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Distribution, Biology, Damage and Control Methods of *Anoplophora glabripennis* (Motschulsky), 1853 (Cerambycidae: Lamiinae)

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Abstract: The Asian longhorned beetle (ALB), *Anoplophora glabripennis* (Motschulsky), is a polyphagous sapwood borer cerambycid beetle found in many hardwood species and capable of killing healthy trees. ALB is a native Asian pest but as a result of international trade, it is introduced to new places. According to the observations, it mainly occurs in China, Japan, Korea; while occurring less commonly in Malaysia, Myanmar, Taiwan, Vietnam, Indonesia and Philippines, and they occur as invasive species in North America, Canada, Denmark, Holland, France, Italy and Romania. The main purpose of eradication is detection, identification and improving the success of control efforts. The studies about ALB that have been conducted so far aimed at identifying the countries in which ALB was detected, its epidemic mechanism, regions where ALB was detected, control methods, how it transfers and, which tree species are affected, and international efforts to prevent new introductions. These studies have been reviewed to highlight the control strategies against ALB that spreads between countries by solid wood packaging, decorating plants and trade of seedlings.

Key Words: Invasive species, review, insect infestation, control methods.

1. Introduction

The Asian longhorned beetle is both primary and secondary pest and, native to the far eastern regions of Asia. Researchers believe that this beetle was introduced into the U.S. in early 1990's through solid wood packaging or crating materials on cargo ship from China. By 2012, this beetle had also infested Canada (Ontario) and Europe (Austria, Czech Republic, France, Germany, Italy, Netherlands and United Kingdom). All models demonstrate that it is found in many locations worldwide. At present, control methods are applied against *A. glabripennis* in areas where it has been introduced, as a result of which reduction in its population is observed. After an infestation is discovered, extensive surveys are conducted and, if breeding populations are detected, at the very least the infested trees are removed and destroyed. Quarantines and eradication programs were launched to protect high-risk tree genera such as *Platanus*, *Acer*, *Aesculus*, *Populus*, *Corylus*, *Salix*, *Citrus* and *Ulmus*. Close attention is paid to imported solid wood packaging materials and living plants to prevent new introductions. Unlike many cerambycid species, *A. glabripennis* can attack healthy trees as well as trees under stress. Several generations can develop within an individual tree, leading eventually to its death (Anonymous, 2015b). We reviewed the taxonomy, diagnostics, distribution, damage, basic biology, host plants, epidemic mechanism, current control methods, bionomics, invasion history and management of *Anoplophora glabripennis,* including the information available in the extensive worldwide literature.

2. Morphology and Biology of Alb

Typically cerambycid in shape, adults are 25 mm (male) to 35 mm (female) long. Antenna is 2.5 times longer than body length in males; 1.3 times longer than body length in females. The beetle is shiny black with about 20 irregular, white spots on the elytra. The antenna has 11 segments and segments are approximately 5 millimetres, each with a whitish blue base. Egg deposition begins a week after copulation. The eggs, about 32 per female (Wong and Mong, 1986), are laid one by one under the bark, in oviposition slits chewed out by the female. Slits are generally cut on the eastern side of the trunk or of branches greater than 5 cm in diameter (Li and Wu, 1993). Eggs hatch after about two weeks. ALB eggs are off-white and about 5.7 mm long, the tip of the eggs is slightly concave (Peng and Liu, 1992). Just before hatching, eggs turn yellowish-brown. The larva is a legless grub up to 50 mm long when fully grown. It is creamy white in colour, with a chitinized brown mark on the prothorax. The larva feeds in the cambial layer of bark in the branches and trunk and later enters the woody tissues. Optimal temperature for pupas ranges from 10°C to 12°C. Pupas are off-white. Pupation takes place in chambers in the heartwood, accompanied by presence of characteristic wood “shavings” that are packed into the chamber. Adults emerge from large circular holes (1cm dia), which are a visible sign of infestation, above the sites where the eggs were laid. Larva digs the pupation chambers inside the tree, which can be filled with frass (Anonymous, 2015a). In males; elytra covers abdomen, elytra is narrow, antenna is twice as long as the body, and they are generally smaller than females. In females; abdomen partially covers elytra, elytra is rounded, antenna is slightly longer than body (Fig.1). Adults emerge over an extended period from spring to fall, but especially from late June to early July. Adults remain on or near their emergence tree and engage in maturation by feeding on leaves, petioles, and tender bark (Anonymous, 2015). Larva is pale-yellow, worm-like, elongated, and cylindrical with a varied texture on the underside; the eighth segment of the abdomen has a protruding structure. The pupa is 25-30 mm long and 8 mm wide and begins to resemble the adult beetles. Asian longhorned beetle can be distinguished from the related species such as citrus longhorned beetle *Anoplophora chinensis* (CLB) by the markings on the wing covers and the pattern of the antenna (UVM, 2008).

Figure 1. Dorsal view of the Asian longhorned beetle

Classification: The current systematic position of ALB is shown below. The current systematic categories are used in this particular study.

Kingdom: Animalia
Phylum: Arthropoda
Class: Insecta (Hexapoda)
Order: Coleoptera
Family: Cerambycidae
Subfamily: Lamiinae
Tribe: Monochamini
Genus: *Anoplophora*
Species: *glabripennis*
Scientific Name: *Anoplophora glabripennis* (Motschulsky, 1853)
Common Name: Asian longhorned beetle
(Anonymous, 2016).

3. Catching Methods

To identify *Anoplophora glabripennis* damage and infestation; a binocular will be very helpful while checking possible signs of ALB. We should slowly circle the tree and search for the emergence holes on the trunk and the branches. Furthermore, oviposition sites, sap and frass can be recognized. Except conifers and oaks; all trees including all young trees and shrubs should be checked. It is also possible to use acoustic evaluation techniques to detect the damage and signs of ALB exit holes, which is a cost effective option. It's almost impossible to detect ALB because its larvae feed inside the tree. The use of acoustic methods reduces costs and hazards of the inspection. Larval sounds are studied to identify their difference in the spectral and temporal features to distinguish infested trees from others (Mankin, et al., 2008). Identification of certain pheromones is useful to detect male ALBs which are chemically identified in recent studies. Male pheromones, which are two dialkyl ether volatiles, are secreted in a ratio of 1:1. Female pheromones, which are not chemically identified in the studies yet, are only for mating. Nevertheless, the studies conducted in China show that contact pheromones produced by females are involved in sex recognition (Jiafu et al., 2009). Adults are generally active between May and October and live for about a month. Since the Asian Longhorned Beetle has the ability to fly, their rapid growth and expansion in the short term could not be controlled. It is reported that ALBs have the potential to fly 2000 m in a season. Although it is reported that adults can fly 30-225 m weekly in a single flight on a clear day (Wang, pers. comm., 1996), flight of short-distance is typical of many cerambycids. The most active period for adult activity is late June to early July (Li and Wu, 1993). It takes 1-2 years for Asian Longhorned Beetle to develop from egg to adult in China depending upon the climate and feeding conditions. It mainly overwinters as larva but it has been recorded in some cases that it also overwinters as an egg or pupa (Li and Wu, 1993; Poland et al., 2006). Lifespan for adult males is approximately 3-50 days and for females it is 14-66 days, according to the studies conducted in China. Moreover, the studies performed in the USA show that the lifespan is 80-100 days for both genders at 25°C environmental conditions.

4. Control Methods

Different organisms in nature have certain kinds of relationships. The most common relationship is about nutrition. These organisms are considered as harmful or beneficial always depending on their relationships with mankind. The factors influencing the decision about control methods against diseases and pests are variable. These methods can be applied according to the following factors: Type and biology of the pest, type and phenology of the plant, predators, climate factors, economical damage threshold and cost-potential benefit ratio. Control methods for pests and epidemic can be listed as cultural, mechanical, physical, legal, biotechnical, biological, chemical, and integrated control methods. Right after the identification stage, first we should define eradication. Some of the pests and disease factors can spend a part of their lives on a plant, which has served as a host before their most preferred host plants. Eradication refers to the termination of these housing plants and other housing weeds with the cultivated plants when necessary. From the abovementioned control methods; physical, chemical, biological and integrated methods are developed for ALB.

4.1. Physical control methods

Only certified tree care specialists can remove the infested trees, according to the ALB quarantines. This guarantees that the strict guidelines for destroying the trees are followed (UVM, 2008). This is currently the only proven method of control. In addition to catching adults, blocking frass holes, killing eggs and young larva are some other physical control methods. These methods are not cost effective and not convenient.

4.2. Chemical control methods

Direct injection of insecticides or delivery by soil has minimal non-target impacts, while low mammalian toxicity is preferred in eradication programs (Poland et al., 2006). Recent studies regarding the chemical methods (ARS BIIR scientists) show that encapsulated pyrethroid lambda-cyhalothrin (Demand CS - Scimitar CS) insecticide is 100% successful on the adults in the USA. But this successful result of chemical treatment is not enough to solve the infestation. It should be applied as part of the eradication program. Some examples are as follows: spraying the insecticide in the canopies of host trees to kill adults; insertion of sticks containing insecticide into the larval frass holes to kill larva. Nevertheless, chemical control methods are avoided for their harmful effects on the environment. There are also efforts to develop environmentally safe and biological control methods.

4.3. Biological control methods

In conjunction with the eradication programs biological control studies were initiated in order to find, identify, and evaluate parasitoids and other bio-control agents that might successfully control ALB. Entomopathogenic fungi, nematodes, insect parasitoids and predators are on the focus for the biological control of Asian Longhorned Beetle because of their potential to create epidemics (Zhang et al., 1999a; Dubois et al., 2008). Biological control methods require further research development and investment. Fungal bands can spread to the other parts of the environment by the adult beetles; after which all adults exposed to contaminated environments were killed by fungal infection. Adult beetles become contaminated with spores when walking over the fibre bands (Shanley and Hajek, 2008). The nematodes are used in modern biological control to fight a wide variety of pests like cerambycids. Strains of nematodes were found to be the most effective ones against ALB in tests with insects on filter paper, in artificial diet, and in actual galleries. Concentration of 5000 nematodes of *Steinernema carpocapsae* (Agriotas and Beijing strains) per beetle was affective in killing larva and pupa of Asian Longhorned Beetle (Wang et al., 1996). In a field study, where similar protocols were applied, 7500 nematodes per beetle were necessary to reduce the A. glabripennis population by approximately 85% (Liu et al., 1998) (Fig. 2-3). In laboratory bioassays, *Dastarcus helophoroides* Fairmaire (Coleoptera: Bothrideridae) is recognized as a major natural enemy that attacks Asian Longhorned Beetle pupa and larva (Wang et al., 1999). According to some studies conducted in China, when entamopathogenic nematodes were introduced through the exiting holes, the number of new Asian Longhorned Beetle emergence holes dropped significantly.

Figure 2. *Steinernema carpocapsae* nematode
(Photo Courtesy of the Society for Invertebrate Pathology)

Figure 3. ALB larva killed by nematodes
(Photo by L. Solter, University of Illinois

Studies focus on two nematodes (*H. marelatus* and *S. carpocapsae*), which had the highest mortality, survival and reproduction rates. The usage of fungal entamopathogens is the second major approach to bio-control of Asian Longhorned Beetle in the USA. Entomopathogenic fungi are grown on non-woven fabric and cut into bands which are wrapped around the branches or trunk of trees. During the development period when they are reluctant to fly, adult beetles walk across the band (Shanley and Hajek, 2008). Fungal spores stick to their bodies, which then kills them. Coleopteran and hymenopteran parasitoids and predatory woodpeckers have been investigated as bio-control agents. (Jiafu et al., 2009). Woodpeckers (*Dendrocopos major* and *Picus canus*) are the major predators of ALB larva in China, as shown by the studies conducted on the methods to encourage nesting. No detailed report on insect predators of ALB or CLB (Robert et al., 2010) was found.

4.4. Integrated control methods (biological-chemical-physical-mechanical)

Another example for controlling long-horned beetles used in Rome can be the other lodestar method for ALB control. A new non-destructive method for detecting the Asian Longhorned Beetle was developed in 2009 the Bundesforschungszentrum für Wald (BFW) (Department of Forest Protection of the Federal Research and Training Centre for Forests, Natural Hazards and Landscape) (BFW, 2009) in Vienna. These ALB/CLB detection dogs are able to find all stages of development in standing or imported plants and wood packaging materials in different environments (Fig. 4-5). Currently, these four Austrian detection dogs - the first of its kind worldwide – are used all over Europe. Additional infested trees, which were not recognized by monitoring before, are now detected by the dogs.

Figure 4. Jolly investigated imported plants in a nursery standing separately in a hall area

Figure 5. Inspection of the opened crates from the surface by Andor

ALB or CLB can be detected by the specially trained dogs in imported plants, wood packaging material, and standing trees in infestation areas. Natural or urban environment, ports, airports, packing centres, stone importers, nurseries or other companies at destination can be monitoring fields (Hoyer–Tomiczek and Sauseng, 2013). In an historical area of Rome, as invasive longhorned beetle infestation was detected, control methods were used immediately (Fig. 6-7-8-9), and the condition reported as: “The outbreak of *Anoplophora chinensis* - citrus longhorned beetle – in Rome municipality regards an area of considerable historical and archaeological value. Thus, the peculiar features of this area led to take into account phytosanitary measures. These measures, alternative to mechanical removal or destruction of infested trees and stumps, were found in order to ensure both effective phytosanitary actions on infested plants and preserve the archaeological heritage of this area”(Roselli et al., 2013).

Figure 6. Excavation for undergrounding the wire mesh used to cover the root system of *Platanus* spp.

Figure 7. Caught adult by wire mesh

Figure 8-9. Wire mesh covering trunks and soil (using mosquito polyethylene net)

The figures above show that some of the infested stumps are neutralized by using wire mesh. Because they are not mechanically removable due to their location on a sloping ground, the inspectors of the Plant Protection Service carry out weekly inspections on these plants throughout the entire insect flight period to monitor the efficiency and efficacy of these alternative measures. In several cases, adult insects trapped under the metal mesh used to neutralize the infested stumps were detected. These alternative measures for mechanical removal are equally effective (Roselli et al., 2013).

5. Discussion and Conclusion

In international trade, *A. glabripennis* is most likely to move as eggs, larva or pupa in packing materials or dunnage made of the wood of host species (Malumphy, pers. comm., 1999). *A. glabripennis* is usually introduced into more urban areas and not in native forests, which makes eradication more feasible; furthermore, since *A. glabripennis* often do not fly very far, this increases the possibility of eradication, although there are challenges in detecting these beetles and this is definitely a concern in eradication efforts. (Jiafu et al., 2009). Today, infested trees are recognized and destroyed immediately and trading materials are carefully monitored. There is also an important hidden issue, which is the fact that ALB weakens the trees structurally and this is dangerous for pedestrians and vehicles as the limbs of the trees may fall (Smith et al., 2002). Public awareness should be raised in the countries of the region; otherwise it will be easier for ALB to spread in these countries because the invasive insects can also travel on luggage, shoes, and clothing. All regions that have an Asian Longhorned Beetle infestation should have ‘’emergency call line’’ to report suspected infestations, and prevent the dispersion. The awareness of people is important to look for and prevent further infestations, and the removal process can begin sooner. It is hard to detect the species on the plants or small trees that are imported in winter because it overwinters rarely at pupal stage instead of larval stage. But it can also be detected due to the intense damage it causes on the plants. It is also easy to detect the damage by recognition of the adults on the plant and emergence holes. But at that phase, the infestation of the other plants in the area already starts. The use of Solid Wood Packing Materials (SWPM) for maritime shipping is regulated for adequate treatment methods at certain ports in some countries (Anonymous, 2016). To minimize the harmful effects of ALB and to prevent its dispersion, forest composition should be formed by repellent and/or resistant trees. But if there are preferred trees, a mixed plantation that combines repellents should be used. It is possible to restrict the spread of ALB and reduce damage by combining appropriate species including resistant and trap trees. The recommended ratio between resistant trees, non-host trees and trap trees for a mixed forest is 50-45% to 50-45% to 0-10% (usually 5 to 10%) (Yang, 2005). The following trees are suitable for planting to replace the removed ALB infested trees: Serviceberry or Shadbush, Ironwood, Southern catalpa, Hackberry, Turkish filbert, Ginkgo, Honey locust, Kentucky coffee tree, Tulip tree, Dawn redwood, White oak, Swamp white oak, Bur oak, English oak, Japanese lilac, Bald cypress, Basswood, Little leaf linden (UVM, 2008).

In the light of the abovementioned studies, Discussion and Conclusions can be presented as follows;

- Municipalities, ministries and research facilities should be informed following the detection of the infested areas.
- You should consult your local cooperative extension service, diagnostic labs, or state department of agriculture if you have detected a suspicious sample.
- Quarantine procedures should be applied following the detection of the ALB damage to prevent epidemic.
- Holes should be blocked.
- Infested trees should be destroyed. (Cut, chip and burn)
- Quarantine zone should be fumigated systematically with insecticides beside physical control methods in line with relevant workplace safety procedures and instructions.
- Countries should work on the legal regulations regarding the solid wood packaging in terms of trade.
- Inspections should be carried out by the people employed by Ministry of Forestry and Water Affairs.
- All necessary prevention methods, inspections and strict packaging and shipping regulations should be applied for national and international trade of all kinds of wooden raw material, ornamental plants, and citrus plants.

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