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*Shelterbelt Management and Control of
Asian Longhorned Beetle, *Anoplophora glabripennis*
in the Three North Region of China*

*Review of the Asian Longhorned Beetle
Research, Biology, Distribution and Management
in China*

by

Pan Hong Yang

The General Station of Forest Pest Control
The State Administration of Forestry
Shenyang, Liaoning, China

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Background

This paper is one of a series of FAO documents on forest-related health and biosecurity issues. The study was carried out as part of a Technical Cooperation Programme (TCP/CPR/2903), Shelterbelt Management and Control of Asian Longhorned Beetle *Anoplophora glabripennis* in the Three North Region of China; a technical agreement between FAO and the Government of the People's Republic of China.

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Quantitative information has been compiled according to sources, methodologies and protocols identified and selected by the authors. For standardized forest inventory methodologies and assessments on forest resources, please refer to FAO, 2005. *State of the World's Forests 2005*; and to FAO, 2001. *Global Forest Resources Assessment 2000 (FRA 2000)*. FAO Forestry Paper No 140.

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Comments and feedback are welcome.

For further information please contact:

Gillian Allard, Forestry Officer
(Forest Protection and Health)
Forest Resources Division
Forestry Department
FAO, Viale delle Terme di Caracalla
00100 Rome, Italy
Fax: + 39 06 570 55 137
Email: gillian.allard@fao.org

Pierre Sigaud, Forestry Officer
(Forest Genetic Resources)
Forest Resources Division
Forestry Department
FAO, Viale delle Terme di Caracalla
00100 Rome, Italy
Fax: + 39 06 570 55 137
Email: pierre.sigaud@fao.org

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BACKGROUND

ASIAN LONGHORNED BEETLE (ALB) OCCURRENCE AND DAMAGE STATUS IN CHINA

There are more than 100 species of longhorned beetles in China but only about 10 species have wide distribution, including *Anoplophora glabripennis* (Motsch.), *Anoplophora nobilis* Ganglbauer, *Apriona germari* (Hope), *Batocera horsfieldi* (Hope), *Saperda populnea* Linnaeus and *Xylotrechus rusticus* Linnaeus. Some of these species are widely distributed, may cause considerable damage and are difficult to control. The Asian longhorned beetle (ALB) *Anoplophora glabripennis* is the most important and most widespread and causes significant damage to poplars and willows, the main shelterbelt species.

Records of ALB in China date back to at least the Qing Dynasty but significant losses attributed to the insect were not recorded until the 1980s when vast tracks of poplars were grown as shelterbelt trees in the Three North Region, especially in the northwestern area. Population explosion and spread were rapid and within a decade (1980s-1990s) the damaged area increased from about 70,000 ha to more than 150,000 ha and the infested area increased from 70 counties to more than 240 counties. Many trees died and the forest shelterbelt was destroyed because of the damage of ALB. In heavily damaged areas, 80-100% of trees were infested, with insect levels reaching several hundreds per tree. Extensive larval tunnels in the trunk rendered the timber unsalvageable and trees had to be destroyed to prevent further spread of the insect. In the Three North region of China more than 0.2 billion trees, equivalent to approximately 120,000 ha had to be cut and destroyed.

Two examples on occurrence and damage status of ALB in the Three North Region are provided below for Ningxia Province and Inner Mongolia as these represent pilot areas that were the subject of study for the Technical Cooperation Programme (TCP/CPR/2903) between the Chinese Government and the Food and Agriculture Organisation of United Nations (FAO).

Asian Longhorned Beetle (ALB) Occurrence and Damage Status in Ningxia Province

ALB was first recorded in Ningxia province at the beginning of the 1980s, but distribution was very rapid and the damaged area rapidly increased from 2000 hm^2 to more than 40,000 hm^2 affecting more than 200 villages and towns of 20 counties. Percentage of trees infested was 90% with more than 100 beetles recorded in one tree. The local government was forced to cut down 80 million infested trees in order to control ALB, which effectively eliminated the first generation of shelterbelt forest. Since 1986 only "tolerant" tree species, such as *Fraxinus mandshurica*, *Alnus altissima*, *F. chinensis*, *Populus bolleana*, *P. tormentosa* and *P. hopeiensis*, have been selected for the second generation of shelterbelt forest. However, farmer's preference still leaned towards "conventional" poplars with faster economic returns and the shelterbelt forest was again damaged by ALB. Percentage of trees infested ranged from 30 to 40% in most areas while highs of 80 to 90% were recorded in some areas.

Asian Longhorned Beetle (ALB) Occurrence and Damage Status in Inner Mongolia

More than 11 million trees have been felled in Inner Mongolia since 1992, not only causing economic losses but also affecting the protection role of the shelterbelt forest. In addition, *Anoplophora nobilis* Ganglbauer was found in Qinghai Province for the first time in 1992, and is now found in eight counties/cities. *A. nobilis* is believed to be a separate species by some authorities but by others to be only a colour variant of *A. glabripennis* (Luo Youqing, Huang Shaoming, 2002^[190]).

BIOLOGY OF ASIAN LONGHORNED BEETLE

Host range in China

ALB has a wide recorded host range but in China the preference is for poplar, willow, elm and maple trees. High levels of infestation occur in weak trees and those grown in monoculture. Within poplars there is a noted ranking of preference related to species tolerance/resistance, first are balsam poplars of section *Tacamahaca* then black poplars (section *Aigeiros*), with the least preference for white poplars (section *Leuce*), for further details please refer to “Review of tree selection and afforestation for control of Asian Longhorned Beetle in North China” (Yin Weilun; Lü Wen, 2005)

Damage

ALB is a trunk borer and there may be several larval tunnels in the trunk, degrading the quality and even causing the death of trees rendering the timber valueless. According to experiments, 4 to 10 year old poplars will die after 2 to 4 years of consecutive damage by ALB, and poplar forests grown in monoculture can die after 3 to 5 years of consecutive damage. Within 5 to 8 years, severe damage may occur depending on tree species, forest structure and growing status.

Distribution

ALB is a weak flyer. After eclosion and copulating, females will lay eggs within 300 to 1000 meters of the emergence site. Eggs, larvae, pupae and adults can be transported great distances with host logs or by vehicles. The shelterbelt forests are generally planted close to rivers or transport routes and hence become more easily infested by adults that may be spread by wind, flowing water and/or by animals.

Life cycle and management

It is difficult to monitor, quarantine and control ALB effectively as the adult stage may only last one month and it is difficult to find and control ALB at the early stage of damage during the concealed larval stages. The life cycle is long but uneven and fecundity is high and there may be one or two generations per year. Adults may mate several times. Adults feed on bark, leaves and leaf stalks soon after exiting from eclosion holes prior to mating and egg laying. The female makes an oval-shaped slot on the bark and then lays individual eggs in each slot (oviposition site). In North China, ALB overwinters as larvae or eggs and larvae start feeding the following March, pupating in May with adult emergence starting in May or June, peaking in the middle of July and ending in October. There are few natural enemies due to the predominantly concealed nature of the life stages, making management difficult.

ASIAN LONGHORNED BEETLE CONTROL IN CHINA

More information on sanitation and cultivation measures for North China is available in “Review of tree selection and afforestation for control of Asian Longhorned Beetle in North China” (Yin Weilun; Lu Wen, 2005). Forest Health & Biosecurity Working Papers, Working Paper FBS/7E, FAO, Rome, Italy.

Control measures against ALB

In China records about the management of poplar longhorned beetles, especially *Anoplophora glabripennis* and *Anoplophora nobilis* have been found as far back as the Qing Dynasty. Since the 1980s many measures have been adopted by the government for ALB control and the State Forestry Administration (SFA) carried out demonstration projects for management of *Saperda populnea* Linnaeus and ALB. In 1991 a five year integrated management project against ALB was carried out in Shaanxi, Gansu, Ningxia, Inner Mongolia and Shanxi provinces and autonomous regions. Pilot control measures for ALB were carried out in Inner Mongolia by SFA during the period of 1998 to 2000. A national project for all poplar longhorned beetles was started in Shaanxi, Gansu, Qinghai and Heilongjiang provinces in 2000-2002. “The poplar pest and disease control project”, which included ALB, was carried out in 2003.

Important control measures

Planting with different tree species for pest control including non-host and “resistant” tree species to regulate the structure of the forest. Mixed forests are created and trap trees are used to restrict the spread of ALB.

Cultivating fast-growing timber forest. Planted trees grow much faster with careful tree selection and tending. The rotation of the tree is shortened and the chance of being damaged by ALB is theoretically reduced.

Planting trap trees to kill ALB collectively and to protect high value trees. Trap trees, which are preferred by ALB, are planted to lure ALB to lay eggs which are then destroyed.

Sanitation felling to remove damaged trees to reduce breeding sites. This is fundamental for ALB management but it is essential to treat and/or remove the damaged trees after clearing to reduce the chance of secondary infestations.

Management of the shelterbelt forest. Integrated measures employing several different methods have been used to control ALB. At the same time, it is necessary to consider ecological benefits and the welfare of the farmers. For example, measures can include removal of the damaged portion of the tree trunk from breast height; grafting Chinese white poplars after removal of the damaged trunk; or cutting the damaged tree as early as possible to restrict the spread of ALB.

Physical and direct chemical control measures. Including precise placement of insecticide impregnated sticks into larval sites, blocking the larvae (frass) holes with insecticide impregnated mud, spraying pesticides directly on to adults, application of trunk injections with pesticides to attempt to kill the larvae and capturing the adults and physically killing eggs and larvae.

Biological control. Measures include encouraging nesting of woodpeckers which predate on larvae; application of fungal entomopathogens and entomophilic nematodes and augmentation of classical biological control agents such as *Scleroderma guani* and *Dastarcus helophorides*.

ACHIEVEMENTS

The damage of ALB has been controlled and the population density decreased considerably in the Three North Region of China after an intensive management campaign. The infested area has been reduced from more than 50000 hm² in 13 prefectures to 26000 hm² in 7 prefectures in Gansu province. The ratio of damaged trees has been reduced from more than 15% to less than 5% in Bameng area of Inner Mongolia as a result of integrated measures described above; including sanitation felling, replanting damaged forests, biological control including augmentation of natural enemies and physical control measures. This area has now been designate as a demonstration area for ALB management.

In 1983 preliminary field studies were undertaken in Ningxia province with “resistant” poplar trees. Non-host trees, resistant trees and trap trees were planted in mixed stands. Concurrently, cooperation with other countries on the research of ALB control was established and some effective management methods were developed. Many experiments were duplicated in other provinces.

REVIEW

This working paper tabulates and summarises the main components of ALB management in China and includes a review of research (Table 1), control methods (Table 2), monitoring and forecasting measures (Table 3) and quarantine measures (Table 4) for ALB and other important longhorned beetles.

RESEARCH WORK

Since 1985, ALB has been the subject of priority research funded by the National Science Fund in three phases. Research into integrated management for ALB was also carried out as the main agenda of local governments in northwestern and northern provinces. Research on biology, physiology, taxonomy, control and integrated management of ALB has been carried out in depth and the results have been tabulated in *Table 1 Literature review of ALB and other important longhorned beetles in China*. A summary of the main findings is provided below.

Summary of the main research activities

Fundamental research work such as relationships between the damage of ALB and the structure or development phase of the forest was carried out. Ecological characteristics of ALB were studied and spatial distribution, monitoring, prediction, spread and other related factors.

Research on selection of resistance to ALB was carried out coupled with clonal selection, and recommendations were made to develop resistant tree species.

Trap trees were tested and found to be of value for luring beetles and to collectively protect high value trees.

Mixed forest stands with resistant, non-host and trap trees have been recommended as sound management practices.

Intensive research was carried out with varying success on biological control measures, including isolation, rearing and field release of entomopathogenic fungi and entomophilic nematodes. Woodpeckers were encouraged and evaluated as predators of ALB and augmentation of natural enemies was carried out.

Preliminary extractions and tests of female ALB pheromones were carried out and male attraction was determined.

Integrated pest management of ALB included research on methods to control ALB in different tree species and different damage situations. In addition, insecticides were tested in field situations and recommendations were made for those methods with least environmental impact including trunk injections and insertion of insecticide impregnated sticks.

All the research achievements mentioned above are an integral part of integrated pest management for ALB, and are helpful to increase knowledge. The integrated approach was developed from the original control method that relied solely on chemical treatments.

CONTROL METHODS

A review of the control measures used in China has been completed and is presented in *Table 2 Evaluation of Control Methods for ALB*. The review includes an overall evaluation of the methods and the extent to which they are applied. Methods are aimed at three levels; the individual beetle, the tree host and the whole shelterbelt forest ecosystem.

Designing new planting models with different tree species. It is possible to restrict the spread of ALB and to reduce damage by combining appropriate species including resistant and trap trees. All these afforestation models received attention and were promoted in Three North Region. The main non-host tree species are *Fraxinus mandshurica*, *Ailanthus altissima*, *F. chinensis* and *Robinia pseudoacacia*. The resistant tree species are *Populus hopeiensis*, Chinese white poplars including *Populus alba var pyramidalis* and *P. bolleana*. The recommended ratio between resistant tree, non-host tree and trap tree for mixed forest is 50-45% to 50-45% to 0-10% (usually 5 to 10%).

Shortening the rotation time by planting fast-growing trees to resist or evade the damage of ALB. Management measures were used to reduce time to maturity so that the rotation time is reduced. The annual growth should be more than 3cm breast diameter. Theoretically, eggs and larvae are exposed or

crushed because the tree is very fast growing. In addition, poplar can be harvested earlier for papermaking and for timber; this is effective in reducing the damage of ALB. Cutting away the trunk at breast height and pruning in time are also useful for reducing the damage of ALB (but the quality of the final wood is much reduced).

Planting trap trees for protecting high value trees. Trap tree can be used to attract beetles for effective control and to protect high value trees. It is easy to use this method for trapping and killing beetles and this method is popular in Three North Region at the present time. The ratio of trap trees is about 5 to 15% in the main valuable forests of *Populus opera*, *Salix spp.*, *Acer spp.*, *Ulmus spp.* etc. Resistant trees may be used for restricting the spread and damage of ALB and in addition, the protection and separation belts can also be successfully used to control ALB.

Grafting Chinese white poplars with cut poplar radicle. Grafting Chinese white poplar or some other resistance tree onto original poplar stumps has been used (Yan Junjie). This technology can make full use of the cut stump and reduces the costs of afforestation. In addition, the grafted Chinese white poplar grows very fast with very good resistance against ALB. This technology is one of the main measures for tree regeneration and ALB control, and has been promoted for ALB control in northwestern area.

Selecting and introducing resistant poplar tree species and clones. Resistant poplar clones are important in reducing ALB damage. Some varieties such as Chinese white poplars, (*Populus hopeiensis* and *Populus alba var pyramidalis*) are suitable for plantations in the northwestern area. In addition, species with coarse and keratose bark are effectively resistant against the damage of ALB.

Dynamic management on shelterbelt forests. Integrated management measures which consider ecological benefits along with the farmer's economic benefits, should be promoted in the northwestern area e.g. revitalising the heavily damaged forest or old forest will reduce the beetle source. Killing beetles attracted to trap trees, and cutting trap trees when infested will help reduce the ALB infestation. In addition, in areas where water is sufficient and poplar grows very fast, early harvesting and shorter rotation time should reduce damage. In areas where the weather situation is harsh, new trees should always be planted before the old damaged trees are removed. These methods are ecologically sound and provide economic benefits by using the timber from the shelterbelt forest.

Integrated pest management. Methods include chemical control such as the application of Cypermethrin, Fenitrothion, "Green Pesticide", the use of sticks and mud balls impregnated with pesticides and pesticide injections. Physical methods include capture of adults, killing eggs and young larvae by hand, killing older larvae with wires, cutting damaged branches and strengthening the treatment and quarantine of damaged trees. These methods are very useful to control beetles that live in trees around houses, trees of shelterbelt forests, in isolated trees, trap trees, ornamental trees, old trees and trees in the immature forests.

Biological control measures. ALB control has been attempted through introducing and protecting woodpeckers in some areas of Ningxia, Gansu and Bameng of Inner Mongolia. The ratio of predated ALB is more than 30%. In addition, *Scleroderma guani* as a carrier of entomopathogenic fungi and

Dastarcus helophorides have also been used extensively to control ALB larvae with varying degrees of success.

MONITORING METHODS

Evaluation of monitoring methods. There are many monitoring and investigation methods for ALB in practice now; these include systematic monitoring, use of light and pheromone traps and planting trap trees. Methods have been reviewed and evaluated in *Table 3: Monitoring and Forecasting Measures for ALB* and the degree of application noted.

QUARANTINE

Table 4 lists and reviews *Quarantine measures for ALB* noting that this is a vital component of any management strategy for ALB and that quarantine measures have to be applied at all stages of tree production and processing to avoid and prevent further distribution of the pest.

MAIN FINDINGS AND CONCLUSIONS

MAIN PROBLEMS

In the early days attention was focused on chemical control in many areas and little attention was paid to quarantine and monitoring and there was poor communication between the sectors involved with pest control, quarantine and monitoring. Thus beetles were transported great distances from the original foci of infestation. At the same time, beetles could not be detected and treated in time before they became established.

The initial pattern of pure stands of poplar, limited clonal diversity, coupled with poor management are no doubt the main reasons for the extreme outbreak situations encountered. Despite recommendations for mixed planting of resistant trees, there is still a difficult dilemma, as many farmers still want to plant susceptible trees, such as poplar, willow and elm in many areas because of the shortage and costs of resistant tree species. In addition, management methods need to be improved to protect forests and to prevent further spread.

There are still many problems being faced by the Three North Region of China, including application of outdated management methods in a vast area. There is a need to promote new technologies and to improve the biological methods for ALB control.

The ALB monitoring and prediction system should be improved in order to manage infested areas and to prevent future outbreaks. It is easy to miss the “treatment window” for ALB because the larvae live inside the trunk for 10 to 20 months and they are difficult to detect and control during this phase; in addition, the eclosion time is as long as five months and it is difficult to control effectively.

RECOMMENDATIONS

1. Strengthening monitoring work on ALB

It is necessary to enhance existing monitoring measures, to develop new monitoring techniques for ALB in shelterbelt forests of the Three North Region. It is also necessary to understand the dynamics of ALB populations and to provide timely monitoring and prediction results in order to manage new outbreaks.

2. Quarantine measures

It is necessary to strengthen and enforce quarantine measures and to teach farmers how to prevent the spread of ALB. One method of restricting the spread of ALB is through regulations and laws.

Phytosanitary measures have been enforced for the transport of wood and quarantine measures imposed in production areas. In an infested area, quarantine is essential to contain the pest and prevent spread. In non-infested areas, quarantine is essential to ensure that no insects are introduced either on infested seedlings or by other means. Transportation of ALB through human activities is prevented through strict quarantine measures including transportation of logs and seedlings and inspection of packaging materials. Infested trees need to be treated and movement restricted to prevent the spread of ALB to non-infested sites.

3. Integrated pest management with emphasis on prevention

It has been shown that one control measure alone cannot be used to manage ALB or stop the spread of this pest. An integrated approach is required to restrict the spread and manage infested areas.

4. Raising awareness of mixed planting in the Three North Region

Changing traditional planting models and promoting the use of updated economical measures for afforestation with fast growing resistant tree species should be encouraged. It is also necessary to summarize existing information and to develop improved technologies. The adaptability, resistance and protection functions should be considered together. Some resistant tree species from other countries could be introduced, but the local resistant species should also be used rationally. In the heavily damaged areas, Chinese white poplars *Populus hopeiensis* and grey poplars should be promoted to create a resistant forest while resistant clones, such as Chinese white poplar, No. 741, should be introduced at the same time.

5. Raising awareness of the benefit of trap trees

The appropriate ratio of trap trees e.g. maple, elm and *Populus opera*, should be determined in order to attract beetles in high value areas. The ratio of trap trees is usually about 5 to 15%.

6. Raising awareness about the benefits of biological control

Biological control agents such as *Scleroderma guani* and *Dastarcus helophorides* and entomopathogenic fungi have shown promise and should be considered for control of ALB. At the same time, new biological control methods should be studied especially in the pilot areas of Ningxia and Gansu provinces.

7. Increased training capacity

Technology training should be strengthened for farmers to improve their knowledge of forest management and pest control. Some training courses should be held on ALB monitoring and control.

Suggestions for training include the following:

- Monitoring and prediction of ALB outbreaks
- Quarantine measures including transportation of logs, quarantine of production areas
- Integrated management of ALB
- Mixed planting designs in the Three North Region
- Management practices including fast-growing forests for ALB control
- Biocontrol methods including beneficial birds and other natural enemies

TABLE 1: LITERATURE REVIEW OF ALB AND OTHER IMPORTANT LONGHORNED BEETLES IN CHINA

* Important Longhorned Beetles in China other than ALB

Activity	Summary	Research and Application
Silvicultur		
Plant mixed forest	Plant mixed forests to increase biodiversity; and to reduce level of infestation common with susceptible monocultures	Some silviculture measures have been used in Inner Mongolia ALB project control area and some positive results have been achieved ^[4]
		Lu Wen <i>et al.</i> emphasize the significance of prevention and monitoring measures as first line management, i.e. quarantine and forecasting. Integrated approaches are recommended including extending planting of non-host trees and resistance trees, encouraging mixed forest, cultivating healthy, fast growing trees, adopting short rotation practices, using 5% to 10% trap trees as silviculture measures to effectively control ALB together with some physical, chemical, biological and manual measures ^[5]
		It is recommended that <i>P. alba var. pyramidalis</i> , <i>P. tomentosa</i> and <i>P. hopeiensis</i> should be the main tree species to be planted in East Gansu, and mixed with <i>P. × beijingensis</i> , <i>P. nigra var. thevestina</i> and <i>P. cathayana</i> as trap trees ^[6]
		Modelling of stand resistance as a function of its species diversity ^[7]
		Investigations were carried out on the growth of 19 major tree species in the protection forests in Ningxia and their resistance to longhorned beetles determined. The ranks of resistance were shown by cluster analysis. Suggestions of species suitable for protection forests in Ningxia are discussed in the paper ^[11]
		Liu Haiqing's studies indicate that forests mixed with poplar and willow can control ALB ^[89]
		Effect of ecological control on the relative sensibility of tree species ^[90]
		The status of damaged <i>Populus alba var. pyramidalis</i> was investigated in plantations of different structures in northern Ningxia, and four types of stands were studied. The insect-resistant effects of each stand type were analyzed on the basis of the degree of damage ^[114]
		After several years of study of resistance of the major species in each area, it was concluded that the main cause of the longhorned beetle outbreak was attributed to the man-made establishment of ALB susceptible shelter forests, resulting in an unbalanced ecosystem. The strategic policy to get at the root of this problem is to establish sustainable shelter forests of economic/ ecological type resistant to ALB by using integrated management of insect pests ^[123]

Activity	Summary	Research and Application
		About 10% of forest stands are susceptible to <i>Anoplophora glabripennis</i> and <i>A. nobilis</i> in Three North protection forests. The paper discusses the establishment of sustainable protection forests without infestations of longhorned beetle by putting theory into practice ^[141]
Replacing damaged forests	Grafting resistant tree species on the stumps of susceptible species after felling	The technology of using poplar scions on cut stumps not only reduces the population density of ALB, but also quickly renews the forest ^[83]
		Since 1992, Bameng applied the technology of renewing forests by coppicing to control ALB 241.3 thousand mu ^[101]
		Su Yueling <i>et al.</i> applied the technology of grafting resistance trees on to susceptible poplar stumps to control ALB to achieve regeneration in the same year ^[117]
Forest management	Remove the pest and improve forest management to enhance growth potential	*In orchards, remove wild <i>Broussonetia spp.</i> to decrease the kind and amount of susceptible plants to <i>Apriona germari</i> (Hope.) ^[1]
		It is suggested that improving the availability water and fertiliser is an important method to control poplar longhorned beetles ^[2]
		Egg laying preference is reduced following three years of cutting the branches below 6m before the poplar trunk reaches 10cm ^[3]
		Planting fast-growing or adopting short rotation practices can control poplar longhorned beetles ^[5]
		*Plants of <i>Moraceae</i> were removed to reduce supplemental feeding sources for <i>A. germari</i> and to inhibit the propagation of <i>A. germari</i> . The rate of beetle infestation decreased by 80% ^[8]
		*To control <i>A. germari</i> ; supplementary nutrition sources such as mulberry trees, were removed. The percentage of infested trees in the poplar plantations dropped from 5% to 1.2% for the treatment, compared to an increase from 2.1% to 7.1% for the control ^[9]
		In a 67 ha I-69 poplar plantation, test trees were irrigated and fertilized before adult <i>A. glabripennis</i> were caged on the tree trunks. No ALB larvae were found alive when 310 egg pits were dissected 25 days after being deposited ^[9]

Activity	Summary	Research and Application
		<p>Qin Xixiang's research indicates that improving forest management and enhancing growth potential, etc can reduce ALB infestations^[10]</p> <p>Zhang Xiankai <i>et al.</i> cleaned, burnt or immersed damaged plants to control ALB^[12]</p> <p>Han Peiyi determined that removal of damaged plants could reduce the ALB population density^[126]</p>
Plant resistant species	Improve poplar resistance to ALB	<p>*Chinese white poplar, Italy No.53 and No.72 poplar have high resistance to white spotted longhorned beetle, but have no resistance to <i>Apriona germari</i> (Hope) and white striped longhorned beetle^[2]</p> <p>Planting some species of poplar such as Hebei poplar, Xinjiang poplar and Liaohu poplar should be encouraged, to reduce preferred breeding and feeding sites of the white spotted longhorned beetle^[5]</p> <p><i>A. glabripennis</i> mainly damaged hybrid poplars belonging to Sect. Aigeiros Duby, so it was recommended that damaged stumps should be grafted with resistant tree species. Extent of infestation with <i>A. glabripennis</i> decreased by 50%^[8]</p> <p>*I-69, I-72, Zhonglin-46,S-307-26, PE-19-66, Zhonglin-28, Zhonglin-14 and <i>Populus tomentosa</i> have high resistance to <i>Anoplophora chinensis</i> (Forster)^[13]</p> <p>Evaluations were made of poplar growth, basic wood properties, resistance to <i>A. glabripennis</i>, growth and stem form. <i>P. × eumericana</i> cv. Jiqin-1 and <i>P. × eumericana</i> cv. Jiqin-2 were selected as improved poplar clones with high resistance to <i>A. glabripennis</i>, exhibiting fast growth and fine wood properties, which should be grown over large areas^[14]</p> <p>Great success has been achieved with new afforestation schemes. The new forest had resistance to <i>A. germari</i> and <i>A. glabripennis</i>^[15]</p> <p>* It is recommended to plant trap trees of poplar and weeping willow around the edge of I-69 and I-72 forests, to encourage <i>Anoplophora chinensis</i> (Forster) to lay eggs^[17]</p>

Activity	Summary	Research and Application
		<p>Zhou Zhangyi, Qin Xixiang and Wang Yongjun's research shows that: there is an important relationship between the damage of ALB and I-69 and No.50 poplar which show resistance to <i>Anoplophora glabripennis</i> (Motsch.). Yang Xueyan's research showed that Xinjiang poplar and Hebei poplar exhibit resistance to <i>Anoplophora glabripennis</i>. Liu Jinquan's research showed that trembling aspen, Chinese white poplar and <i>Populus simonii</i> have resistance to <i>Cryptorrhynchus lapathi</i> L.^[18]</p> <p>Adult <i>A. glabripennis</i> (Motsch.) have certain host preferences. Preferred poplar clones for oviposition include Da Guan (<i>Populus dakuanensis</i>). The physiological response by the poplar clone to oviposition is also different^[103]</p> <p>Wang Gongwei confirmed Langfang poplar has resistance to <i>A. glabripennis</i>^[119]</p> <p>The growth and the relative insect-resistance of 14 poplars in Ningxia are described. <i>Populus tremula</i> gigas and <i>Populus tomentosa</i> var truncata and several other poplar species have greater resistant ability under certain environmental conditions. The order of resistance of these poplar species is provided. They all have higher resistance than <i>Populus alba</i> var. <i>pyramidalis</i> which is the main species grown in Ningxia^[124]</p>
Plant trap trees	Trees with known attraction to ALB are planted to protect high value forests	<p>Guo Benming planted <i>Morus broussonetia</i> as trap trees to attract adult ALB because they use the bark as a supplementary nutrition source^[3]</p> <p>Lu Wen found that planting 5 to 10% trap trees in poplar stands can attract ALB and thus poplar trees can be protected^[5]</p> <p>To control <i>A. glabripennis</i> (Motsch.), a cluster of four trap trees (<i>Acer negundo</i>) were planted on the perimeter of poplar plantation every 200m. Confidor (a.i. Imidacloprid, 1500×) was sprayed onto trap trees to control adult ALB. Percentage of infested trees in the poplar plantation dropped from 5% to 1% for the treatment, compared to an increase from 2% to 7% for the control^[9]</p> <p><i>A. glabripennis</i> (Motsch.) and <i>A. nobilis</i> Ganglbauer are serious destructive trunk borers. Many trees have been damaged, including 10 families, 14 genera and 34 species in Ningxia. Four species including <i>Elaeagnus angustifolia</i> have been selected as suitable trap trees^[20]</p> <p>*Gao Ruitong research on <i>Apriona germari</i> (Hope) trap tree methodology indicates that adults can fly up to 2500m to find food with an average flight of 250 to 550m. When trap trees are taller, the results are better. Using trap trees for adult control, the infestation rate of trees decreased from 28% to 95% to 5 to 59%^[24]</p>

Activity	Summary	Research and Application
		The results show that ashleaf maples attracted significant numbers of <i>A. glabripennis</i> (Motsch.). The attraction rate decreased and the repellent ability increased gradually after feeding-damage ^[26]
		A rational model of multi-tree species planting was proposed with the proportion of non-host trees, resistant trees and trap trees being 45 to 50%:45 to 50%: 5 to10%. Landscape and protection benefits were considered critical in the backbone belt, so non-host trees and resistant trees were selected for the shelterbelt. Benefits to farm protection and prevention against ALB infestations were considered in the secondary shelterbelt, so trap trees were set at the ratio of 5 to10% in this belt ^[27]
		Sun Wenkang planted mulberry and common paper-mulberry as trap trees to control ALB. The rate of damaged plants decreased from 9 to 0.29% ^[28]
		Sun Jinzhong planted chinaberry and hard maple as trap trees to control <i>A. glabripennis</i> (Motsch.). After three years, the infestation rate and population density decreased significantly ^[29]
		The percentage of trees infested by larvae in poplar plantations with paper-mulberry planted as trap trees was 62%, which was lower than the control plantations after two years. The percentage of trees infested by larvae in poplar plantations where mulberry and paper-mulberry had been cleared was 42 to 77% lower than plantations with no trap trees ^[30]
		The use of trap trees in poplar plantations decreased ALB infested trees from 95.4% to 18% ^[31]
		When <i>Melia azedarach</i> isolation belts were planted at the border of a poplar forest, the rate of poplar trees with <i>A. glabripennis</i> (Motsch.) decreased by 53% compared to the forest without isolation belts. An average of 0.076 beetles per tree was found, a decrease of 71% compared to forests without isolation belts. <i>M. azedarach</i> isolation belts can play an important role in restricting the infestation of adult <i>A. glabripennis</i> (Motsch.) and thus the natural control ability of poplar forests will be improved ^[33]
		Based on research on resistance in 11 families, 18 genera, 120 species of trees, Shao Qianghua found that some species of <i>Tiliaceae</i> and <i>Cornaceae</i> were suitable as trap trees for <i>A. glabripennis</i> (Motsch.) ^[93]

Activity	Summary	Research and Application
		<p><i>Elaeagnus angustifolia</i> L. can be used as an attractive oviposition site for <i>A. glabripennis</i> (Motsch.). According to field experiments, the maximum number of oviposition sites in <i>Elaeagnus angustifolia</i> L. trees is 63.5 (minimum number of sites is 47.6). In protective forest belts of <i>Populus</i> L. and <i>Elaeagnus angustifolia</i> L., the mean number of oviposition sites of <i>A. glabripennis</i> (Motsch.) has dropped from 9.8 to 1.5^[110]</p> <p>In the protection forests of the Ningxia Hui Autonomous Region, the attraction rate of <i>Acer negundo</i> for <i>A. glabripennis</i> (Motsch.) adults within a radius of 100m is at least 66%. The area of attraction covers a distance of at least 240m^[132]</p>
Biological control		
Entomopathogens	Application of entomopathogenic fungi to control ALB	<p>The application of biological measures such as natural insect enemies, entomopathogenic fungi, entomopathogenic bacteria, entomophilic nematodes, woodpeckers and sterilization against longhorned beetles is summarized^[35]</p> <p>Zhang Bo and Bai Yang carried out research on the pathogenicity of <i>Beauveria bassiana</i> against <i>A. glabripennis</i> (Motsch.). The effect was positive^[36]</p> <p>Wang Suying isolated <i>Paecilomyces farinosus</i> from infected larvae of <i>A. glabripennis</i> (Motsch.). Infectivity rate was 89%^[92]</p> <p>Zhang Bo found the pathogenicity of <i>Beauveria bassiana</i> spp. against <i>A. glabripennis</i> (Motsch.) reached 48 to 85%^[39]</p> <p>A synergist has been selected for control of <i>Anolophora glabripennis</i> (Motsch.) by using entomopathogenic fungi. The synergist can increase the spore-output of pathogenic fungi and speed up the mortality rate of <i>A. glabripennis</i> (Motsch.). The ALB exhibits symptoms of the disease on Day 6 post-inoculation with 100 % mortality on Day 16. when a 0.02 percent of synergist is added to a liquid suspension of <i>Beauveria bassiana</i> sp (spore content 10⁸/ml), and by inoculating <i>A. glabripennis</i> (Motsch.) larvae with the suspension^[99]</p> <p><i>Beauveria bassiana</i> and <i>B. brongniartii</i> were cultured on non-woven fabric strips to test natural spread and viability of the spores. The dispersal of the spores was more than 40 meters in a NW wind at a speed of 0.9m/s. The direction of dispersal was linked to wind direction. The generation rate of spores on non-woven fabric strips was more than 70% within nineteen days. For adults of <i>A. glabripennis</i> (Motsch.), the infectivity with fungi on non-woven fabric strips was 61% in cages and 38% in the field^[104]</p>

Activity	Summary	Research and Application
		<p>Thirteen species of entomopathogenic fungi (isolates) of <i>Anoplophora</i> spp. were isolated and cultured from soil and infected insects obtained in the field in Ningxia Hui Autonomous Region, China. Twelve isolates were screened for pathogenicity to <i>A. glabripennis</i> (Motsch.) larvae. Five isolates, including <i>Beauveria bassiana</i> and <i>B. brongniartii</i> with a high degree of virulence to <i>A. glabripennis</i> (Motsch.) larvae were selected. The highest mortality rate of <i>B. bassiana</i> was 100% compared to <i>Metarhizium anisopliae</i> at 70%^[112]</p> <p>The experiments show that the pathogenicity of <i>Paecilomyces farinosus</i> 9101, <i>Beauveria bassiana</i> Z28 and <i>B. brongniartii</i> on <i>A. glabripennis</i> (Motsch.) is 100%, and <i>P. farinosus</i> Z26 is 88%. The optimum lethal temperatures are: <i>P. farinosus</i> Z26 15-20 °C; <i>P. farinosus</i> 9101 15°C-25 °C; <i>B. bassiana</i> Z28 20-30 °C .A concentration of 4×10⁸ spores/ml plus 0.02% of synergist are applied to the holes bored by <i>A. glabripennis</i>. Larval mortality was above 92%^[142]</p> <p>*<i>Beauveria bassiana</i>, isolated from <i>A. chinensis</i> for control of <i>A. chinensis</i> reached an infection rate of up to 78%. <i>Steinernema feltiae</i> and <i>S.carpocapsae</i> were used in the control of <i>A. chinensis</i> and the infestation rate was over 90%^[172]</p> <p>Bethyls (parasitoids) as carriers for <i>Beauveria bassiana</i> (Bals.) and <i>Paecilomyces farinosus</i> were applied to control <i>A. glabripennis</i> (Motsch.) in a 400 mu area^[41]</p> <p>Xujinzhu's study showed that the application of non-woven fabric bands impregnated with fungus killed more beetles than sprays of conidia scraped off the bands, especially in the 3rd to 7th day after application. Less oviposition was observed in the fungal bands^[66]</p> <p>Wang Suying found <i>Beauveria bassiana</i> to be pathogenic to <i>A. glabripennis</i> (Motsch.). The infection rate was 100% in the laboratory^[171]</p>
	Application of Bacteria	Wang Suyin separated 36 strains of bacteria from <i>A. glabripennis</i> (Motsch.) infected larvae and pupae. Eight strains of bacteria whose lethal rate was over 30% have been screened ^[127]

Activity	Summary	Research and Application
		<p>A new pathogen <i>Nosema glabripennis</i> Zhang has been recovered infecting <i>A. glabripennis</i> (Motsch.). According to field investigations, approximately 3% of the natural pathogens recovered from dead ALB were microsporidiums while other pathogens were mostly saprophytic or other parasitic organisms that parasitize the beetles after infection by the microsporidium. The results of bioassays showed that the mortality of the longhorned beetle larvae was 27%. The microsporidium possess the ability for vertical dissemination and shows potential as an effective natural organism to control the beetles^[177]</p>
	<p>Application of entomophilic nematodes to control ALB</p>	<p>*Inject <i>Heterorhabditis bacteriophora</i> 8406 3000 individuals/ml into larvae hole to control <i>Apriona germari</i> (Hope); success rate is 87%^[34]</p> <p>*This paper reports the result of experiments on the control of <i>A. chinensis</i> with ten strains of <i>Steinernema</i> and one strain of <i>Heterorhabditis</i>. Screening indicated that <i>S. feltiae</i> Beijing and <i>S. carpocapsae</i> M.K. were the best strains. They can infest mature larvae, pupae and adults. The mortality of larvae is 95% to 100%. The most appropriate dose is 10000 nematodes per beetle. In the field, efficacy can reach 91% when sponge pieces impregnated with nematodes are plugged into the larval tunnels^[176]</p> <p>Wang Ximeng observed the infective stages and mode of pathogenicity of two strains of nematode, Agriotas (A24) and Beijing, to larvae and pupae of <i>A. glabripennis</i>. The Beijing strain was better than A24, at a concentration, of 500 nematodes/beetle^[121]</p> <p>The pathogenicity of <i>A. glabripennis</i> and carpenter moths controlled by <i>Steinernema bibionis</i> is 60% and 90% respectively^[37]</p> <p>Qin Xixiang found that <i>S. bibionis</i> Otio can parasitize and kill 40 to 80% of <i>A. glabripennis</i> (Motsch.) in natural conditions^[56]</p> <p>*Hou Aijun applied <i>Steinernema</i> sp. to <i>Cryptorrhynchus lapathi</i> L. and achieved a degree of control^[38]</p> <p>Li Pingshu injected nematodes to control <i>A. glabripennis</i> (Motsch.) and <i>A. nobilis</i> Ganglbauer and achieved good results^[55]</p>

Activity	Summary	Research and Application
		<p>The effect of two strains of <i>Steinernema carpocapsae</i>, Agriotas (A24) and Beijing, on control of <i>Anoplophora glabripennis</i> (Motsch.) were observed under different concentrations and different application methods. The field test showed that the effect of the Beijing strain was higher than that of A24 for control of <i>A. glabripennis</i>. The best treatment was injection at a concentration of 7500 nematode/ml with the reduction rate of young larvae holes being 86%^[120]</p> <p>*Lu Xipin applied <i>Heterorhabditis</i> sp. and <i>Steinernema feltiae</i> Agriotas to control some species of longhorned beetle. The results indicated that the control effect was increased when the dosage was 1000 nematodes^[118]</p>
Predators as natural enemies	Insect natural enemies	ALB eggs predators and predation rates were recorded ^[113]
		*Protection and application of natural enemies for effective control of <i>Apriona germari</i> (Hope) is described ^[1]
		Attracting natural enemies to control poplar pests can achieve good results ^[47]
	Woodpeckers	During brood time, a pair of woodpeckers can prey on 2500 beetles. Studies showed that 79% of longhorned beetles had been preyed on, and a pair of woodpeckers can control a 1500-1800mu forest ^[2]
		From 1998 to 2000 Bameng encouraged woodpeckers to control <i>A. glabripennis</i> (Motsch.) and achieved good results ^[40]
		“Inner Mongolia <i>Anoplophora glabripennis</i> control project area” used woodpeckers to control 141,000 mu forest and achieved good results ^[41]
		Zhang Zhongxin’s determined that during the <i>Dendrocopos major</i> brood period, 29 to 58% of their food was composed of longhorned beetle larvae ^[42]
		Zhang Zhongxin’s research showed woodpeckers provided effective control in the forest ^[43]
		A study on the predation of woodpeckers on eight species of insects in poplar plantations was conducted. Predation rates were recorded for the larvae of <i>Paranthrene tabaniformis</i> Rottemburg, <i>A. glabripennis</i> (Motsch.) and <i>Apriona germari</i> (Hope) and for the pupae of <i>Cnidocampa flavescens</i> Walker and <i>Cerura menciiana</i> Moore. Predation rates for the eggs and ootheca of <i>Lymantria dispar</i> (Linnaeus) and mantids were 33.3% and 56.1%~ 68.8% respectively. Some nymphs could still emerge from the ootheca ^[44]
		*In Henan 22 to 24% control of <i>Apriona germari</i> (Hope) was achieved by woodpecker feeding ^[45]

Activity	Summary	Research and Application
		<p>*Liu Huimei studied <i>Dendrocopos major</i> to control <i>Apriona germari</i> (Hope). When the population density reached 0.37-0.55head/hm², 25% of <i>A. germari</i> (Hope) larvae had been pecked^[46]</p> <p>Woodpeckers have become the dominant natural enemy against borer pests in Tianjin and the average predatory rate reached 22%^[89]</p> <p>Shao Yongfeng attracted <i>Dendrocopos major</i> to control <i>A.glabripennis</i> (Motsch.). The results showed 62% of depressions were pecked and 8% hanging branches became nests^[98]</p> <p>In Bayannaoer League woodpeckers were attracted by planting mixed forests, increasing percentage of forest coverage, conserving parts of deadwood and suspending nests^[130]</p> <p>The experiment of Shao Yongfeng showed, 62% of <i>A. glabripennis</i> (Motsch.) larvae were pecked by <i>Dendrocopos major</i> and results were good. Eight percent of hanging branches became nests. The cost of control decreased to 1.25yuan/mu^[175]</p> <p>Field studies during 1996 to 1998 in Longxi County confirmed that both <i>Picus canus</i> (grey- headed woodpecker) and <i>Dendrocopos major</i> (great spotted woodpecker) were dominant predatory birds of <i>Anoplophora nobilis</i> Ganglbauer. In 3133hm² of <i>Populus</i> forest, 54%-60% of larvae and eggs of longhorned beetle on the sampling trees were attacked by birds. In three years, the average population density of <i>A. nobilis</i> Ganglbauer was reduced from 16/tree to 3/tree, which was from 27/tree to 5/tree on the preferred host, and from 7/tree to 2/tree on the non-preferred host. An estimated 6.537million Yuan was saved. Although it was possible that the population density of <i>A. nobilis</i> Ganglbauer would be under the economic-injury level of 2/tree, the limitations of the method were reviewed^[174]</p>
Natural enemies; parasitoids	Parasitoids	<p>* Good results were achieved through breeding and release of <i>Bethyloids</i> and other natural enemies to control <i>Saperda populnea</i> Linnaeus.^[2]</p> <p>Parasitoids of <i>Apriona germari</i> (Hope) and <i>Anoplophora chinensis</i> (Forster) eggs are described. Ichneumonids and braconids are important parasitoids of longhorned beetle larvae and pupae^[35]</p> <p>*Fifty one percent of <i>Saperda populnea</i> Linnaeus. was parasitized by bethyloids in the nursery and 21% in mature poplar forests^[49]</p>

Activity	Summary	Research and Application
		<p><i>Dastarcus helophoroides</i> (Fairmire) can produce 54 generations in three years, and one female adult can parasitize 10 to 12 larvae of <i>A. nobilis</i> Ganglbauer in one year with a mortality rate of 50 to 70%. The distribution pattern of the adult is a Poission distribution and it changes to a negative binomial distribution when the population density is high [50]</p>
		<p>*The first successful laboratory rearing of <i>D. helophoroides</i> (Fairmire) for several contiguous generations is reported. [51]</p>
		<p>It is recommended that <i>D. helophoroides</i> (Fairmire) should be protected and exploited. The insect natural enemies should be transferred to ALB infested areas. The purpose of the method described is to augment the natural population through rearing and release [52]</p>
		<p>In poplar forests infested with <i>A. glabripennis</i> (Motsch.), <i>D. helophoroides</i> (Fairmire) can parasitize 60% of the larvae [53]</p>
		<p><i>Scleroderma guani</i> Xiao et Wu is an ectoparasitic insect of borers, especially the larvae or the pupae of longhorned beetles. In Pingyi county of Shandong province, <i>Scleroderma guani</i> Xiao et Wu was found parasitizing <i>Xylotrechus grayii</i> in 1980. In ten years of study, it was found that this parasitic insect had a wide host range. Field releases of <i>Scleroderma guani</i> Xiao et Wu for control of <i>Xylotrechus grayii</i>, <i>Phytoecia rufwentris</i>, <i>A. glabripennis</i> etc. have continuously achieved good results [96]</p>
		<p>Wang Suying applied bethyloids to control <i>A. glabripennis</i> (Motsch.) The results showed that the parasitism rate of three year old ALB larvae was 100%, reducing to 25% for four year larvae and to zero for 5 years larvae. The infectivity rate of bethyloids as carriers for <i>Beauveria bassiana</i> and <i>Paecilomyces farinosus</i> was 88% and 91% respectively [97]</p>
		<p>The natural enemy complex of <i>A. glabripennis</i> (Motsch.) and <i>A. nobilis</i> Ganglbauer is limited. In Ningxia Hui Autonomous Region, the main natural enemy is <i>D. helophoroides</i> (Fairmire) parasitizing mature larvae, pupae and adults of <i>A. glabripennis</i> (Motsch.) and <i>A. nobilis</i> Ganglbauer [113]</p>
		<p>*Wang Hongqian found 6 to 61% of eggs of <i>Apriona germari</i> (Hope) had been parasitized by <i>Aprostocetus fkutai</i> Miwa et Sonan in poplar forests [54]</p>

Activity	Summary	Research and Application
Physical control		
Physical measures	catch adults, crush larvae and eggs using physical actions	During the period of adult eclosion, adults are caught by hand and destroyed. In July to August, ALB egg sites can be destroyed by hammering or digging out by knife. If new oviposition sites are found, insert thin wires to kill larvae ^[1]
		* <i>Apriona germari</i> (Hope) adults can be easily caught and destroyed when they feed or rest on mulberry or other hosts during the day ^[3]
		Catching adults, crushing larvae and eggs, inserting wires to kill larvae and pruning are discussed as control measures ^[5]
		Some measures such as catching adults, crushing larva and eggs have been used in “Inner Mongolia <i>A. glabripennis</i> (Motsch.) control project area” with good results ^[41]
		At the peak of ALB adult laying, break or crush the bark four cm above new depressions (oviposition sites) using hatchets or hammers in order to kill eggs and newly hatched larvae ^[52]
		*In July, search for U shape wounds created by <i>Apriona germani</i> (Hope) laying eggs then crush eggs and dig up newly hatched larva to achieve control ^[58]
		*On finding frass (excreta) under the crown of a tree or evidence of larvae tunnels on the stem, insert thin wire repeatedly into hole to kill larvae of <i>Apriona germani</i> (Hope) ^[59]
		*Insert wires into newly bored holes to kill larvae of <i>Apriona germani</i> (Hope) ^[63]
		Because the adults of ALB move slowly, they are easy to catch before eggs are laid ^[61]
		It is recommended to gather all possible work force to catch the adults of <i>A. nobilis</i> . Ganglbauer, to crush the eggs and to dig out the young larvae in the period of adult eclosion and egg incubation ^[60]
Light traps	Using light to attract adults and then killing them	Experiments using light to attract <i>A. glabripennis</i> (Motsch.) achieved good results in Anhui province ^[32]

Activity	Summary	Research and Application
High voltage current	Application of electric currents to kill adults	A high voltage current was applied in an experiment on poplar wood damaged by <i>Anoplophora nobili</i> Ganglbauer. The application of a high voltage current was effective in killing first to third instar larvae. The mortality rate ranged from 70 to 80% and 80 to 90%. It was concluded that the application of high voltage current showed promise for application in controlling wood pests i.e. stem borers as well as for lumber quarantine ^[185]
Chemical control		
Fumigants		<p>Fumigation of ALB by applying a plastic membrane of polyvinyl chloride of 0.5mm as tent, size: 9m×12m. Pesticide dosage: is 7 to 9g of 56% Aluminium phosphate per cubic meter when average day temperature is about 10°C for 120 to 168hr. When average day temperature is between 0 to 10°C; 50g of sulphur fluoride for each cubic meter is used for 24 to 48hr^[52]</p> <p>*Fan Di used Aluminim phosphate to control <i>Apriona germari</i> (Hope). The results showed that the dose was 01.g ALP/hole ^[13]</p> <p>*Li qinchun applied 0.2g Aluminium phosphate into larvae tunnels then blocked it with mud; 95% of larvae were killed. During larval stages the application of pesticides to control <i>Apriona germari</i> (Hope) is recommended ^[1]</p> <p>Fan Di applied ALP “poison stick” to control <i>A. glabripennis</i> (Motsch.) and <i>Apriona germari</i> (Hope) by application of Zn₃P₂ with oxalic acid applied to the end of a stick. The stick is then inserted into the hole and poison gas PH₃ is released and death of larvae may resul. ^[13]</p> <p>*Li Yurong used “poison sticks” to control <i>Apriona germari</i> (Hope). The stick is inserted it to the new hole, frass is removed and the hole is blocked up with mud. A safety note reminds handlers that poison gas should be avoided. ^[17]</p> <p>Liu Haiqing compared the effects of inserting poison stickers with catching adults and found that the former is 19.3% of the cost of inserting poison stickers^[89]</p> <p>Toxicity tests of phosphine fumigation of poplar timber infested with <i>A. nobilis</i> Ganglbauer was conducted at the temperature of 4.4, 10.0, 15.5 and 21.1 °C The estimated CT products for Probit 9 kill were 629.8 (5days), 312.2 (5days), 112.8 (4days) and 36.6 (3days) mg.h/l respectively ^[125]</p>
Pesticide Application	General	<p>*Li Qincun injected 10-15ml of 80% DDVP into larvae tunnels and plugged holes with mud. The results showed the lethal rate was over 95% for <i>Apriona germani</i> (Hope) ^[1]</p> <p>Zhou Jiayi used Zn₃P₂ and 2.5% Deltamethrim (Decis) to control <i>A.nobilis</i> Ganglbauer with an 80% mortality rate ^[62]</p>

Activity	Summary	Research and Application
		*Huang Dazuang used poison ointment No.1 to control <i>Apriona germari</i> (Hope) and achieved good control ^[80]
		Wu Zhedong injected seven types of pesticide into larvae tunnels to control the late instar larvae of <i>A. glabripennis</i> (Motsch.) in <i>Populus nigra</i> . The results showed a 40% “kill rate” for Omethoate and 50% for Methamidophos with the rate reaching 90 to 100% when the dosage was 4ml/hole ^[140]
		*The control of <i>A. chinensis</i> (Forster) was attempted in urban areas of Shaoxing City from 1996 to 1998. Three insecticides were used on <i>Salix babylonica</i> with three application doses for each insecticide. The results showed that <i>A. chinensis</i> (Forster) control could be made at the larval stage by putting the insecticide into the holes with 800g/l solution of Dichlorvos 80EC or 3.6g/l solution of Adamectine 1.8EC or 1/16 tablet of 56% Aluminium phosphate, resulting in more than 90% of the larvae being killed. This method was suitable for control <i>A. chinensis</i> which were infesting garden trees, urban parks and scenic areas ^[173]
		*Yang Aidong controlled the larvae of longhorned beetles using ammonia ^[178]
		Application of Phoxim (200×-500×), Cypermethrin (500×-1000×), Fenitrothion(45%), to control ALB ^[5]
		During the peak period of adult eclosion and larvae hatch, spray Difluron (Dimilin) (2000×), 40% Omethoate (800×-1000×), or 2.5% Deltamethrin (Decis) (1500×-2000×) to kill larvae and adults of ALB ^[17]
		Based on the behaviour of <i>Anoplophora glabripennis</i> and selection of insecticide for controlling the beetle, experiments were carried out on the effects of Mothcide II and IV (two new types of insecticide developed by Zhao Xueren but active ingredients were not revealed) to control the beetle. The pathogenicity of both insecticides was more than 90% ^[91,94,111]
		Various pesticides have been recommended for application in “Inner Mongolia <i>Anoplophora glabripennis</i> Motsch. control project area” ^[41]
		Spray insecticides on the outside of ALB egg depressions to control larvae before they enter the woody parts of trees. Inserting insecticide impregnated sticks and injection of pesticides into the larvae holes is intended to eradicate larvae during the growing season. Tree crown spraying is used to control the adults during peak emergence ^[52]

Activity	Summary	Research and Application
		In slightly damaged areas, 40% Dimethoate EC (100×-200×) was used for spraying trunks to control larvae of <i>A.nobilis</i> Ganglbauer under the bark or 25% wettable powder of Carbaryl ((150×) was used for spraying crowns to control the adults. Other measures of control included the application of insecticide impregnated cotton, pesticide impregnated mud and sticks coated with Zinc phosphide for filling holes to control larvae ^[60]
		Spraying 40% Omethoate and 16% Quinalphos resulted in 80% and 76.7% control respectively. Pesticides were tested against ALB and <i>Apriona germani</i> (Hope) ^[64]
		Liang Chengjie found that some pesticides such as Fenprothrin, Azodrin were ideal for controlling the larvae of <i>A. glabripennis</i> (Motsch.) ^[67]
		Mao Shenghe sprayed pesticides to control ALB larvae. The results showed the lethal rate of 40% Methidathion (50×) reached 90%, and the lethal rate of 24% Wanling® with DDVP (2:1) reached 85% ^[86]
		Branches of <i>Broussontia papyrifera</i> were soaked in water solutions of Carbofuran, Aldicarb, Phorate and Monocrofos in concentrations of 50 and 100mg/kg as lure branches and branches of <i>Acer saccharum</i> were soaked in 50mg/kg. The average mortality of the adults, <i>A. glabripennis</i> (Motsch.) and <i>Apriona germari</i> (Hope) was 83.8%, 98.9%, 93.3%, 90.0%, 93.4%, 97.8%, 92.7%, 93.8%, 89.2%, 100.0%, 100.0%, and 96.7% respectively. If the branches were sprayed with water solutions of Monocrofos, Esfenvalerate, Alphamethrin, Fenprothrin and Cyhalothrin in concentrations of 50, 25 and 12.5mg/kg to control the adults of <i>Apriona germari</i> (Hope), the average mortality was 45.9%, 33.4%, 0.0%, 100.0%, 91.6%, 75.0%, 100.0%, 100.0%, 100.0%, 75.0%, 75.0%, 60.0%, 100.0%, 100.0%, and 100.0% respectively ^[100]
		Experiments with pesticides to control different stages of ALB larvae showed spraying systemic insecticides gave good control ^[115]
		Gao Ruitong sprayed Fipronil and Cypermethrin to control two species of longhorned beetles. The results showed the lethal rate reached 100% when the dosage was 2.0×10^{-6} and 110.4×10^{-6} respectively ^[183]

Activity	Summary	Research and Application
	Micocapsules-contact breaking and/or slow release	Degradation and residue determination tests carried out in the Northwest of China showed that the residues of Cypermethrin were maintained above 30% within 45 days after being sprayed onto the bark. In tests with contact-breaking micocapsules against ALB, 90% mortality of <i>A. nobilis</i> Ganglbauer and <i>A. glabripennis</i> (Motsch.) was achieved within 38 days post treatment. These tests indicate that contact micocapsules have some advantages, such as longer duration and increased resistance to environmental factors, especially when active ingredients are synthetic pyrethroids ^[136]
		The result of studying contact-breaking micocapsules showed that they had good results for killing <i>A. glabripennis</i> (Motsch.). Fifty days post-treatment, on average 2.6 <i>A. glabripennis</i> (Motsch.) were killed. There were significant differences between treated and non treated areas ^[137]
		The mortality rate is only 21% when Dimilin 3 (dosage 180ppm) is used on adult poplar beetles. When mixed with other pesticide micro-capsules (19:1), the mortality rate is higher. The best results can be achieved with a mixture of Dimilin 3 and Cypermethrin wettable micro-capsule. A mixture of Dimilin 3 and organic phosphor has a longer effect, while Imidacloprid wettable micro-capsule is the most efficacious in controlling <i>A. glabripennis</i> (Motsch.), <i>Monochamuse alteratus</i> Hope and <i>Apriona swainsoni</i> Hope, at a dosage of 50ppm. The mortality rate is over 95% and persistence is longer than 35 days. High performance Cypermethrin micro-capsules controlled adult beetles but have low persistence ^[68]
		Contact-Breaking Microcapsules have good results for controlling <i>A. glabripennis</i> (Motsch.) and period of viability is over 42 days ^[138]
		Luo Youqing sprayed contact-breaking microcapsule (Green Mine) (50×). The results showed the lethal rate reached 90% after 40 days for ALB ^[27]
		Sun Xinjie sprayed 4.5% contact-breaking microcapsule (250×) to control the adults of longhorned beetle and achieved good control ^[65]
		During the eclosion peaks of <i>A. glabripennis</i> (Motsch.), spraying Green Mine (100×) can kill adults with a residual period of 22.8 days ^[82]

Activity	Summary	Research and Application
		<p>The experiment showed that microcapsules can kill ALB rapidly and have long-lasting effects up to 40 days. After application, the population of the next generation reduced sharply. Application before adult emergence is recommended^[105]</p> <p>It is reported that contact-breaking microcapsules are improved when they are processed at low temperatures. When used to control <i>A. nobilis</i> Gangalbauer and <i>A. glabripennis</i> (Motsch.), they have better effect than slow-release microcapsules. This is achieved by mode of action as when they come in contact with ALB adults, the capsules burst and release all the pesticide contained in the capsules adheres to the legs of longhorned beetles. Viability was maintained for 39 days after being sprayed onto the bark.^[139]</p>
Insecticide treatment of trunks	<p>Trunks are treated by coating or banding with insecticides</p> <p>Trunk injection</p>	<p>Fan di <i>et al.</i> coated trunks with pesticides to control the adults of two species of longhorned beetles. The pesticide was composed of 2.5% Deltamethrin (Decis) and 80% Sulfur-phosphor^[13]</p> <p>Luo Youqing <i>et al.</i> used a mixture of pesticides to coat trunks of trap trees^[27]</p> <p>Trunk banding to control beetles in poplar trees has many advantages including little pollution and long efficiency. The 24-hour mortality rate of beetles in contact with the pesticide for five seconds is 80% to 93.2% respectively. Thirty days post-treatment of willow trunks with 0.5% BL-6 or 25% BL-8, the number of dead beetles in a tree averaged 30.2 and 39.8 respectively. In the control group, it averaged 0.6. The 24-hour mortality rate of beetles which move over the pesticide band can be 100%. Fifty-two days post-treatment of poplar trunks with 0.5%BL-6 or 25%BL-8; the number of dead beetles averaged 7.8 and 7.4 respectively and it averaged 0.3 in the control group^[69]</p> <p>The trunk coating insecticides included in the tests were 0.5% BL-1 (2.5% Deltamethrin: Mouse glue = 1:4), 0.25%BL-4 (2.5% Deltamethrin: Mouse glue = 1:9), 0.5%BL-6 (2.5% Deltamethrin: vaseline= 1:4) and 0.25%BL-8 (2.5% Deltamethrin: vaseline= 1:9). In one test, willow trees were treated with 0.5% BL-1 and 0.25%BL-4. Adult beetles were introduced to contact treated area for 5 seconds and checked 24 hours later. The mortality was 80% for 0.5% BL-1 and 93.2% for 0.25% BL-4. The total number of beetles found dead under treated trees 33 days post treatment averaged 30.3 for 0.5%BL-1 and 39.8 for 0.25%BL-4 for each tree^[181]</p> <p>Trunk injection with 10% Confidor and soil injection with Confidor (a.i. Imidacloprid, 60×), post-application 10-20 days, the number of dead <i>A. glabripennis</i> (Motsch.) adults was 37/tree and 12.0/tree, respectively. However, only 1.8 adults died per tree for the control^[9]</p>

Activity	Summary	Research and Application
		This paper deals with control of the larvae of <i>A. glabripennis</i> (Motsch.) using the technique of autoflowing trunk injection. The results showed that TianNiuDi is the most effective of four insecticides tested and a relationship between control result (P) and dosage (x) (ml/cm ² cross section area) is $P=1.0465+0.3592lnx$. Optimum dosage to control larvae with Tiannudi is 0.5ml/cm ² ~0.7ml/cm ² . Treatment should be done once for a given dosage [23]
		*The control effect was over 90% when trunk injections of 2.5% Deltamethrin (625×) and 80% DDVP (100×) were made into trunks to control <i>Apriona germari</i> (Hope) [25]
		Trunk injections were tested in the project area of Inner Mongolia for control of <i>A. glabripennis</i> (Motsch.) Chemicals included Omethoate, 16% Quinalphos and Bichonglin [41]
		Wang Tongyue adopted injection techniques to control <i>A. glabripennis</i> (Motsch.) The results showed it was a good control measure [48]
		Zou Minjin recommended injection technique to control <i>A. glabripennis</i> (Motsch.), pesticides included 80% DDVP, 25% Phosmet, 10% Chuchongqin (500×) [63]
		Xue Zhicheng injected 80% DDVP (500-1000×) and 50% Fenitrothion (1000×) into trunks to control ALB [70]
		*Liu Suicun injected pesticides into trunks to control <i>Apriona germari</i> (Hope). The results showed the mortality rate of Methamidophos was 71.12%, Monocrotophos was 54.4%, 40%Omethoate was 11.54% [71]
		*Xu Zhongyuan injected 5-12ml of DDVP and Tichlorfon (150-300×) into the larvae tunnel of <i>Apriona germari</i> (Hope) [72]
		*The population density of <i>Saperda populnea</i> L. decreased by 90% after trunk injection of pesticides [73]
		Xu Zhicun found that residues of Imidaclaprid remained in poplar longer than 40 days after being injected into the base of trees and the highest level of residues remained in the trunks, followed by branches and lastly in the leaves. [74]
		Systemic insecticides were injected into stems of trees to control larvae of <i>A. nobilis</i> Ganglbauer and <i>A. glabripennis</i> (Motsch.) The method was manageable and 90% of the larvae could be killed with selected insecticides and correct dosage [75]
		Omethoate, Phorate, Dichlovos were either smeared on or injected into poplar trunks, or borer holes were blocked to control <i>A. glabripennis</i> (Motsch.) of first to fourth instar larvae and 63% of adults were killed by injecting the mixture of Omethoate and Phorate [81]

Activity	Summary	Research and Application
		Zhang Shuhuai injected pesticides into trunks to control <i>A. glabripennis</i> (Motsch.). The lethal rate of systematic pesticide against adults was 95% and the lethal rate of systematic pesticides against larvae was 91 % ^[84]
		This paper recommends that from May to June, pesticides should be injected into trunks to control newly emerged ALB larvae ^[88]
		Trunk injections of insecticides were applied to control the larvae and adults of ALB. Systematic trunk injections had good insecticidal properties and long residual efficiency. The control results were as follows: adult mortality was up to 92.9% in the cage-covered, insect-inoculated trees, 99.9% after being artificially fed on insecticide-injected shoots and 94.7% in the large area windbreak forest ^[95]
		During the peak period of ALB oviposition and hatching, of the four pesticides tested the best results were achieved with injections of 20% Imidacloprid ^[106]
		Lv Xiaohong selected one type of pesticide from 10 tested for trunk injection. Efficacy was up to 97% ^[107]
		Zhu Xiaoling injected Stem Pesticide (No.1) to control ALB and got good control ^[108]
		In Bameng, Omethoate and Bichonglin have been injected into trunks to control ALB and good control effects have been achieved ^[109]
		Confidor 20% SL can be absorbed well and carried by poplars. It is very effective as a trunk injection for control of adults of poplar longhorned beetles, <i>A. glabripennis</i> (Motsch.) and <i>A. nobilis</i> Ganglbauer. Control is long term such that three months after injection, the mortality of the adults fed with the fresh branches and leaves of the treated poplars is 70% to 80% ^[122]
		Wang Huizhen injected Methamidophos into trunks to control the adults of <i>A. glabripennis</i> (Motsch.). The results showed it is durable and effective in controlling beetles ^[180]
		Zhao Shengmei injected 40% Monocrotophos to control <i>Anoplophora nobilis</i> Ganglbauer and achieved good control ^[182]
		The method of injecting 20% Confidor (a.i Imidacloprid) solvent in the base of trees to control the beetles in poplar trees was effective. Recommended for the control of longhorned beetles that have a long but irregular emergence period ^[186]

Activity	Summary	Research and Application
		Lv Xiaohong <i>et al.</i> injected pesticides into the roots to control <i>A. glabripennis</i> (Motsch.). Miezuhling (effective content: 40% Omethoate, 50% Azodrin and 50% Methamidophos) provided 97% control ^[131]
Quarantine measures		
		<p>To strengthen quarantine for nurseries, it is recommended to clean damaged seedlings in a timely manner, and to prohibit spread of infested seedlings. Seedlings should be carefully examined before planting and those seedlings that are infested should be destroyed^[8]</p> <p>During indoor tests, the larvae and pupae of <i>A. nobilis</i> Ganglbauer in poplar wood were killed at a dosage of 104g/m³ at 15.5 °C and 21.1 °C but were not completely killed at the dosage of 120g/m³ and 160g/m³ respectively at 10.0°C and 4.4°C^[16]</p> <p>The ALB was controlled effectively by means of strengthening quarantine in the “Control area of <i>Anoplophora glabripennis</i> (Motsch.) in Inner Mongolia”^[41]</p> <p>Mature trees and those severely damaged by the longhorned beetles were removed at the same time and the insect infested trees were treated using the following methods; bark peeling and drying, fumigation with Aluminium phosphide in a hermetically sealed plastic booth for seven days or soaking in water for 30 days. Damaged wood was downgraded to fire wood status and the salvageable wood was manufactured into 2cm-width or thinner board^[60]</p> <p>Toxicity tests of Methyl bromide (MB) fumigation for the larvae of <i>A. nobilis</i> Ganglbauer was conducted at temperatures of 4.4, 10.0, 15.5 and 21.1 °C. The estimated CT products for Probit 9 were 1133.78, 938.21, 642.39 and 349.87gh/m³ respectively. The larvae and pupae of <i>A. nobilis</i> Ganglbauer were found in poplar timber and all the wood-borers were dead in the confirmatory tests if the CT products had reached the requirements for Probit 9 in the toxicity tests. The MB quarantine standard for the wood-borer in wood packing material was proposed^[76]</p> <p>After being stacked for different periods, poplar logs damaged by beetles (ALB) are sorted into boards of different thickness (1.0cm, 1.5cm, 2.0cm and 2.5cm respectively), the presence of larvae and pupae of ALB inside logs are systematically examined. There are no living beetles in poplar after being stacked naturally for more than seven months, so it can be safely made into solid wood packing materials (SWPM) of different thickness to prevent artificial spread of <i>A. glabripennis</i> (Motsch.)^[102]</p> <p>Quarantine methods were put forward for solid wood packing materials (SWPM) with logs damaged by the beetle^[87]</p>

Activity	Summary	Research and Application
		<p>After being stacked for different periods, poplar logs damaged by beetles (ALB) are thinned into boards of different thickness (1.0cm, 1.5cm, 2.0cm and 2.5cm respectively), the presence of larvae and pupae of ALB inside logs are systematically examined. There are no living beetles in poplars after being piled naturally for more than seven months, so it can be safely made into solid wood packing materials (SWPM) at different thickness to prevent artificial spread of ALB. For newly felled poplar different stages of the beetles are all killed when logs are thinned into boards whose thickness is less than 1.5cm., When logs are thinned into boards 2.0cm in thickness, all galleries of ALB are destroyed and exposed larvae soon die^[184]</p> <p>When the larvae of <i>A. nobilis</i> Ganglbauer were put into three kinds of medium, air, sawdust and poplar wood, and heated by hot air to different temperatures, the mortality results showed that all larvae in different mediums died in the following conditions; in air, at 55 °C and 30% RH for 80mins; in wood, at 55°C for 35 mins; in sawdust, at 55°C for 25 mins, at 60°C for 25mins, at 65°C for 10mins and 70°C for 5 mins respectively^[77]</p>
Pheromones	Pheromone to control ALB	Luo Youqing used column chromatography and folium chromatogram to separate sex pheromone of the female adults of ALB from distilled liquid. Results showed the strong attraction properties to male adults of ALB ^[78]
Repellents	Using tree volatiles to avoid ALB damage.	<p>Luo Youqing demonstrated that <i>Ailanthus</i> sp. has a repellent effect on longhorned beetles^[78]</p> <p>Wang xi meng's research shows the volatile substance of <i>Ailanthus</i> sp has strong repellent properties for the longhorned beetle and ALB is more susceptible than <i>A. nobilis</i> Ganglbauer. If grown around poplar forest its repellent properties can be used to protect poplar stands^[79]</p>
Sterilisation	Irradiation or spraying chemo sterilants	To determine the feasibility of microwave irradiation as an alternative treatment, laboratory experiments were carried out on 10cm×10cm×10cm and 10cm×10cm×2.5cm poplar blocks of wood artificially infested with live Asian longhorned beetle larvae and pupae with subsequent 2450MHz microwave energy irradiation. Experimental results revealed that microwaves could penetrate 10cm thick poplar blocks. Preliminary results showed that 5 minutes and 2 minutes of irradiation at 900 Watts was lethal to all the larvae and pupae in green 10cm×10cm×10cm and 10cm×10cm×2.5cm poplar blocks, only three minutes and 30 seconds was necessary to kill the larvae in dry wood, respectively ^[116]

Activity	Summary	Research and Application
		<p>The female imagos of the longhorned beetle <i>A. glabripennis</i> (Motsch.) were irradiated with ^{60}Co T's ray to study sterility. Results showed that irradiation has no influence on eating behaviour of the female imagos but notable affect on oviposition behaviour with a clear reduction of oviposition capacity in relation to increased irradiation. Impact on its life-span and mating behaviour were chiefly at 200 Gy's irradiation. It caused the marked reduction of the life-span and no mating was observed. Thus, it is concluded that the female imagos of the longhorned beetle can be sterilised by irradiation ^[129]</p> <p>Irradiation had no influence on sperm transfer, but had some negative impact on sperm activity. Under caged conditions, mating frequencies of different mating types were graded by values calculated by probability. Released irradiated LHBs effectively suppressed the reproduction of normal LHBs in release cages. Irradiation had no evident influences on competitive mating ability of released LHBs under field-cage conditions ^[133]</p> <p>Based on the success of the filtration indoor experiment on some chemosterilants, tests were carried out to control the longhorned beetle, <i>A. glabripennis</i> (Motsch.), by spraying wettable powder, chemosterilant CS, during the peak period of eclosion, in order to determine the effect in the field. The field experiment obtained clear results on sterile efficiency to the pest. The mortality rate for eggs and newly hatched larvae was 72% ^[143]</p> <p>Hampa injected into the trunk of <i>Populus</i> was evaluated for sterility effect on ALB. The results show that Hampa in the trunk could be carried up and down and have residual effect for about a month. Thus ALB larvae could eat the Hampa, which would lead to sterility of the adults. When Hampa is injected at a dosage of 40mL per tree, the non-hatch rate of eggs, the deformity-rate of hatched eggs, and the total mortality excluding natural mortality are 80%, 84% and 87% respectively ^[179]</p> <p><i>A. glabripennis</i> (Motsch.) male pupae and male adults were irradiated with ^{60}Co γ-rays to study the effects of male sterility. The results showed that the acceptable irradiation dose for male sterility is 0.097kGy, the optical period for irradiation adults, and fatal irradiation dosage is 0.776 kGy ^[128]</p>

* Important Longhorned Beetles in China other than ALB

TABLE 2: EVALUATION OF CONTROL METHODS FOR ALB

Control methods are aimed at three levels; the individual beetles, the host tree and for the whole shelterbelt forest ecosystem.

Control Measures	Brief Description	Overall Evaluation	References
Aimed at individual beetles			
Mechanical control			
Capture adults	Before the oviposition period capture and kill adults	Simple and convenient and reduces oviposition and hence controls the population density ²	1,3,5,41, 58,60, 61, 85,89
Physically crush eggs and small larvae	At the peak of egg laying, break or crush the bark 4cm above fresh depressions using hatchets or hammers in order to kill eggs and newly hatched larvae	Effectively reduces the number of eggs and first instar larvae ³	1,3,5,41, 52,58-60, 63,85,89
Use of wires in larvae tunnels	Thrust wires into larvae tunnels to kill larvae	Directly kills many larvae ³	1,5,59, 60,63
Block oviposition sites and holes with cement	Clean larvae tunnels and fill holes with cement	Effectively smothers and kills larvae ³	1,5
Application of electric currents	Use of electric current on infested trees damaged by ALB	Kills ALB effectively ³	185
Chemical control			
Injecting insecticides into larvae tunnels (excrement holes)	Inject insecticides into larval tunnels and fill with absorbent cotton	The mortality rate can reach 90%. It is secure, effective and free from contamination ¹	1,13,140 173,178
Inserting “poison sticks”	Insert sticks impregnated with Zinc phosphide into holes to kill larvae		13,17,62 80
Fumigation	Insert Aluminium phosphide into holes and filling with mud to fumigate larvae		1,13,52,125

Control Measures	Brief Description	Overall Evaluation	References
Block larvae tunnels with pesticide impregnated mud	Fill holes with pesticide impregnated mud to kill larvae	Effectively kills larvae ²	17,80
Biological control			
Application of biological control agents into larvae tunnels	Fill holes with entomopathogenic fungi and entomophilic nematodes	The mortality rate of larvae can reach 65% ²	34,35
Sterilisation			
Radiation	Irradiate adults and pupae	New control measures ⁴	128-129,133
Chemosterilant	Spray chemosterilant		143,179
Aimed at individual host trees			
Sivicultural measures			
Pruning	Prune twigs to prevent adults from laying eggs	Effectively reduces oviposition ²	3
Trunk treatment	Treat the trunk with compound of lime, sulphur and water to inhibit the adult from laying eggs		126
Stump grafting	Cut down trees which are badly damaged and grafting resistant species onto the stumps	Effectively renews damaged forest ³	4,15,16,117
Cut down infected trees	Cut down old and dying trees to reduce the population density	Effectively reduces population density ¹	12,126
Cut upper trunk to renew growth	Cut upper trunk (over 1.6-1.8m). Use coppices for renewed growth	Effectively reduces population density ³	4
Regeneration by coppice	Cut down trees, regenerate by coppice		4,83,101

Control Measures	Brief Description	Overall Evaluation	References
Chemical control			
Trunk application of pesticides	Apply insecticide round the trunk with a brush dipped in pesticide paste (banding)	Effectively kills adults, especially good for small poplar trees and trap trees ²	13,27,69 181
Trunk injection for adult control	During the peak adult evergreens insecticides are injected into trunk to kill adults	Injecting 40% Omethoate can kill 90% adults, good for high value trees ¹	9,23,25,48, 63,69-75, 81,84, 91,94,95
Injecting insecticides into trunk for larvae control	Before the tree is three years old, inject insecticides into trunk to kill larvae under the bark	The mortality rate can reach 70-80% ¹	106-109, 111,122,131, 135,140,182
Injecting insecticides into the lower trunk	Injecting insecticides in the lower trunk to control larvae	Effective for larvae under the bark ²	69,71,74 180
Insecticide application to crown and trunk	During peak adult and larvae emergence, spray insecticides into crown and trunk to control adults and larvae	Effectively kills adults and larvae ¹	5,17,27,4152, 60,64-68,82, 86,100,105, 115,126, 136-139,183
Biological control			
Application of entomopathogens	Using <i>Beauveria bassiana</i> , <i>P. farinosus</i> , BtK, entomophilic nematodes etc.	Effective for killing adults and larvae ¹	34-39,99,104, 112,118,127,142, 171,172,176,177

Control Measures	Brief Description	Overall Evaluation	References
Aimed at shelterbelt systems management			
Sivicultural measures			
Enhance tree growth and vigour	Irrigate and fertilize in time to improve tree health.	Effectively improves tree vigour and tolerance to insects ³	2,9-10
Sanitation cutting	Cut trees with serious pest problems in a timely fashion. Remove weak wood, dead and dying wood and ensure proper disposal and improve condition of standing forest to eliminate pest source	Effectively reduces the population density ³	1,8,9,12
Plant isolation belts	Because the adults cannot fly far, plant 1-2 km isolation belts composed of tolerant tree species or poplars resistant to longhorned beetle	Effectively prevents longhorned beetle from being introduced and reduces the population density ²	4,32,33
Plant trap trees	Plant trap trees to attract adults and to reduce the population density. Trap trees includes <i>Acer negundo</i> , Ash-leaf Maple, etc.	The attraction rate reaches 66%. Effectively reduces the population density ²	5,20,24-33,93,110,132,134
Plant mixed forest	Plant mixed forest composed of many tree species and plant protection forests using multi-tree species	Enhances ability to withstand ALB outbreaks ³	4-7,11,27,89,90,114,123,141
Plant resistant species	Plant resistant poplar species to enhance the capability of managing ALB		2,4,5, 13-39,90,103,119,124
Encourage fast-growing poplar plantations	Encourage planting of fast-growing poplars or shorten the felling cycle to resist and avoid the peak emergence of ALB	Effectively protects forests ²	5

Control Measures	Brief Description	Overall Evaluation	References
Biological control			
Encourage natural enemies, predators	Hang bird's nests in forests to protect and attract woodpeckers that feed on ALB larvae	Can contribute to sustained control ²	2,40-46,89, 98,113,130, 174,175
Encourage natural enemies, parasites	Rear and release parasites such as trichogrammatids, <i>Scleroderma</i> sp., <i>Zombrus</i> sp., <i>Schreineris</i> sp. etc		35,41,47-57, 92,96-97,113 120,121

¹Wide application ²Local application only ³Limited practice ⁴Research still needed

TABLE 3: MONITORING AND FORECASTING MEASURES FOR ASIAN LONGHORNED BEETLE

Measures	Brief Description	Application	Evaluation	References
Monitoring				
General investigations				
Survey	Select survey method dependent on forest type	General investigation on ALB ¹	Reflects the present pest situation at the time of sampling and should be combined with systematic monitoring	144-147, 150
Monitoring of sample plots	Evaluate a designate temporary sampling plot twice a year			
Light traps	Set up light traps to attract adults	General investigations ⁴		148-150
Pheromones	Use pheromones to lure adults			151
Systematic monitoring				
Investigation of egg stages	Examine egg grooves and hatching in permanent sample plots	Monitoring and forecasting of a specific pest ¹	By systematic investigation, the exact pest status of ALB can be determined	144-149
Investigation of larval stages	Evaluate the survival rate and development of the larvae in permanent sample plots			
Investigation of pupal period	Evaluate the development of the pupae in permanent sample plots			
Investigation of adult stages	Evaluate adult eclosion and adult laying in permanent sample plots			

Measures	Brief Description	Application	Evaluation	References
Forecasting				
Forecasting frequency				
Based on morphological characteristics of ALB	Based on morphological characteristics of the developmental stages to estimate the timing of the next stage	Pest which has long life stages ³	Exact short-term forecasting	150,152, 153
Development cycle	Based on the development phase to forecast the timing of the next generation.	Pest whose development cycle is known. ¹	Exact short-mid-term forecasting	153-158
Accumulative temperatures	Based on the temperature for development zero and the current temperature used to forecast the period of occurrence	Pest whose temperature of development zero is known and where temperatures are recorded ¹		154,155, 158,159
Phenology	Based on the relationship between the occurrence of ALB and environmental conditions	Applicable for locations where environmental conditions are recorded ³	Crude short-term forecasting	144,155, 157
Trap trees	Plant trap trees to attract adults. Capture rate is used to forecast pest occurrence	General application ²	Exact	148,149, 160-163
Forecast of numbers				
Empirical measurements	Based on empirical measurements and current pest numbers. The data is used to forecast potential numbers	Applicable where historical data is recorded and accessible ¹	Rough	152,156- 158,164

Measures	Brief Description	Application	Evaluation	References
Mathematical model	Determine the interrelationship between historical data with the different factors to build a forecasting model		Exact	152,154, 156,165-167,169
Life table	Use factors in the life table to forecast degree of establishment in a new area		Exact	152,168
Forecast of trends				
Empirical formula	The index of occurrence trend=climate level * the resistance degree of species * the management degree of silviculture – the degree of natural enemies – the degree of soil	General application ³	Rough	148,152
Forecast of occurrence area				
Climatic factors	Forecasts are made based on the biological characteristics of ALB and the current climatic factors			148,152
Ecological factors	Forecasts are made about infestation sites based on the proportion and distribution of poplar trees, access and human activities	Local ³	Rough	148,170

¹Wide application ²Local application only ³Limited practice ⁴Research still needed

TABLE 4: QUARANTINE MEASURES FOR ASIAN LONGHORNED BEETLE

Measures	Brief Description	Application	Overall Evaluation
Quarantine at source of infestation			
Nursery	The nursery must be located far from the pest source, ideally more than 3-5km. The trees planted around the nursery should be resistant species	All nurseries located in the infested area ¹	Effectively protects ALB from being introduced to non-infested areas
Quarantine in nurseries and poplar forests			
Evaluation of pest situation	First appraisal of situation followed by establishment of a test plot to investigate pest situation (if present) systematically over time	All nurseries and poplar forests located in the epidemic area ¹	Effectively prevents ALB from spreading
Quarantine treatment	If the damage rate is <5%: cut down the damaged trees; clear the infested plots; replant healthy resistant trees. In seriously damaged forests cut down all trees. Destroy or treat all felled trees		
Quarantine in lumber storage and processing plant			
Take samples	Log, wattle: >50m ³ , sample 3%; 2-50 m ³ : 5%; < 2m ³ : check all. Panel, square and packing timber: >50m ³ , sample 0.5%; 2-50 m ³ : 1%; < 2m ³ : check all	Applicable in lumber storage and processing plants, can generally be used in infested areas ¹	Effectively prevents ALB from spreading

Measures	Brief Description	Application	Overall Evaluation
Quarantine check	Dissection and check		
Quarantine treatment	See section on quarantine treatments		
Transport Quarantine			
Application for Quarantine certificate	Application for quarantine takes 15 days	General application in infested areas ¹	Effectively prevents ALB from spreading.
Quarantine of seedlings and young trees	Sample 5% to check for infestation		
Quarantine of timber and productions	Take samples to check for infestation. Log, wattle: >50m ³ , sample 3%; 2-50 m ³ : 5%; < 2m ³ : check all. Panel, square and packing timber: >50m ³ , sample 0.5%; 2-50 m ³ : 1%; < 2m ³ : check all		
Quarantine Treatments			
Fumigation	Use fumigation to kill ALB, such as Bromomethane, Aluminium phosphide, Sulfuryl fluoride	Large quantities of infested materials ²	Rapid, effective, but pollution concerns and human health issues
Heat treatment	Use heated air or kiln drying to kill ALB.	Small quantity of infested materials ²	Rapid, effective and free from pollution
Water immersion	Submerge infested materials in water.	Can only be used where water resource is abundant ³	Rapid, effective, free from pollution but needs a long time.

Measures	Brief Description	Application	Overall Evaluation
Decorticate and saw	Remove the bark and saw the timber.	Logs with bark ³	Effective and free from pollution but labour intensive

¹Wide application ²Local application only ³Limited practice ⁴Research still needed

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