Asian longhorned beetle: renewed threat to northeastern USA and implications worldwide

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Adult male Asian longhorned beetle; note ALB may have white or yellow spots (Photo: Michael T. Smith)

New England's famous fall colours are under threat following the discovery of a large infestation of Asian longhorned beetle (*Anoplophora glabripennis;* ALB) in Worcester, Massachusetts in July 2008, only 70 km from the Vermont border. This is the fifth time the pest has been found infesting trees in North America (four times in the USA and once in Canada) since 1996, but it is the closest they have been found to New England's woodlands, which are a magnet for tourists every fall.

The US Department of Agriculture – Animal and Plant Health Inspection Service (USDA-APHIS) began quarantine and eradication campaigns after the pest was first found in the USA in 1996. At the same time, research by the USDA-Agricultural Research Service (ARS; USDA's chief scientific research agency), US Forest Service, APHIS, Cornell University, State University of New York (SUNY) at Syracuse and others swung into action to find the best methods for detection and control.

If ALB establishes and spreads beyond the known infested areas, the potential impact could be devastating. An estimated 30–35% of the trees in urban areas in eastern USA are species commonly attacked by ALB. The beetle also puts at risk the maple hardwood lumber and sugar maple syrup industries, as well as tourism associated with the fall colours. Collectively, potential losses have been estimated in the tens to hundreds of billions of US dollars.

The latest discovery of the pest in Massachusetts was thanks to an alert citizen who reported finding an unusual beetle in a maple tree – and ultimately was due to the outreach campaign by APHIS, US Forest Service, University of Vermont, and numerous state agencies and civic organizations which have publicized the pest and its symptoms, and encouraged businesses and private citizens to be vigilant for and report signs of ALB.

Preventing entry is the optimum way of combating invasive pests. However, given the challenges of blocking pathways for entry, early detection of an invasive species such as ALB and a rapid response are vital if attempts at eradication are to have any chance of success.

This article first provides an overview of the tree species at risk of attack by ALB, the ALB life cycle, and how to recognize the signs and symptoms of attack. Second, it presents the time line of the ALB infestations outside its native range of China and the Republic of Korea and describes the quarantine and eradication approaches to safeguarding the natural resources at risk. Third, measures used or under development to combat ALB are outlined. Finally, threats from the related citrus longhorned beetle are noted.

Hardwoods and geographic areas at risk

In its native range the primary hosts of *A. glabripennis* are poplars (*Populus* spp.), maples (*Acer* spp.), elms (*Ulmus* spp.) and willows (*Salix* spp.), but it also attacks linden (*Tilia* spp.), Russian olive (*Elaeagnus angustifolia*), birch (*Betula* spp.), horsechestnut (*Aesculus* spp.), seabuckthorns (*Hippophae* spp.), London plane tree (*Platanus* spp.),and panicled golden-rain tree (*Koelreuteria paniculata*). Outside its Asian native range (i.e in USA, Canada and Europe) the host species thus far found attacked by *A. glabripennis* include maple, willow, elm, birch, horsechestnut, London plane tree, linden, mountain ash (*Sorbus* spp.), poplar, hornbeam (*Carpinus* spp.), beech (*Fagus* spp.) and plum (*Prunus* spp.).

The geographic range of ALB extends across climatic zones in China that correspond to North American regions from southern Mexico to southern Canada, including the Maritime Provinces and British Columbia. The climatic zones at risk in Europe were evaluated and published in 2002 (http://dx.doi.org/10.1016/S0261-2194(02)00016-9).

Life cycle and behaviour

The beetle completes most of its life cycle inside its host tree. Adult beetles emerge through exit holes from late May through October. However, peak abundance typically occurs from late June through late July, but may extend into early September in colder climates. Adult beetles feed on the outer layer of twigs and the petiole of leaves, and the primary leaf veins. Newly eclosed female beetles require 9–15 days, during which they feed, before becoming sexually mature. The adult females then chew small pits, referred to as oviposition pits, sites or scars, into the bark surface into which they inject a single egg per pit.

Upon hatching young larvae tunnel under the bark for about three weeks, slowly destroying the vascular system and disrupting sap flow of infested trees. Older larvae then tunnel into the heartwood where their feeding slowly destroys the structural integrity of infested trees. During the same year that eggs were laid, both young and older larvae may be found feeding within infested trees from June to November (until first frost). ALB

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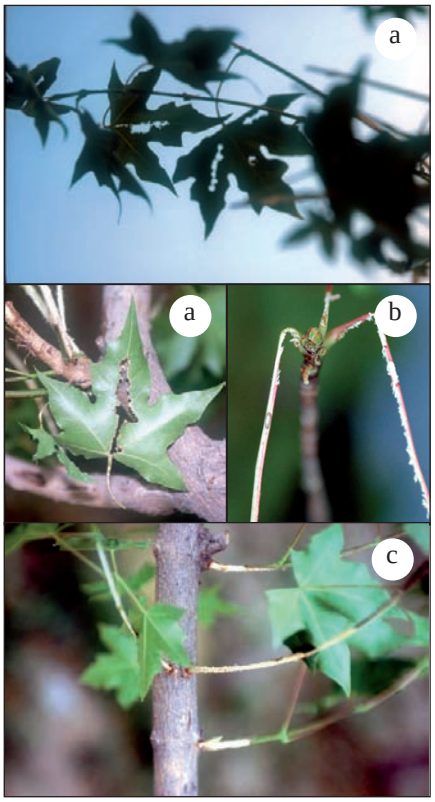


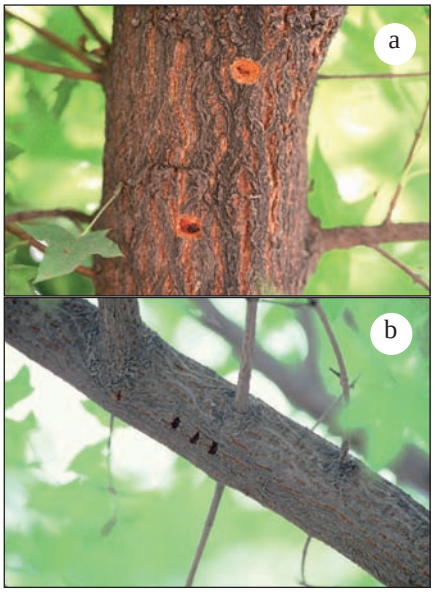
Adult feeding damage on (a) leaf; (b) petiole; (c) twig (Photos: Michael T. Smith)

typically overwinter as early to late instar larvae. Once temperatures begin to warm the following spring larvae resume feeding, with pupation subsequently occurring from late spring to early summer. Teneral adults remain for up to seven days before chewing an exit hole and emerging.

Development from egg to adult requires approximately 12–24 months. Repeated attack of the same tree over several years leads to dieback of the crown, structural deterioration and, eventually, death of the tree.

Since the larvae live inside trees most of the year, they can easily and unknowingly be moved in firewood, trimmings cut from live trees (trunk and branches) or the main trunk of fallen and felled trees. ALB also spreads by natural means; annual spread of adult beetle populations averages approximately 900 metres, while individual beetles have been recorded flying distances of over 1300 metres in a single day. However, both the rate of population spread and individual beetle flight depend largely on local population density and availability of suitable trees to attack. For example, officials reported that the ALB infestation found on Prall's Island, New York City, was initiated by beetles that had flown more than 300 metres over open water from the nearby ALB infestation in Linden, New Jersey.

Oviposition pits: (a) newly formed pit on trunk of maple – lower pit shows dark frass plug commonly deposited by female beetles at the centre of the pit after laying the egg and as the ovipositor is pulled out – note circular shape; (b) weathered pit on branch of maple – note slit-like or oblong shape (Photos: Michael T. Smith)



ALB infestations may be recognized in several ways:

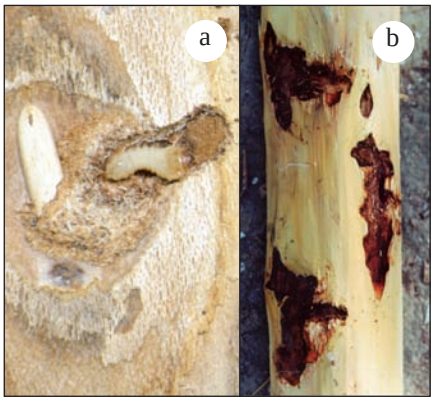
- Sighting the adult beetles themselves during the summer and until frost, particularly from July through September: large shiny black beetles with white or yellow spots, measuring 2.5–3.5 cm in length not including the black-and-white banded antennae; these, which give the insect its common name, are as long as the body in females and almost twice the body length in males.
- Infested trees pockmarked with female oviposition pits , typically oval pits in the bark surface, and perfectly round exit holes (about 1–1.5 cm in diameter) made by emerging adult beetles. These signs of attack are typically found on the trunk and main branches, including branches as small as ca. 7.5 cm. It is important to note that beetles typically initiate attack the first year in the mid to upper canopy, thereby making it difficult to see these signs of attack.
- During feeding, adult beetles remove the outer surface layer of young twigs and of the stem of leaves (petiole), and clip out the main veins of leaves. It is worth noting that the leaves in which the main veins have been removed can most easily be spotted by looking up into the canopy when there is ample back lighting.
- Frass (wood shavings and sawdust) produced by larval feeding and tunnelling. Frass can be found on the bark surface (i.e. crevasses and branch crotches) and on the ground underneath the tree, particularly from May though September.
- Tree sap may be found oozing from the oviposition pits or from small holes resulting from larval tunnelling to the bark surface. It is also possible that sap may not be apparent, but that the bark may appear to have dark moist areas.
- Crown dieback and what appears to be early senescence (leaves showing unseasonal yellowing, or drooping in absence of dry weather) may occur.
- Dead branches.

Bark removed to expose ALB egg laid on surface of sapwood; egg is about the size of a grain of rice (Photo: Michael T. Smith)

Timeline of ALB infestations outside the native range

ALB was first recorded in the USA in New York City in August 1996. The source of the infestation was subsequently identified as solid wood packing material from China. Since then, US authorities have put in place stringent regulations and control measures at national, state and local level to prevent the spread of ALB, to eradicate existing infestations, and to prevent future incursions of this and other timber-borne pests. However, additional infested trees have been found in New York City and/or on Long Island in most years since 1996, including in Manhattan's Central Park in 2002.

- In July 1998, thanks to APHIS' national ALB pest alert campaign (see below) an infestation was discovered by a citizen in Chicago, Illinois. This was concluded to be the result of a separate introduction to the country.



(a) Newly hatched larva beginning to feed in cambium; (b) larval feeding damage in cambium (Photos: Michael T. Smith)

- In October 2002 ALB was found killing trees in Jersey City, New Jersey.
- In August 2004 ALB was found killing trees in Middlesex and Union County, New Jersey, the first time since 2002 that ALB had been found outside quarantined areas.
- In June 2005 a warehouse in Sacramento, California was found to contain wooden pallets infested with ALB, and some of the live beetles escaped from the warehouse. Subsequently, a three year survey programme led by the California Department of Food and Agriculture (CDFA) using highly attractive sentinel trees (see below under research) turned up no additional beetles and no infested trees.
- In March 2007 infested trees were discovered on Prall's Island and Staten Island, New York City.
- In April 2008, the New Jersey Department of Agriculture held a press event to declare ALB eradicated in Jersey City, New Jersey. A total of 113 infested trees and 348 high-risk host trees were removed during the eradication programme.
- In April 2008 APHIS and the City of Chicago announced the official eradication of ALB from Illinois after an eradication programme spanning almost 10 years, resulting in the removal of 1551 infested and 220 high-risk host trees. For an official declaration of ALB eradication in the USA, APHIS eradication guidelines have set the standard as five years of finding no signs of an infestation. Therefore, this announcement came after years of extensive surveys for infested trees, during which no signs of attack had been found since 2003. However, an adult beetle was discovered by a Chicago citizen in August 2008 and subsequent surveys have thus far turned up no additional beetles or infested trees.
- Until the July 2008 report from Massachusetts, eradication efforts and quarantine measures had successfully confined known ALB infestations to Chicago, New York, and New Jersey. Unfortunately, as a result of continued discovery of infested trees the eradication campaigns in New Jersey and New York are ongoing. As of 8 November 2008, a total of 616 infested trees and 20,904 high-risk host trees have been removed in the Middlesex and Union County infestations in New Jersey, and a total of 6256 infested and 12,140 high-risk trees have been removed in the New York City infestation.
- In July 2008 ALB was found in Worcester, Massachusetts, with additional infested trees subsequent discovered in nearby West Boylston. As of 8 November 2008, a total of 3801 infested trees have been confirmed, but this number is continuing to increase with each update report.

ALB has also reached Canada, with the first sightings made in Toronto and Vaughan, Ontario, in September 2003. The Canadian Food Inspection Agency (CFIA), Natural Resources Canada – Canadian Forest Service (CFS), City of Toronto and USDA-ARS instituted an aggressive eradication campaign based upon a coordinated research–eradication programme that provides real-time feedback for quarantine, survey and control. ALB has been also intercepted in Europe, including in the UK (1998); Austria (Braunau am Inn – 2001); France (Gien – 2003 and Sainte-Anne-sur-Brivet – 2004); and Germany (Neukirchen am Inn, Bavaria – 2004), and risks of ALB in Europe have been assessed (see references). Trees infested with ALB have been cut, chipped and the chips burned in Austria (20 trees in 2001) (http://bfw.ac.at/400/1517.html), France and Germany.

Frass on (a) bark and crotch; (b) ground (Photos: Michael T. Smith)

Sap oozing from oviposition pits and boring holes on maple (Photo: Canadian Forest Service)

Cargo infested with ALB has been discovered and eliminated in warehouses in at least 17 states across the USA, as well as in Canada, Italy, Austria, Germany, France and Poland.

Quarantine key to keep alien pests out

The pathway by which ALB reached the USA underlines the importance of quarantine as a first line of defence for countries against invasion by exotic pests. Wood packing materials are a known hazard, and ALB has been intercepted at ports and found in warehouses throughout the USA. The threat from invasive pests arriving with trade goods has increased with increasing international trade; e.g. the volume of Chinese imports to the USA increased from US$5 billion in 1985 to $72.8 billion in 1997, and the quantity of wood packaging increased with it. Wood packing materials can harbour other insect pests including spruce bark beetle (*Ips typographus*) and Mediterranean pine engraver beetle (*Orthotomicus erosus*).

Keeping out such pests has relied on the exporting countries debarking all wood and certifying that wood products are free of bark beetles, and on the import-

Older larva boring in wood, showing frass (Photo: M. Bohne, US Forest Service)

ing countries inspecting all wood at the ports of entry.

- When the pathway of entry of ALB into the USA was confirmed, APHIS enacted tough measures to exclude new introductions. In December 1998, APHIS put in place an interim rule requiring all solid wood packing materials entering the USA from China to be heat treated (kiln-dried), fumigated, or treated with preservatives. Previously, regulations only required most such imported materials to be totally free from bark and apparently free from live plant pests.
- Since September 2005, all wooden packaging materials imported into the USA have to be heat treated or fumigated with methyl bromide and marked with the International Plant Protection Convention (IPPC) logo and appropriate country code designating the location of treatment (see below).

APHIS has further direct measures in an attempt to minimize the risk of additional ALB incursions.

- Plant Protection and Quarantine (PPQ) officers conduct visual inspections of high-risk cargoes and in high-risk areas, such as cargo distribution warehouses.
- Pest alerts have been issued to ports-of-entry personnel.
- Outreach has been undertaken with US importers. For high-risk importers (warehouses that have previously received infested cargoes), secondary inspections and surveys of the environs are carried out.

US heat treatment and fumigation programme

As wood packaging material made of unprocessed raw wood is a recognized pathway for the introduction and spread of pests through international trade, the IPPC adopted the International Standards for Phytosanitary Measures Guidelines for Regulating Wood Packaging Material in International Trade (ISPM No. 15) to limit the entry and spread of such pests. The IPPC is an international treaty to secure action to prevent the spread and introduction of pests of plants and plant products, and to promote appropriate measures for their control.

The presence of ALB in the USA has implications for the timber industry; 40% of harvested hardwood in North America is used for solid wood packaging, and this is threatened if it cannot be guaranteed free from ALB. USDA and the wood packaging sector of the US timber industry have therefore cooperated in devising and implementing the Export Wood Packaging Material (WPM) Fumigation Program to guarantee compliance with the import requirements of trading countries. The programme ensures certified treatment and marking of wood packaging material for international trade, while maintaining traceability of the packaging material.

APHIS campaigns for ALB eradication

The eradication programme being implemented by APHIS and its cooperators hinges on several elements: rapidly delimiting new infestations, imposing quarantine, and implementing control measures within the quarantine zone.

When ALB is reported, intensive visual inspections are conducted throughout the neighbourhood to delimit the infestation. Infested trees and those species considered to be at high-risk of attack within a radius of 400 metres from the edge of the known infestation (the distance varies with locality) are felled and chipped. High-risk trees within a radius of a second 400 metres are also either removed and chipped or injected with a systemic insecticide. APHIS and US Forest Service scientists and their collaborators have developed a method of using the systemic insecticide, imidacloprid, which has been shown to kill adult beetles while feeding on twigs and leaves, thereby helping to contain the spread of the beetle. The infested area is re-surveyed at least once a year for the next five years after beetles are found.

Federal quarantine regulations introduced in March 1997, which are implemented when an infestation is found, place restrictions on movement of firewood (all hardwood species), cuttings and nursery stock of ALB's host trees, including maple, horsechestnut, birch, sycamore, poplar, willow, mountain ash and elm, and anything an inspector may deem to present a risk of spreading ALB.

Collectively, from 1997 to 2006, APHIS and the states of New York, Illinois and New Jersey and local governments have spent more than $800 million on ALB eradication measures.

Research and development of early detection and rapid response for ALB

Research has been conducted nationally and internationally, including at federal, state and local government levels, and at numerous universities. Much of the research has been conducted collaboratively with colleagues outside the USA, including the Chinese Academy of Forestry and Chinese Academy of Agricultural Sciences, CFS and CFIA in Canada, and the ARS European Biological Control Lab (France) and Fondazione Minoprio (Italy).

Research Entomologists with the ARS Beneficial Insects Introduction Research Unit (BIIR) in Newark, Delaware, and their colleagues have made a number of discoveries since they began researching the pest, including:

- *Predicting the rate of spread.* Models of population spread were developed by ARS BIIR scientists from empirical data collected in natural infestations. Studies resulted in guidelines used in the eradication programmes described above for establishing boundaries for survey efforts and implementing con-

Exit holes on trunk of maple (Photo: Michael T. Smith)

trol strategies to contain and limit the spread of ALB.

- *Predicting seasonal occurrence of adult ALB.* A degree-day model for predicting when adult ALB will be present in the landscape was developed by ARS BIIR scientists from empirical data collected in natural infestations. Linking the model with historical temperature data from around the world resulted in an online mapping method that has enabled the effective prediction of when (timing) survey, detection and control methods that target adult beetle should be implemented.
- *Detection of infested trees.* Visual inspection, tree-by-tree, is the only method thus far used for detection of infested trees. This method generally includes two approaches, inspection by ground survey crews using binoculars and by trees climbers, which are reported to be approximately 30% and 70% effective, respectively. Thus, development of new methods continues to be of paramount importance for early detection and post-treatment evaluation in both eradication and management of ALB. To date, the *Training guide for detecting signs and symptoms of the Asian longhorned beetle injury* was co-published in 2007 by City of Toronto, CFS, CFIA, and ARS (available from CFS – see below). Additional technologies are being developed and evaluated by ARS BIIR scientists and their colleagues.
- *Detection of adult ALB: Sentinel trees*. Adult ALB show a preference for attacking maple species. However, ARS BIIR scientists showed that adult beetles are strongly attracted to the Shantung maple (*Acer mono*), a species native to eastern China and the Republic of Korea. Research results showed that potted Shantung maples (3 m tall) can be used as 'sentinel' trees to attract the beetles, where their presence can be confirmed either directly by sighting the adult beetle, or through telltale signs of its feeding. This method has thus far been utilized by CDFA in California, and is of much interest in the high-risk northeastern states in the USA and in Europe. It has also caught the attention of several European countries, including Italy, where the related citrus longhorned beetle (*A. chinensis*) is causing considerable damage.
- *Detection of adult ALB: Artificial lure*. ARS BIIR scientists and colleagues at Simon Fraser University have isolated and identified compounds produced by the Shantung maple that are being developed into a semiochemical-based trapping system that can lure the beetles over long distances. Results from lab olfactometer and field trapping studies have been encouraging and a commercial lure will hopefully be forthcoming over the next few years.
- *Encapsulated pyrethroid lambda-cyhalothrin (Demand CS – Scimitar CS).* ARS BIIR scientists showed that this insecticide gives rapid and almost 100% knock down of adult beetles, meaning it could be used as a monitoring tool; beetles attracted to potted Shantung maples that have been spot treated with the insecticide would be quickly killed and fall into a collection funnel wrapped around the base of the trees; or beetles walking across 15-cm (six-inch) wide bands treated with the insecticide that have been wrapped around branches of landscape trees would be quickly killed and fall to the ground and be collected. The same encapsulated insecticide, according to APHIS, may also have niche uses in eradication and management of ALB. This insecticide has been successfully used for population suppression in China, where ca. 99% control was achieved in large urban landscape maple trees.
- *Biological control*. ARS BIIR scientists and colleagues have employed three approaches for development of biocontrol for ALB. First, in surveys for natural enemies of ALB in its countries of origin, they have found two wasp species of particular interest that may specifically parasitize ALB larvae within infested trees. These species require additional field studies before they can be considered for importation to and release in the USA, including studies to confirm their host specificity (host range), their host searching ability and their rates of parasitism (efficacy). Collectively, the objective of these efforts is to identify host specific parasitoids that are highly effective at searching for, finding and parasitizing ALB, particularly at low ALB population levels. Second, in collaboration with colleagues in the Department of Entomology at University of Vermont and University of Illinois, they have been surveying for natural enemies, native species already present in the USA that parasitize wood borers also native to the USA. Thus far, these surveys and subsequent studies have identified at least four native species that will parasitize and complete development on ALB larvae in quarantine. Finally, in collaborative studies with the US Forest Service, surveys will begin in early 2009 for native natural enemies that are parasitizing ALB within the ALB infestation in Worcester, Massachusetts. Collectively, the objective of these studies is to identify native natural enemies that can be used in biological control that could potentially play a key role in limiting the spread of ALB.

Scientists in the ARS Systematics Entomological Lab and the Department of Entomology, Cornell University investigated the taxonomy of the *Anoplophora* species throughout the world. Their extraordinary efforts resulted in an excellent text for identifying this very important group of wood boring species.

Scientists in the Department of Entomology at Cornell University and their colleagues in China and with ARS BIIR have been developing a fungus that kills adult beetles. The fungus, grown on woven fabric, is cut into bands and wrapped around the trunk or branches of trees. When adult beetles walk across the bands, fungal spores stick to their bodies and they are ultimately infected and killed. Results from field studies have shown the fungal spores are viable and effective for approximately 60 days. Additional research may be needed, including to determine the number of bands required per tree and/or per unit area.

Scientists in the CFS, CFIA, Toronto Department of Parks, Forestry and Recreation, the Department of Ecology and Evolutionary Biology and Department of Entomology at Cornell University, and at ARS BIIR have been conducting detailed studies of the ALB infestation in Toronto. This collaborative effort will ultimately provide the first in-depth analysis of the invasion process of ALB into countries outside its native range, including analysis of host preference and host suitability, and analysis of the spatiotemporal pattern of attack of individual trees and landscapes. Once completed, these studies should

prove valuable in predicting landscapes at risk of establishment by an invasive population of ALB, and the direction and rate of spread once it becomes established. The value of these predictive tools includes their consideration for planning green spaces to minimize the risk of establishment, and for early detection and rapid response (e.g. survey and control) to limit spread of existing and new introductions.

Scientists in the Department of Entomology at SUNY and Pennsylvania State University and the ARS Invasive Insect Biocontrol and Behaviour Lab in Beltsville, Maryland have identified the male and female sex pheromones of ALB. Although ALB attraction to traps baited with different sex pheromone lures has produced mixed results, there is some evidence of attraction within infested trees. Scientists are continuing studies to improve the lures and find ways of incorporating the lure into detection programmes for ALB.

Scientists at the ARS Subtropical Insects Research Unit in Fort Pierce, Florida, in collaboration with ARS BIIR scientists, have been using molecular methods to develop genetic markers to screen frass to identify whether a host is ALB; and to investigate evidence of a genetic response to lambda-cyhalothrin to see how resistance to the pyrethroid might work and in turn help avoid the problem of insecticide resistance.

Citrus longhorned beetle

The citrus longhorned beetle (*A. chinensis*; CLB) is a very close relative of ALB. As its name implies, it is a severe pest of citrus. However, it also attacks most of the same tree species attacked by ALB. Unlike ALB, however, CLB typically attacks its host in the lower 0.5 metres of the trunk, around the root collar and on exposed roots. Therefore, CLB quickly girdles and kills its hosts. While CLB is also native to Asia (e.g. China, Japan), it has been intercepted twice in the USA (once on bonsai) and in a number of locations in Europe. More alarming are the new CLB infestations found in the Netherlands in 2007 and in Germany in 2008. Furthermore, the first CLB infestation found in Europe, specifically in northern Italy, has continued to expanded in the past few years. Therefore, in 2009 colloborative efforts between the ARS European Biological Control Lab (France), Fondazione Minoprio (Italy), ARS BIIR and others will be initiated with the goal of developing practical methods for limiting the spread of CLB, and eradicating or managing this invasive insect pest species.

Adult female CLB laying egg and numerous, typically obscure, oviposition pits (Photo: Matteo Maspero)

CLB larval feeding damage to the lower trunk and below ground (Photos: EMB Citrus)

Fact sheets and references

USDA-ARS information on research, impact and publications:
www.ars.usda.gov/pandp/people/people.htm?personid=5254
www.ars.usda.gov/is/AR/archive/may06/beetle0506.htm

USDA Forest Service ALB homepage:
www.na.fs.fed.us/fhp/alb/index.shtm

USDA-APHIS information on government regulations and actions to control ALB:
www.aphis.usda.gov/plant_health/plant_pest_info/asian_lhb/index.shtml

USDA National Invasive Species Information Center:
www.invasivespeciesinfo.gov/animals/asianbeetle.shtml

Detecting signs and symptoms of Asian longhorned beetle injury: Training guide. Natural Resources Canada–CFS, Great Lakes Forestry Centre, Sault St. Marie, Ontario; excellent resource for the identification and biology of ALB:
http://warehouse.pfc.forestry.ca/glfc/26860.pdf

Risks of Asian Longhorn Beetle in Europe: MacLeod, A., Evans, H. F., Baker and R.H.A. (2002) An analysis of pest risk from an Asian longhorn beetle (*Anoplophora glabripennis*) to hardwood trees in the European Community. *Crop Protection* 21(8), 635–645.

European infestations of citrus longhorned beetle:
www.eppo.org/QUARANTINE/anoplophora_chinensis/chinensis_IT_2007.htm
www.fondazioneminoprio.it/
University of Vermont Entomology Research Laboratory; information on ALB:
www.uvm.edu/albeetle/index.html