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The Emerald Ash Borer: A New Exotic Pest in North America

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Yet another new exotic forest pest has been discovered in North America, and this time the infestation is centered in Michigan and Ontario. In May and June 2002, adults of an unidentified buprestid beetle were collected from ash (*Fraxinus*) trees in the Detroit area of southeastern Michigan. Later, in July 2002, after various world experts examined the beetles, they were positively identified as the Asian species *Agrilus planipennis* Fairmaire. This finding was quickly followed by the discovery of *A. planipennis* in neighboring Ontario, Canada. A flurry of activities soon followed, including conducting surveys, establishing quarantines, hosting public meetings and initiating research programs.

Common name. The name "Emerald Ash Borer" was submitted to the Entomological Society of America for consideration as *A. planipennis*' official common name by Richard Westcott (Oregon Department of Agriculture) and Natalia Vandenberg (USDA-ARS Systematic Entomology Laboratory). Discussions on a common name were initiated by several entomologists even before final confirmation was made on the beetle's identity. This was done to preempt the press from choosing their own common name once the presence of this new exotic was made public. Several adjectives were suggested to capture the beetle's color (emerald, green, metallic green), host range (ash), origin (Asian), feeding habits (borer), and taxonomic affiliation (*Agrilus*, buprestid). But when all the votes were counted, "Emerald Ash Borer" was the clear winner.

Adult Emeral Ash Borer and D-shaped exit hole

The discovery trail. In May and June 2002, adults of an unknown buprestid were reared from ash trees from various parts of southeastern Michigan. In June, David Roberts, Michigan State University (MSU) Extension, sent some of the adults to the Entomology Department at Michigan State University, where Gary Parsons identified them to the genus *Agrilus*. There were no similar species in the MSU insect collection and so the beetles were suspected to be exotic. Soon more beetles were collected and either beetles or digital images were sent

to five beetle experts in the US: Chuck Bellamy (California Department of Food & Agriculture), Robert Carlson (USDA-ARS Systematic Entomology Laboratory), Henry Hespenheide (University of California at Los Angeles), Natalia Vandenberg and Richard Westcott. Although all agreed that it was exotic, and probably Asian in origin, a positive identification could not be made. On 30 June, Richard Westcott e-mailed a description and digital images of these unknown beetles to Eduard Jendek in Slovakia, an expert on Asian *Agrilus* species. Based on this information, E. Jendek tentatively identified the beetles as *A. planipennis* on 31 June. In the meantime, Robert Carlson mailed some actual specimens to Slovakia, and on 9 July, E. Jendek was able to positively confirm that the beetles were *A. planipennis* Fairmaire (1888).

On 10 July 2002, Canadian forest health specialists Ed Czerwinski (Ontario Ministry of Natural Resources = OMNR), Doug Lawrence (Natural Resources Canada - Canadian Forest Service = NRC-CFS), and Dan Rowlinson (OMNR), found similar looking beetles and dead and dying ash trees in neighboring Windsor, Ontario. The beetles were then forwarded to the NRC-CFS lab in Sault Ste. Marie, ON, and then to Bruce Gill, an insect identifier for the Canadian Food Inspection Agency (CFIA) in Ottawa, ON. Bruce Gill suspected them to be *A. planipennis*, and forwarded some adults to Richard Westcott in Oregon for final confirmation, which came on 7 August 2002.

Taxonomy. *Agrilus planipennis* Fairmaire (1888; type China) has several synonyms, including *A. marcopoli* Obenberger (1930; type China), *A. marcopoli ulmi* Kurosawa (1956; type Japan), and *A. feretrius* Obenberger (1936; type Taiwan) (Jendek 1994). EAB is referred to as *A. marcopoli* in much of the Chinese literature and as *A. marcopoli ulmi* in Japan. Based on the morphology of the scutellum, deep pronotal medial sulcus, and robust body, *A. planipennis* appears most closely related to the Asian species *A. auristermum* Obenberger, *A. cyaneoniger* Saunders, and *A. lubopetri* Jendek.

Native range. EAB is native to northeastern China (Jilin, Liaoning, Heilongjiang, Inner Mongolia, Hebei, and Shandong), Korea, Mongolia, and Japan (Hokkaido, Honshu, Kyushu, Shikoku) (Chinese Academy of Science 1986, Ko 1969, Kurosawa et al. 1985, Sugiura 1999, Yu 1992). It is also native to the Russian Far East (Alexeev 1979) and Taiwan (type locality of junior synonym *A. feretrius*).

Host range. In China, ash (*Fraxinus*) is the only host reported for EAB, including, *F. chinensis* var. *chinensis*, *F. chinensis* var. *rhynchophylla*, and *F. mandshurica* (Chinese Academy of Science 1986, Yu 1992); the above ash taxonomy is based on Wei and Green (1996). In Japan, where *A. planipennis* is considered a subspecies under the name *A. planipennis ulmi* (Kurosawa 1956, Akiyama and Ohmomo 1997), the host range includes *Fraxinus mandshurica* var. *japonica*, *Juglans mandshurica* var. *sieboldiana* and var. *sachalinensis*, *Pterocarya rhoifolia*, and *Ulmus davidiana* var. *japonica*, (Akiyama and Ohmomo 1997, Sugiura 1999). Although these species of *Juglans*, *Pterocarya*, and *Ulmus* occur in China (*Flora of China* at http://flora.huh.harvard.edu/china/), they have not been reported as EAB hosts in China. In Michigan and Ontario, EAB has so far only been found infesting ash trees, including *F. americana*, *F. nigra*, and *F. pennsylvanica*.

Identification. EAB adults are slender, elongate beetles, 7.5-15 mm long (Yu 1992, Sugiura 1999). Adults are metallic, coppery-green in color. Mature larvae reach 26-32 mm in length (Yu 1992). Larvae are white, flat, slender, and like all *Agrilus*, have a pair of brown, pincer-like appendages (urogomphi) on the last abdominal segment. The larval head is relatively small, brown, and retracted inside the enlarged prothorax. Photos of larvae and adults are available in McCullough and Roberts (2002) and on several internet websites.

Biology. Information on EAB biology in Asia is scarce. To date, we have only found two short articles on EAB: Chinese Academy of Science (1986) and Yu (1992). In general, based on information in these two Chinese references, EAB typically

completes one generation per year in northeastern China, although some individuals may require two years. Adults are active from mid-May to July. Adults lay eggs on the bark surface, inside bark cracks and crevices, usually from early June to late July. Larvae actively feed in the cambial region of the trunk from mid-June to mid-October. EAB overwinter as fully grown larvae in pupal cells constructed in the outer sapwood or in the bark. These larvae pupate the following spring during late April and May. For larvae that are not fully grown by fall, they overwinter in the cambial region, initiate feeding again in April, and complete development later in summer.

Field observations in Michigan over the past few months noted EAB adults on ash trees from late May (David Roberts, MSU, pers. comm) to early August (David Cappaert, MSU, pers. comm). Similarly, most larvae were 2nd instars by late July, most were 3rd instars by early August, and most were 4th instars by late August. We first found larvae in pupal cells on 20 August 2002. Most larvae constructed pupal cells in the outer sapwood, but many were also constructed in the thick outer bark (RA Haack et al., unpublished data). Because many other *Agrilus* species have four larval instars (Haack and Benjamin 1982, Loerch and Cameron 1983), we assume that EAB also has four instars, but this needs to be verified.

Again, based on literature from China (Chinese Academy of Science 1986, Yu 1992), adults walk to the crown of their host tree and begin feeding on foliage soon after emergence. Adults eat small amounts of foliage throughout their life, averaging about 0.5 cm^2 per day. Initial flight usually begins within 3 to 4 hours after the first feeding. EAB adults are often active from 6:00 to 17:00 hours, especially when the weather is warm and sunny. Adults typically fly in 8 to 12 meter bursts (Yu 1992), but long distance flight of more than one kilometer is possible (Minemitsu Kaneko, Japan Wildlife Research Center, Tokyo, Japan, personal communication). Adults often rest in bark cracks or on foliage when rainy or very cloudy, and they usually remain on foliage at night. Adult males typically live 2 weeks and females 3 weeks. Females lay 68-90 eggs in their lifetime. Eggs are usually deposited individually on the bark along the trunk and lower portions of major branches. Eggs hatch in about one week. The new larvae tunnel through the bark to the cambial region and feed on the inner bark (phloem) and outer sapwood during the summer and early fall. Larval galleries are typically S-shaped (serpentine), packed with frass, and increase in width as the larvae grow. After pupae transform to adults, it takes 1 to 2 weeks before the new adults chew their way out of the tree. Adult emergence holes are D-shaped and about 3-4 mm in width.

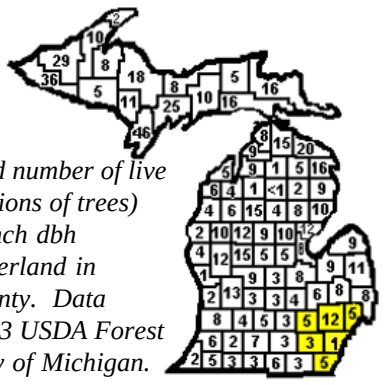
Attack pattern. In China, EAB most often attacks ash trees that are growing in the open or along the forest edge (Chinese Academy of Science 1986), but entire stands can be killed during outbreaks (Yu 1992). Attack densities are highest along the lower trunk in China. In Michigan and Ontario, EAB has infested and killed ash trees in both open settings and inside woodlots. Likewise, in Michigan and Ontario, EAB appears to initiate attack along the upper trunk and lower portions of the main branches, with succeeding years of attack being concentrated along the lower trunk. Tree death usually occurs in 3 years, but trees could die in 1 to 2 years when EAB populations are at outbreak levels. In Michigan and Ontario, EAB has infested apparently healthy ash trees from as small as 4-5 cm in diameter to mature forest trees that are over 1m in diameter.

EAB larval galleries

EAB-infested ash showing epicormic branches

Signs and Symptoms. For trees that die over a 3-year period, first-year EAB infestations are difficult to detect because eggs are laid deep inside bark cracks, larval feeding occurs under the bark, and oviposition usually begins along the upper trunk. Not until the summer following initial attack are the D-shaped exit holes first evident on the bark surface. However, in the absence of other signs or symptoms, exit holes can easily escape detection when in low numbers. Typically, little crown dieback occurs during the first year of attack. In the second year of attack, (1) less foliage develops and crowns appear thinner, (2) the sapwood forms callus tissue around the larval galleries from the first year, which can result in longitudinal bark splits 5-10 cm long, and (3) epicormic branches ("sprouts") develop along the main trunk and on some major branches. In the latter year's of infestation, if EAB larval populations remain high, foliage on the epicormic branches often turns brown prematurely in late summer. The characteristic frass-filled, S-shaped larval galleries can be seen only after removing the bark, although some galleries can be glimpsed through cracks in the bark. The galleries are most common along the upper trunk in the first year of attack, but can be found throughout the trunk in succeeding years. Typically, by the third year of attack, many branches have died, little foliage is present, bark splits are common, exit holes are present throughout the trunk, and epicormic branches are common, especially along the lower trunk and at groundline.

Resource at risk. There are about 60 species of ash worldwide, including 16 species in North America and 22 in China (Little 1979, Wei and Green 1996). Ash occurs naturally throughout much of eastern North America and along the west coast. Ash is an important timber species, landscape tree, and wildlife food. Based on the 1993 USDA Forest Service forest inventory data for Michigan, there are about 692 million ash trees growing on timberland



Map 1. Estimated number of live ash trees (in millions of trees) greater than 1-inch dbh growing on timberland in Michigan by county. Data based on the 1993 USDA Forest Service inventory of Michigan.

in Michigan, of which about 31 million occur in the six counties that are now infested with EAB (Map 1; http://fia.fs.fed.us/dbrs_setup.htm). These estimates do *not* include urban trees growing in yards and along streets. Ash is a common street tree, often representing 5-20% of all street trees in many midwestern and Canadian cities. The potential loss of ash as an urban street tree greatly reduces the selection of suitable species available to home owners and municipalities and will likely contribute to urban heating.

Map 2. Quarantined counties where Emerald Ash Borer has been detected in Michigan (1-6) and Ontario (A)

Quarantine, survey, and infestation history. On 16 July 2002, the Michigan Department of Agriculture (MDA) enacted an interior quarantine on five Michigan counties where EAB was initially found to occur: Livingston, Macomb, Oakland, Washtenaw, and Wayne (Map 2). Monroe County was added in September 2002. The aim of the quarantine is to stop human-assisted movement of ash products that could harbor EAB. The quarantine regulates movement of live ash trees, limbs, firewood, logs, and untreated ash lumber to areas outside of the six infested counties.

Leading up to the quarantine were a series of surveys conducted primarily by MDA staff . In general, a minimum of 25 sites in each of 13 counties were surveyed for EAB, which resulted at first in 5 positive counties and 8 negative counties (Map 2). Surveys are continuing in Michigan, including eventually all nurseries and sawmills that deal with ash. Aerial surveys for ash suspected to be infested with EAB began in southeastern Michigan in late August 2002. These surveys, along with aerial photography, photo interpretation, and ground-truthing are being coordinated by MDA, the Michigan Department of Natural Resources, and USDA Forest Service and APHIS (Animal and Plant Health Inspection Service).

Ground surveys have also occurred in Ontario. In August 2002, delimitation surveys were conducted by CFIA in the vicinity of the city of Windsor in the western portion of Essex County, Ontario (Map 2). Also, information packages were sent to all major municipalities in Ontario with a request to survey for EAB. At this time, EAB has not been found elsewhere in Canada and the current infestation appears limited to the greater Windsor area of Ontario.

Given the current extent of EAB's distribution in Michigan and Ontario, and the presence of both dead and dying trees, local entomologists now believe that EAB first arrived more than 5 years ago (McCullough and Roberts 2002). Early evidence of EAB infestation was likely masked by general ash decline throughout the East and the presence of a disease known as ash yellows, both of which cause crown dieback in ash trees. It is not known how EAB arrived in North America, but infested crating, dunnage, or pallets from Asia are suspected.

Actions taken and future needs. Many activities have taken place since the discovery of EAB. At the time of announcing the quarantine, MDA sponsored press releases and hosted meetings with several impacted industries. A 1-800 hotline was established by MDA to handle questions from the public. Several EAB websites have been constructed. The two most complete are hosted by MDA (www.michigan.gov/mda using the key words "ash borer"), and the USDA Forest Service (http://www.na.fs.fed.us/spfo/eab/index.html). USDA APHIS organized a New Pest Advisory Group to discuss the EAB situation, and so far two conference calls have taken place. USDA APHIS is now planning to organize an EAB Science Panel to address questions regarding EAB biology and management. In addition, in August and September, field trips were organized for state and federal plant health specialists to visit the EAB-infested sites in the US and Canada. An EAB management plan is now being formulated by various state and federal employees in Michigan.

In Canada, CFIA and OMNR are developing EAB websites; the CFIA website is at www.inspection.gc.ca. CFIA is now in the process of establishing consultative committees to provide science-based guidance on how best to deal with EAB. CFIA expects to impose a ministerial order on the infested area in the very near future that will prohibit the movement of suspect infested materials including ash trees, nursery stock, and firewood. Given that Essex County is one of the least forested counties in southern Canada (with less than 4% forest cover) quarantine action to preclude the movement of possibly infested materials is expected to be effective in slowing the spread of EAB. Few nurseries are located in Essex County and very little nursery stock traditionally moves from this area to either the US or other parts of Canada.

A few research projects have already been initiated by USDA Forest Service and Michigan State University entomologists. They include aspects of seasonal development, within-tree distribution, evaluation of systemic insecticides, survival in cut logs, and natural enemies. Many more scientists, both in the US and Canada, are planning a wide array of studies in both North America and Asia.

Other exotic *Agrilus* in the US. Besides *Agrilus planipennis*, at least six other *Agrilus* species are established in the United States. These are *A. cuprescens* (= *aurichalceus*) on *Rosa* and *Rubus; A. cyanescens* on *Alnus, Betula, Fagus, Quercus,* and others; *A. derasofasciatus* on *Pistacia* and *Vitis*, *A. hyperici* on St. Johnswort, *Hypericum perforatum; A. pilosovittatus* on *Wisteria,* and *A. sinuatus* on *Pyrus* and other Rosaceae (Campbell and McCaffrey 1991, Hespenheide 1968, Hoebeke 1980, Mattson et al. 1994, Solomon 1995).

Recent *Agrilus* interceptions in the US. USDA APHIS reported 245 interceptions of buprestids at US ports of entry during the period 1985-2000 (Haack 2002). Of these 245 interceptions, there were 38 *Agrilus* interceptions as well as 41 records

Map 3. Interceptions of Agrilus *in the U.S.: 1985-2000*

where the insects were not identified below the family level Buprestidae. Of the 38 *Agrilus* interceptions, 37 were identified to the genus level only and 1 to the species level: *A. sulcicollis*, which was intercepted in dunnage on a shipment from Belgium. The 38 *Agrilus* interceptions were made at US ports in 11 different states (Map 3). It is interesting to note that no *Agrilus* were intercepted in Michigan, although at the nearby port of Toledo, Ohio, *Agrilus* specimens were intercepted on at least 8 occasions. Of the 38 *Agrilus* interceptions, 28 were recovered from dunnage, 4 from crating, 4 from grape leaves, 1 from a cutting, and 1 was at large in the ship hold.

The 38 *Agrilus* interceptions originated from at least 11 countries, including Belgium (16 interceptions), Germany (5), Israel (3), France (2), India (2), Finland (1), Italy (1), Jordan (1), Korea (1), Mexico (1), Russia (1), Europe (1), and unknown (3). Of these countries, EAB is native to only Korea and Russia. Similarly, of the 41 buprestids that were not identified beyond the family level, 6 originated in China and 2 in Japan, which are two additional countries where EAB is native. Given that few *Agrilus* are intercepted and of those very few are identified beyond the genus level, the *Agrilus* interception data provide few clues as to the likely origin of the EAB population now established in North America.

Outlook. The North American ash resource is at risk from EAB. So far, all species of North American ash growing in the infested area have been successfully attacked. A Pest Risk Assessment recently completed by CFIA (Dobesberger 2002) concluded that EAB could potentially spread throughout the range of ash in North America and cause considerable economic and environmental damage. A vigorous research and management program along with harmonized quarantine actions are urgently needed to contain this new exotic tree pest.

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