval development rates are faster, with only 75 percent and 62 percent as much time in the larval stage as *L. nigrinus* at 9°C and 12°C, respectively (Lamb et al. 2008).

IV. Affected Environment

A. Native North American Species

1. Species related to the Hemlock woolly adelgid

There are 13 described species of Adelgidae known to be native to North America (Havill and Foottit 2007), and at least three introduced species besides HWA, including two known pests, the balsam woolly adelgid (*Adelges piceae*) and the eastern spruce gall adelgid (*Adelges abietis*) (Johnson and Lyon 1991). Identified hosts of these 16 species are spruce, pine, fir, Douglas-fir, larch, and hemlock. The HWA is the only adelgid species in North America, and possibly the world, which utilizes hemlock.

Adelgids have complex life cycles which can be divided into two types: species with only parthenogenetic (no sexual reproduction) cycles; and holocyclic species, which are species with both parthenogenetic and sexual cycles. Havill and Foottit (2007) provide the following description of adelgid life cycles and habits:

> Five generations make up the typical adelgid holocycle. Three are produced on the primary host, where sexual reproduction and gall formation occur; two are produced on the secondary host that supports a series of asexual generations. The entire cycle takes two years to complete. Spruce (*Picea* spp.) is always the primary host and another conifer genus (*Abies*, *Larix*, *Pseudotsuga*, *Tsuga*, or *Pinus*) is always the secondary host. Adelgids are highly host specific: A given species can survive and reproduce only on certain tree species within a single primary and secondary host genus. For example, *Pineus orientalis* can alternate between *Picea orientalis* and *Pinus silvestris,* but it cannot survive on *Picea abies*, *Pinus strobus*, or *Pinus cembra.*

The primary hosts for HWA in Japan appear to be the spruce species *Picea jezoensis hondoensis* and *P. polita*, neither of which occurs in eastern north America, so HWA cannot complete the sexual cycles in the eastern United States.

2. Hemlock Woolly Adelgid

a. Native range of hemlock woolly adelgid

HWA is native to Asia and likely also western North America (Cheah et al. 2004, Havill et al. 2006). The population of HWA in the Pacific Northwest of North America was first described on western hemlock by Annand (1924). Havill et al (2006) determined that this population is molecularly distinct from populations in Asia and the eastern United States, and thus likely native to the region. It is present throughout this region of western North America, but at typically harmless densities (Furniss and Carolin 1977, Tait et al. 1985).

b. Present distribution of HWA in eastern North America

In eastern North America, HWA has spread gradually from the introduction in Richmond VA and presently is known to occur in 18 states from Maine to Georgia (see Appendix 1). Approximately 40 percent of the *T. canadensis* range within the United States and 100 percent of the *T. caroliniana* range is infested (Tighe et al. 2005).

c. HWA life history in eastern United States

Basically, there are three parthenogenetic generations of HWA each year on hemlock in eastern United States: an overwintering generation that occurs from July through April in the northeast, and two spring generations that occur simultaneously from April through June. All three of these generations have six stages of development: the egg; four nymphal instars (size stages); and the adult. One spring generation remains on hemlock, the other migrates to spruce, but the nymphs that hatch and begin to feed on spruce in July all die within a few days; none develop beyond the first instar on any of 15 different north American spruce species (McClure 1987, 1991). The adults from the spring generation (all female) each lay a cottony egg sack sometime in June or July. The crawlers (first stage nymphs) that hatch migrate to new growth on the tree and settle to feed but enter aestivation that lasts until October when they resume feeding (McClure 1996).

3. Species related to *Laricobius osakensis*

Species in the genus *Laricobius* (Coleoptera: Derodontidae) feed only on Adelgidae. The remaining species of Derodontidae in North America feed on various species of fungus during their entire life cycle. *Laricobius* is represented in North America by 4 species: *L. erichsonii* Rosenhauer, *L. laticollis* Fall, *L. nigrinus* Fender and *L. rubidus* LeConte. *L. erichsonii*, was introduced from Europe as a biological control agent of the balsam woolly adelgid, *Adelges piceae* (Ratzeburg). *L. laticollis* has been infrequently collected in the northwest and host associations are not known (Zilahi-Balogh et al. 2003b). The remaining two species of *Laricobius*, *L. rubidus* (eastern North America) and *L. nigrinus* (western

North America), have been noted feeding on HWA. *Laricobius rubidus* completes development, and survives well on a diet of HWA (Zilahi-Balogh et al. 2005). It is present in Connecticut (Montgomery and Lyon 1996), North Carolina, Virginia (Wallace and Hain 2000), Maine, New Hampshire, Massachusetts, District of Columbia, Pennsylvania, New York, Michigan, Quebec, Ontario, and New Brunswick (Lawrence 1989, Downie and Arnett 1996). The primary host of *L. rubidus* is the pine bark adelgid, *Pineus strobi* Hartig (Clark and Brown 1960), and is not commonly observed feeding on HWA.

The known distribution of *L. nigrinus* ranges from northern California to British Columbia, Alberta, and northern Idaho (Furniss and Carolin, 1977; Lawrence 1989). An extensive 2 year survey of predators of HWA in Washington and British Columbia resulted in the collection of 55 species of predators. Just three species, *Laricobius nigrinus*, *Leucopis argenticollis* Zetterstedt, and *Leucopis atrifacies* (Aldrich) (Diptera: Chamaemyiidae) comprise 59 percent of all the predators collected, with *L. nigrinus* being the most abundant (Kohler et al. 2008).

Laricobius nigrinus has one generation per year which is very well synchronized with HWA throughout the year (Zilahi-Balogh et al. 2003a). Both the predator and prey are active in the fall, winter, and spring, and both diapause in the summer. Adults emerge from the soil in the fall, disperse to hemlock branches, feed on HWA nymphs, adults, and eggs (available during early-mid spring), and then die. In the laboratory tests conducted at Virginia Tech, *L. nigrinus* completed development on HWA but not on several other eastern adelgids and aphids tested. Because of its specificity to HWA, *L. nigrinus* was released from quarantine by USDA-APHIS (Zilahi- Balogh et al. 2002), and has subsequently been released in 16 eastern states where HWA is present.

B. Hemlock Resources in North America

Eastern hemlocks, *T. canadensis*, are long-lived, late successional climax trees that, if left undisturbed, eventually dominate stands. Eastern hemlock, may take 250-300 years to reach maturity, live for 800 years, and attain heights of 150-175 feet. Eastern hemlock is the most shade tolerant tree species in North America, capable of surviving underneath a shaded forest canopy for as long as 350 years (Quimby 1996). Because it is so shade tolerant and long-lived, hemlock is a late successional (or "climax") tree that can dominate a forest for centuries.
Eastern hemlock forests create distinctive microclimates and provide an important habitat for a wide variety of wildlife. In the Northeast, 96 bird and 47 mammal species are associated with hemlock forests (Yamasaki et al. 2000). Of these, at least eight species of birds and ten species of

mammals have strong ecological linkages with hemlock forest habitat. In Connecticut alone, almost 90 species of birds use hemlock as a food source, nesting site, roost site, or winter shelter (McClure et al. 2001). Examples of birds include black-throated green warbler, blackburnian warbler, blue-headed vireo, winter wren, red-breasted nuthatch, ruffed grouse, and the northern goshawk. Examples of mammals include black bear, bobcat, snowshoe hare, red squirrel, and southern red-backed vole. Hemlock is an important winter habitat for white-tailed deer. Many native plant species thrive in hemlock stands, including leatherwood, rattlesnake plantains, bunchberry, goldthread, bluebeard, Canada mayflower, wood sorrels (Evans et al. 1996, McClure et al. 2001).

Hemlock forests are often a critical factor in supporting native brook trout populations, by maintaining cool stream temperatures and stable flows. A study conducted by Snyder et al. (2001) in the Delaware Water Gap National Recreation Area showed that small streams in hemlock forests are three times more likely to support native brook trout populations than similar streams in hardwood forests in the park. The study showed that small streams in hemlock forests are typically 1-2°C (2-3.5°F) cooler in the summer than similar streams in hardwood forests. Furthermore, hemlock forest streams typically support about 65 species of aquatic insects, compared to only about 35 species in hardwood forest streams. About 15 species of aquatic insects seemed to occur almost exclusively in hemlock forest streams in this park (Snyder et al. 2001).

For these and other reasons, hemlock stands are very popular recreational sites for fishing, hiking, hunting and bird watching. Hemlock is not a valuable timber species, but it is used widely for pulpwood and utilitarian uses (such as pallets). Hemlocks are valued landscape plants, however: with 274 cultivars of eastern hemlock, it is one of the most cultured and cultivated landscape trees in the United States (McClure 2001).

C. Relationship of HWA with eastern hemlocks

1. Continued spread of hemlock woolly adelgid

McClure and Cheah (1999) reported that from 1985 to 1999, the rate of spread of HWA averaged nearly 30 km (19 miles) per year. A later report by Evans and Gregoire (2007) calculated an average rate of spread of 12.5 km (7.8 miles) per year since 1990. However, several factors influenced this rate of spread, the most important being exposure of the HWA nymphs to temperatures of around -25°C (-13°F). Thus the average rate of spread is only 8 km (5 miles) per year for Pennsylvania and north, and 15.6 km (9.7 miles) per year for areas further south. Winter mortality of

HWA has been observed on many occasions. The lowest temperature tolerated by a sample of individuals from both northern and southern US sites appears to be approximately -18°C (0°F), with some variation between individuals, and more individuals in northern sites tolerating temperatures slightly lower than 18°C (Costa et al. 2008). Nevertheless, it is widely considered that HWA will eventually occupy all of the natural range of eastern hemlocks (see Appendix 1)

2. Impact on hemlock resources

a. Tree decline and mortality

Eastern hemlock is classified as highly susceptible to HWA (Hoover et al. 2008). HWA has caused significant mortality of hemlock trees over the last 20+ years. As HWA infestations rapidly spread to other states in the 1980's, and these HWA outbreaks had steadily grown in size, impacts from HWA infestation appeared to be worsening and by the mid 1990's tree mortality was being reported from at least four states.

Tree decline and mortality is highly variable site to site and year to year, often showing cycles of decline and regrowth and decline for individual trees and stands, mainly in response to HWA induced changes in nutritional quality of the tree on which they feed (McClure et al. 2001). Site and weather factors (i.e., drought) plus secondary pests attacking the weakened trees, are thought to influence when and where mortality occurs (Souto et al. 1996). For example, in Shenandoah National Park, some sites experienced a rise in mortality from 8 percent to 48 percent in just two years, with several site factors deemed to be important including, elevation and which cardinal direction a slope faces (Blair 2002).

By about 2005, hemlock mortality and logging in anticipation of mortality had become so widespread that there was concern about the future viability and preservation of the species. However, there appears to be some innate resistance in a small minority of surviving hemlocks from devastated stands, based on propagating and then challenging these apparently resistant trees with HWA infestation (Casswell et al. 2008).

b. Economic, Social and Recreational Impacts

Landowners today have several options for monitoring and management HWA and tree mortality (Ward et al. 2004, Orwig and Kittredge 2005, Costa and Onken 2006). However, no practical options are available to prevent hemlock decline in forest settings, and thus, these stands are transitioning to hardwoods and invasive plants (Orwig and Foster 1998, Orwig et al. 2002, Eschtruth et al. 2006).

Loss of hemlock landscape trees due to HWA infestations in residential properties has been estimated at $2,000 – $7,000 per home (Holmes et al.

2005). Hemlock losses as a forest product resource have not been estimated due to the fact that hemlock is not an especially valuable or unique forest product resource.

Hemlock mortality in the forest does have significant impact on recreational use, and large federal parks have engaged in integrated pest management (IPM) programs to address the varied recreational and ecosystem needs on their properties. For example, long term monitoring, ecosystem studies, and management efforts were begun at the Delaware Water Gap National Recreation Area in 1993 (the Park was originally infested in 1989). Monitoring has shown a rapid decline and mortality and as of 2006, 28 percent of originally healthy plot trees had died and none of the remaining trees were in healthy condition (Evans and Shreiner 2008). The Great Smokey Mountains National Park has engaged in an aggressive IPM program to respond to the infestation which threatens over 35,000 acres of hemlock dominated forest (Johnson et al. 2008).

3. Ecosystem impacts of HWA

Richard Evans (2002) of the National Park Service commented that the “decline and loss of our remaining eastern hemlock stands could be more ecologically significant than the loss of American chestnut (*Castanea dentata*) in the early 1900s due to chestnut blight” due to the fact that hemlock would not be replaced by ecological equivalent species as occurred with the loss of the American chestnut. The large scale removal of hemlock trees due to HWA caused mortality, and in some cases the resulting salvage logging of stands is well documented (Kizlinski et al. 2002, Orwig et al. 2002, Foster and Orwig 2006)

Impacts include negative effects on brook trout (reversal of cooler summer and warmer winter stream temperatures), carbon cycling (Nuckolls et al. 2009), soil and water chemistry (Yorks et al. 2003). Loss of foliage and tree mortality in hemlock dominated stands often results in the invasion of exotic and native species which provide less shade and cover during the summer and winter seasons, significantly impacting temperature and moisture microhabitats.

Reduction in biodiversity after tree mortality due to HWA has been reported extensively (Yamasaki et al. 2000, Brooks 2001, Evans 2002, Snyder et al. 2002, Tingley et al. 2002, Ross et al. 2003, Ross et al. 2004, Buck et al. 2005, Ellison et al. 2005, Lishawa et al. 2007). Hemlock mortality is also changing ecosystem processes, structure, and function (Jenkins et al. 1999, Stadler et al. 2005, Cobb et al. 2006, Stadler et al. 2006), water quality (Yorks et al. 2003).

V. Environmental Consequences

A. No action

The infestation and damage caused by HWA in urban and forest landscapes has received considerable attention from landowners and landmanagers, both public and private. Several management tactics have been implemented to reduce the infestation level of HWA and the damage and mortality it causes. The use of chemical insecticides and biological controls at current levels would be expected to continue if the "no action" alternative is chosen. These environmental consequences may also occur even with the implementation of the biological control alternative, depending on the efficacy of *L. osakensis* to reduce infestations HWA and levels of damage to eastern hemlocks.

Similarly, the current rate of spread, and levels and trends of eastern hemlock mortality and other environmental consequences from infestation by HWA are expected to continue if the "no action" alternative is chosen. Likewise, these environmental consequences may also continue at some level even with the implementation of the biological control alternative

1. Impact from use of other control methods

a. Chemical control

In recent years chemical control of HWA in both ornamental and forest situations has predominantly utilized imidacloprid applied as a soil drench, soil injection or trunk injection. The injection techniques use a Kioritz injector (soil) or any of a variety of injection systems for trunk injection. Some proprietary designs have been specifically developed for application against HWA (Doccola et al. 2008). Imidacloprid acts systemically (taken up by the hemlock tree and is translocated via the plants vascular system). Typically pest suppression is evident for more than one year after application (Webb et al. 2003).

It appears that very little to no run off occurs from properly applied soil injections (Churchel et al. 2008). Further, hemlocks frequently grow in stream-side locations and in steep, rocky ravines with little intact soil, and trunk injection is used instead of soil injection in these situations. Another avenue for imidacloprid entry into the environs outside of the live tree is via leaf fall in deciduous trees. However with the needle retention of hemlock, this is less of a concern. Other insecticides will have different environmental fate scenarios.

Predatory organisms feeding on HWA on treated plants have the potential to be exposed to insecticides, including imidacloprid, through ingestion of contaminated prey. For example, predator poisoning was observed in one laboratory trial that investigated this issue. However, a strong feeding preference for healthy (untreated) adelgids was shown by *L. nigrinus* and *Sasajiscimnus tsuga* (Eisenback et al. 2008). A secondary impact could result from ingesting poorer quality prey items (i.e., less preferred and less suitable prey species) in treated areas.

b. Biological control

Information from surveys of native parasites and predators of HWA, indicates there are no parasites, and that the predators attacking HWA are generalist species, most of which were predatory flies in the families Cecidomyiidae, Syrphidae, and various lacewings (Chrysopidae, and Hemerobiidae). Only two coleopteran predators were noted, the invasive ladybeetle, *Harmonia axyridis*, and *Laricobius rubidus*. However, predator abundance was not great enough to exert any controlling effect (Montgomery and Lyon 1996; Wallace et al. 2000; Salom et al. 2008).

Three species of predators have been released in eastern United States against HWA: *Laricobius nigrinus* (from northwestern United States), and *Sasajiscimnus tsuga*, and *Scymnus sinuanodulus* (both from Asia). Many of these releases have been in recent years, thus, recovery and establishment is limited or not yet confirmed in many areas (Grant 2008, McDonald, et al. 2008). Recovery of the Asian coccinellid predators has been limited despite widespread releases and the release of over 2 million *S. tsugae*. However, *Laricobius nigrinus* has been recovered in 60 per cent of release sites (Mausel et al. 2008). Population buildup of this species has been noted in a few sites, for example in northwestern North Carolina (McDonald et al. 2008).

Research of other biological control agents continues, including release and recovery efforts for the three species mentioned above (Salom et al. 2008)

B. Issue permits for environmental release of *L. osakensis*

1. Effects on target non target prey species

a. Scientific literature and sources

The genus *Laricobius* is known to be specific to Adelgidae (Zilahi-Balogh et al. 2003b). Museum specimens at the Osaka Museum of Natural History were all collected on *Tsuga sieboldii* and *T. diversifolia* infested with HWA. Hundreds of adults, eggs, and larvae of *L. osakensis* have also been collected from HWA on *T. sieboldii* during 2006 and 2007 visits to Japan for research.

L. nigrinus likewise may have become somewhat specialized on HWA in western North America. Zilahi-Balogh et al. (2007) reported that *L. nigrinus* highly preferred HWA over three other adelgid, two aphid and one scale species, and that it could not complete larval development on these alternate hosts yet was successfully reared on HWA.

b. Field Observations

L. osakensis appears to be well adapted to this host, feeding specifically on it. The seasonal cycles of the life histories of the two species are tightly synchronized as is evident in several regions in Japan. For example, during autumn 2008 in northern Japan, HWA became active on October 14 and predators were found feeding on it, while at the same time in the Kansai area, regular sampling had revealed that HWA was still in diapause on October 13 and no predators were found.

L. osakensis appeared to have an observable direct effect on HWA. This was shown by a field test in Japan in winter 2007-2008 using cages on hemlock branches which prevented the free living *L. osakensis* in the area from feeding on the HWA inside the cages. There was a large decrease of HWA on branches exposed to *L. osakensis* compared to caged branches.

c. Host specificity testing

Host range testing was conducted using adelgid species and other related species available in North America. Several adelgid hosts were used, as well as two scale species, and a woolly aphid. These alternate hosts were chosen because they are closely related to HWA, or are on hemlock trees, or because they have a specific non-target concern. The results indicate that HWA, *Adelges tsugae,* is the preferred host. Following is additional information about these species and results from these tests.

i. Species tested

Adelgid species

Balsam woolly adelgid (**BWA**), *Adelges piceae* (Ratz.), is of European origin but is now distributed in eastern and western North America and attacks various firs trees (*Abies* spp.). Pine bark adelgid (**PBA**), *Pineus strobi* (Hartig), is native to the eastern United States, and mainly attacks eastern white pine, *Pinus strobes,* but occasionally attacks other species of pine (*Pinus*). Larch woolly adelgid (**LWA**), *Adelges laricis* Vallot, is native to Europe and attacks larch (*Larix* spp.) in North America. Eastern spruce gall adelgid (**ESGA**), *Adelges abietis* (Linneaus), introduced from Europe, primarily attacks white spruce (*Picea abies*) and Norway spruce (*P. glauca*).

Woolly aphid and scales

Woolly alder aphid (**WAA**), *Paraprociphilus tessellates* (Fitch), is generally considered a pest, but it may be an insect of concern for non-targets effects because it is the host of the only carnivorous Lepidopteran in North America, the harvester butterfly, *Feniseca tarquinius* (Fabricius). WAA is found east of the Mississippi river and requires both alder and silver maple to complete its lifecycle. This aphid is woolly, therefore there has been some concern that *Laricobius* would be attracted to it. Elongate hemlock scale (**EHS**), *Fiorina externa* Farris, is a scale of Japanese origin that is found in several eastern states where it has been introduced and spread. It attacks both eastern and Carolina hemlocks, *T. canadensis* and *T. caroliniana*, thus, it is frequently in the same areas as HWA. It is considered a pest and contributes to the decline in hemlock trees. Pine needle scale (**PNS**), *Chionaspis pinifoliae* (Fitch), is a native scale that is commonly a pest on coniferous trees.

ii. Tests conducted:

No-Choice Tests – Adult Feeding and Oviposition

Female *L. osakensis* were placed individually on HWA, BWA, or PBA for 5 days at 12°C**,** and the number of host eggs eaten and the number of eggs laid was recorded (see Table 1). Female *L. osakensis* were placed individually with WAA for 7 days, and the number of aphids eaten was recorded. Adult feeding and oviposition (egg laying) was higher on HWA than either of the other hosts (Tables 1 and 2)

Table 1. Mean (±SD) host eggs consumed and oviposition rate by *L. osakensis* when offered hemlock woolly adelgid (HWA), balsam woolly adelgid (BWA) or pine bark adelgid (PBA) during a 5-day no-choice test.

Host	n	***L. osakensis* Feeding (host eggs/day)**	***L. osakensis* Oviposition (eggs/day)**
HWA	8	17.3 ± 5.6 a_	3.7 ± 1.9 a
BWA	10	2.1 ± 2.7 c	0.1 ± 0.1 b
PBA	11	7.1 ± 3.8 b	0.5 ± 0.8 b

Table 2. Mean (±SD) number of woolly alder aphids eaten in 7 days when given no choice.

Host	**n**	**Feeding**
WAA	10	0.7 ± 0.82

Choice Tests – Adult Feeding

A series of choice tests measuring feeding and oviposition on HWA and one alternate host were conducted at 10°C for 7 days. For each test, a single adult was placed in each of 10 petri dishes with a sufficient amount each HWA and the alternate host. In each test, the number of HWA eaten was significantly greater than the number of alternate hosts eaten (Table 3.)

Table 3. The mean number of hosts eaten in a 7-day choice test using hemlock woolly adelgid and an alternate host. Alternate hosts include pine needle scale (PNS), balsam woolly adelgid (BWA), woolly alder aphid (WAA), elongate hemlock scale (EHS), and pine bark adelgid (PBA).

Test	n	Mean HWA Eaten	Mean Alternate Host Eaten
HWA vs PNS	10	6 +/- 0.68a	0 b
HWA vs BWA	10	6 +/- 0.92a	1.7 +/- 0.21 b
HWA vs WAA	10	7.9 +/- 1.18a	1.3 +/- 0.45 b
HWA vs EHS	10	3.6 +/- 0.27a	0.5 +/- 0.22 b
HWA vs PBA	10	3.8 +/- 0.39a	2.0 +/- 0.47 b

Means with the same letter within a row are not significantly different (p=0.05 Student T-test).

No-Choice Tests - Larval Development

L. osakensis eggs were placed on HWA and 5 alternate hosts, BWA, PBA, LWA, ESGA, and WAA. Individuals were held at 9°C and survival of each individual was assessed every 2-3 days (Table 4). *L. osakensis* was able to complete development from the egg stage through all larval stages to adult only on HWA (see trail #1). There was no survival beyond the first larval stage (no feeding) when fed LWA and WAA (Trail #1). Cohort survival to prepupal stage was below 20% on BWA (7%), and PBA (see Trials #1 and #3), while cohort survival on HWA exceeded 50% in two of three trials. Trail #2, (average 43%). *L. osakensis* survival from egg to prepupal stage averaged 31% on PBA, and was 43% for ESGA.

Despite limited data, it is clear that there was no development on the only non-adelgid species tested (WAA), while development to prepupa occurred on four of the five adelgid species tested. Regarding development being restricted to adelgids, these data are consistent with results from similar trials with *L. nigrinus* and three other adelgids (BWA, ESGA, PBA), and two aphid species (Zilahi-Balogh et al. 2002).

Table 4. The number and percentage of individuals of *L. osakensis* surviving to each life stage for each test prey species in No Choice conditions.

Trial #1						
Stage	HWA		LWA		WAA	
	n	% survival from egg stage	n	% survival from egg stage	n	% survival from egg stage
Egg	9		20		20	
L1	9	100	20	100	20	100
L2	8	88	0*	0	0*	0
L3	7	78	0	0	0	0
L4	7	78	0	0	0	0
Prepupae	5	56	0	0	0	0
Pupae	?	?	0	0	0	0
Adults	4	44	0	0	0	0
*L1 larvae did not feed on LWA and WAA and did not develop to L2						
Trial #2						
Stage	HWA		ESGA		PBA	
	n	% survival from egg stage	n	% survival from egg stage	n	% survival from egg stage
Egg	28		14		29	
L1	28	100	14	100	29	100
L2	24	86	14	100	26	89
L3	11	39	12	86	21	72
L4	7	25	8	57	18	62
Prepupae	5	18	6	43	13	44
Pupae	?	?	?	?	?	?
Adults	0	0	0	0	0	0
Trial #3						
Stage	HWA		BWA		PBA	
	n	% survival from egg stage	n	% survival from egg stage	n	% survival from egg stage
Egg	11		14		18	
L1	11	100	14	100	18	100
L2	10	91	2	14	12	67
L3	9	82	1	7	12	67
L4	9	82	1	7	10	56
Prepupae	6	55	1	7	3	17
Pupae	?	?	?	?	?	?
Adults	0	0	0	0	0	0

iii. **Summary and Discussion: Host specificity of *L. osakensis***

The life history pattern of *L. osakensis* indicates that it is naturally synchronized with the life history pattern of HWA, including a period of aestivation in the summer followed by active feeding and development in the colder months of September to June, which itself is synchronized with the annual pattern of growth and transpiration of the hemlock hosts (very high rates in the early spring). The literature shows that *Laricobius* species are specialist predator on adelgids. Results from the laboratory tests on *L. osakensis* and the native *L. nigrinus* demonstrate a very narrow host range. *L. osakensis* is not expected to be able to survive on a diet of prey of other North American species related to HWA. Although *L. osakensis* adults may feed on these other adelgids, the results from paired choice test show they are not preferred. The synthesis of this information– specialized life history, and high degree of prey choice preference among the alternate hosts tested, coupled with the inability to survive on prey other than HWA, suggest very minimal direct impact on other potential prey species in the environment in North America.

d. Competition with other predators

The life history of *Laricobius osakensis* appears to be similar to *L. nigrinus*. This was confirmed by weekly field sampling conducted in 2007-2008, and is summarized as follows. In the fall, after the summer aestivation ends, the adult *L. osakensis* emerge from the ground and go to hemlock trees, where they feed on HWA throughout the fall and winter months. Female *L. osakensis* begin begin laying eggs in December and continue through March. Beginning in January, larvae hatch and feeding on HWA eggs through April. The larvae finish their growth and drop to the ground during late March and April and bury into the soil for pupation. Adults emerge from the pupal stage by early summer, but remain in the soil in aestivation for the summer and into early fall when they become active and start the cycle again.

Since this species is active in the winter, and aestivates in the summer, it does not interact or compete with other predators on hemlock except perhaps the biological control agent *L. nigrinus* which has been introduced and established in the eastern United States. This species may also interact with the native *L. rubidus* that feeds on pine bark adelgid but is known to occasionally feed on HWA. The potential interactions of all three species are currently being studied at Virginia Tech. Laboratory studies of adult beetle interaction among all three species show no negative interactions to the impact on the target host (see Fig. 3 below) and in the number of predator eggs deposited in HWA ovisacs (egg clusters) (Fig. 4). Additionally, survivorship among the three species appears unaffected (Fig. 5).

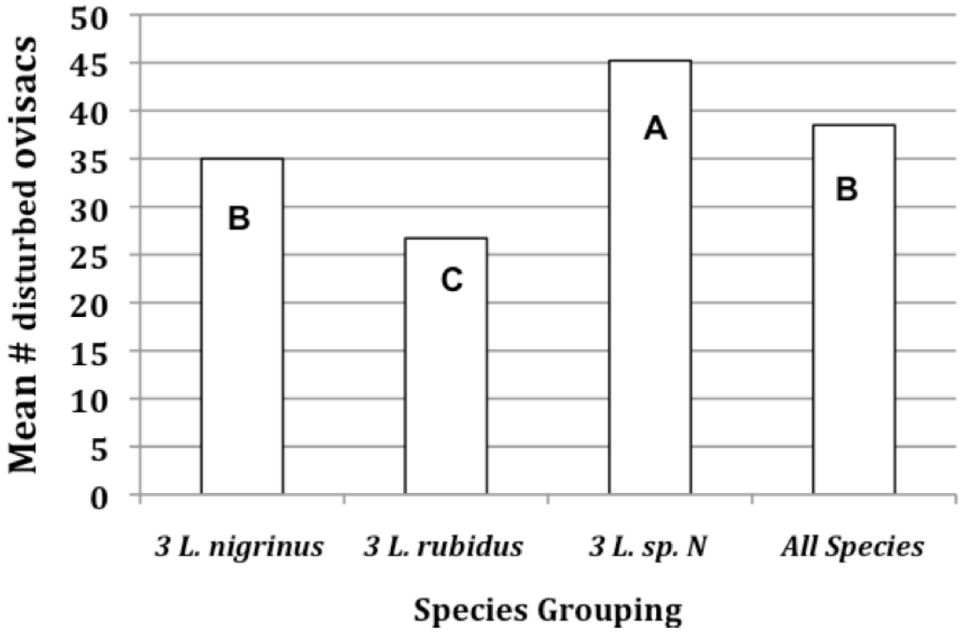


Figure 3. Mean number of HWA ovisacs disturbed by adult *Laricobius* spp. when placed in groupings by themselves or all together in the laboratory. All treatments contained a total of 3 adult beetles. "***L. sp. N.***" = *L. osakensis.* Treatments denoted by different letters are significantly different from each other (Tukey's studentized test; $p < 0.05$).

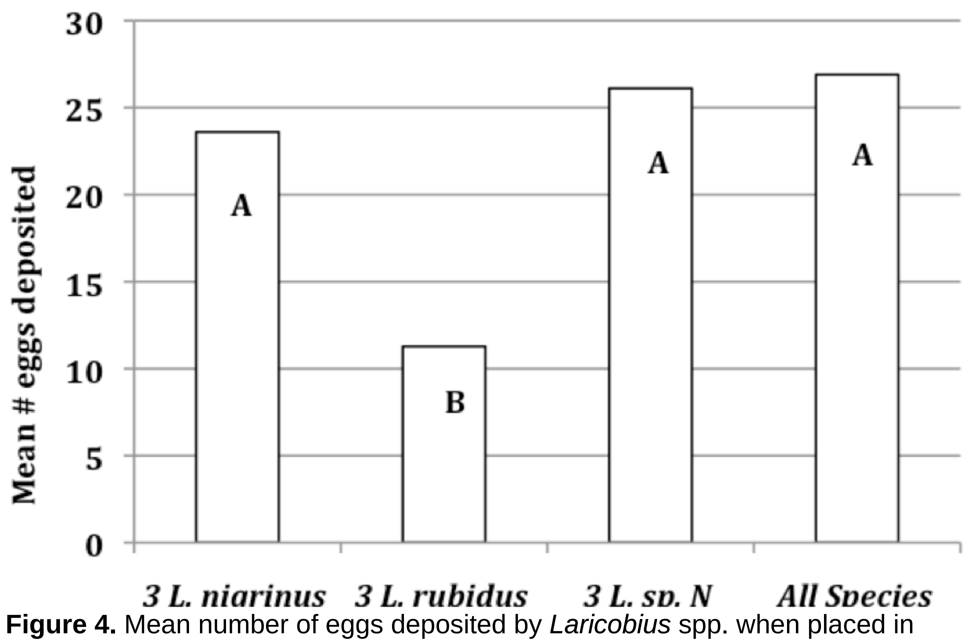


Figure 4. Mean number of eggs deposited by *Laricobius* spp. when placed in groupings by themselves or all together in the laboratory. All treatments contained a total of 3 adult beetles. "***L. sp. N.***" = *L. osakensis.* Treatments denoted by different letters are significantly different from each other (Tukey's studentized test; $p < 0.05$).

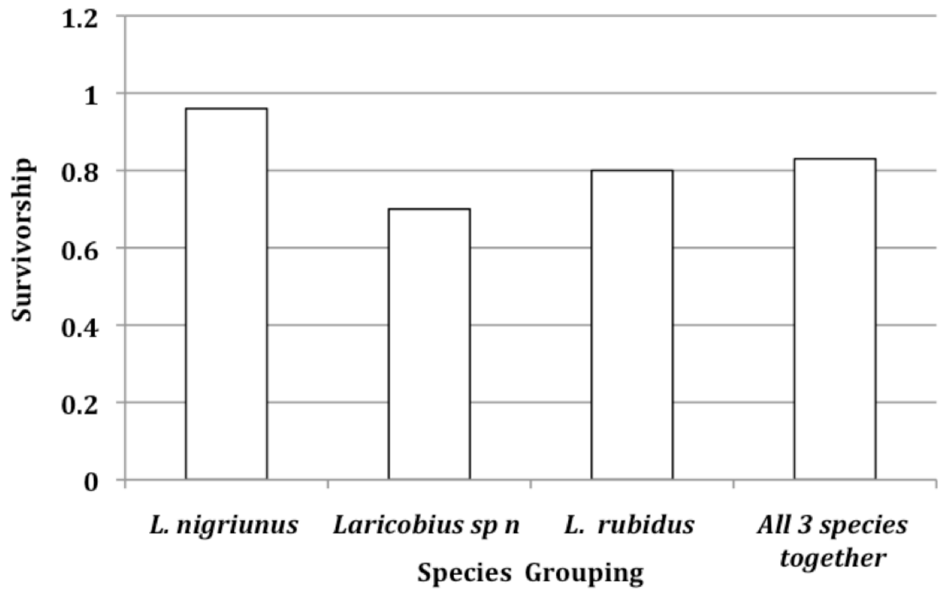


Figure 5. Survivorship of each predator species when placed in groupings by themselves or all together in the laboratory after 6 days. "***L. sp. n.***" = *L. osakensis.* No differences in treatments were observed (ANOVA; $p > 0.05$)

Based on these results with high but typical density of host ovisacs, no negative interactions are apparent. Under lower densities, preliminary results show no statistical differences at densities ½ and ¼ of the tests depicted above. There is some tendency for each species to consume their own and competitor's eggs. Again preliminary results show a trend (not significant) where *L. nigrinus* may prefer *L. osakensis* eggs somewhat to their own, but both *L. osakensis* and *L. rubidus* seemed to prefer their own eggs. In summary, there is no evidence of negative interspecific competition among these three specialized predators.

2. Uncertainties regarding the environmental release of *L. osakensis*

Once a biological control agent such as *Laricobius osakensis* is released into the environment and becomes established, there is a slight possibility that it could move from its preferred prey (HWA) to preferentially attack other nontarget prey, such as PBA, or native woolly aphids. Prey shifts by predators are not uncommon, especially opportunistic feeding on very abundant prey items in the environment. However, adaption to other prey by larval *L. osakensis* would require both nutritional as well as life history shifts in order to successfully survive on other prey, which significantly lowers the likelihood of such an occurrence.

If other insect species were to be attacked by *L. osakensis*, the resulting effects could be environmental impacts that may not be easily reversed. Biological control agents such as *L. osakensis* generally spread without intervention by man. In principle, therefore, release of this biological control agent at even one site must be considered equivalent to release over the entire area in which potential hosts occur and in which the climate is suitable for reproduction and survival.

In addition, these agents may not be successful in reducing HWA populations in the continental United States. Approximately 12 percent of the introductions of biological control agents against pests have led to "complete" control of the target pests (Greathead and Greathead 1992). Actual impacts on HWA populations by *L. osakensis* will not be known until after release occurs and post-release monitoring has been conducted. The environmental consequences discussed under the "no action" alternative may occur even with the implementation of the biological control alternative, depending on the efficacy of those agents to reduce HWA populations in the continental United States

3. Cumulative impacts

"Cumulative impacts are defined as the impact on the environment which results from the incremental impact of the action when added to other past, present and reasonably foreseeable future actions regardless of what agencies or person undertakes such other actions" (40 CFR 1508.7).

Many states and counties, as well as individual federal, state and local and private property ownerships conduct their own programs to manage HWA as well as other invasive forest pests. Chemical, mechanical, and biological controls, as described previously in this document are used in a wide range of habitats.

Release of *L. osakensis* is not expected to have any negative cumulative impacts in the continental United States because of its specificity to HWA. Effective biological control of HWA will have beneficial effects for forest and ornamental pest management programs, and may result in a long-term, non-damaging method to assist in maintaining native hemlock trees and hemlock stands in good health.

4. Endangered Species Act

Section 7 of the Endangered Species Act (ESA) and ESA's implementing regulations require Federal agencies to ensure that their actions are not likely to jeopardize the continued existence of federally listed threatened endangered species or result in the destruction or adverse modification of critical habitat.

APHIS has determined that based on the host specificity of *Laricobius osakensis*, and since there are no listed species related to HWA, or dependent on HWA, there will be no effect on any listed species or designated critical habitat in the continental United States

VI. Other Issues

Consistent with Executive Order (EO) 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-income Populations," APHIS considered the potential for disproportionately high and adverse human health or environmental effects on any minority populations and low-income populations. There are no adverse environmental or human health effects from the field release of *L. osakensis* and will not have disproportionate adverse effects to any minority or low-income populations.

Consistent with EO 13045, "Protection of Children From Environmental Health Risks and Safety Risks," APHIS considered the potential for disproportionately high and adverse environmental health and safety risks to children. No circumstances that would trigger the need for special environmental reviews is involved in implementing the preferred alternative. Therefore, it is expected that no disproportionate effects on children are anticipated as a consequence of the field release of *L. osakensisi*.

EO 13175, ―Consultation and Coordination with Indian Tribal Governments, was issued to ensure that there would be "meaningful consultation and collaboration with tribal officials in the development of Federal policies that have tribal implications….".
Consistent with EO 13175, APHIS sent letters of notification and requests for comment and consultation on the proposed action to tribes in Connecticut, Florida, Maine, Massachusetts, Michigan, Minnesota, Mississippi, New York, North Carolina, Rhode Island, South Carolina and Wisconsin. APHIS will continue to consult and collaborate with Indian tribal officials to ensure that they are well-informed and represented in policy and program decisions that may impact their agricultural interests, in accordance with EO 13175.

VII. Agencies, Organizations, and Individuals Consulted

North American Plant Protection Organization (NAPPO).
A petition for consideration of release ref. NAPPO Standard RSPM No. 12 (available at: http://www.nappo.org/Standards/Std-e.html) to APHIS and forwarded to the AAFC Biological Control Review Committee fro review and recommendation. The Committee recommended that release of *Laricobius osakensis* be approved with the conditions that: 1) a detailed post-release monitoring plan be provided; and 2) authoritatively identified voucher specimens of the *L. osakensis* populations released are deposited in the national entomological collections in North America.
Agencies and organizations represented on the committee are:
Agriculture and Agri-Food Canada, Research Centre, Ottawa, ON (Chair);
Centro Nacional de Referencia de Control Biológico, Enasica, Colima, Mexico;
Pest Management Regulatory Agency, Ottawa, ON;
Canadian Forest Service, Victoria, BC;
North Carolina State University, Raleigh, NC

U.S. Department of Agriculture
Animal and Plant Health Inspection Service
Plant Protection and Quarantine
Registrations, Identifications, Permits and Plant Safeguarding
4700 River Road, Unit 133
Riverdale, MD 20737

U.S. Department of Agriculture
Forest Service, Northeast Area, State and Private Forestry
Forest Health Protection
Morgantown Field Office
180 Canfield Rd.
Morgantown, WV 26505

Virginia Polytechnic Institute and State University (Virginia Tech)
Department of Entomology
Blacksburg, VA 24060

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Appendix 1

Map of hemlock woolly adelgid infestations 2008

Map shows current and recently infested counties and native range of eastern hemlock (*Tsuga canadensis)*

Source: http://na.fs.fed.us/fhp/hwa/maps/distribution.shtm.