Host associations between xylophagous longhorn beetles (Coleoptera: Cerambycidae) and American commodity tree species from Chinese collection sources

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Abstract

A small number of longhorn beetle species (Coleoptera: Chrysomeloidea: Cerambycidae) have the potential to become invasive forest pests. International trade in live plants and wood packaging material are known invasion pathways for longhorn beetles. Once an invasive pest is intercepted in a new region, a rapid pest risk analysis is often needed to determine the appropriate response. For accurate risk quantification, natural history evidence is necessary. This information is also vital in preventing introduction. This study gathered insect collection data, especially references to host plants, of xylophagous longhorn beetles from the Institute of Zoology, Chinese Academy of Sciences, Beijing, China. Beetle associations with three important host groups were investigated: Fagaceae, Citrus spp., and avocado (Persea americana). We performed a systematic literature review to identify previously documented cerambycidae associated with these plants. Here, we report insect-plant host associations for 39 species of longhorn beetles based on a review of the literature; 43 interactions were documented, 10 interactions were novel. No host associations were recorded with avocado in China. This information serves as a foundation for pest risk analysis in determining threats posed by potentially invasive longhorn beetles into new regions.

Key words: forest pest, host plant, wood borers, longicorn, biosecurity

Introduction

Longhorn beetles, also commonly called long-horned or longicorn beetles, are often intercepted in new regions. While most are harmless, a small number can be highly invasive forest pests. Many species cannot successfully invade new regions. Yet, a small percentage can travel over long distances through human mediated transport and cause significant damage. All longhorn beetles are phytophagous, with juveniles often feeding internally on the xylem of the plant tissue and adults feeding externally on fast growing twigs and branches. The xylophagous species consume woody tissues, but even within this group there is a high degree of variability in behavior and host selection (Haack and Slansky 1987). Tree hosts of
Longhorn beetles from pine, Fagaceae, and citrus in China

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xylophagous longhorn beetles may be attacked under a range of conditions, from healthy trees to those recently dead (Wang 2017). The larvae of xylophagous longhorn beetles feed either under the bark or in the xylem (Hanks 1999). Most cerambycid species colonize dead or severely stressed trees, but some are able to colonize living trees, in which they damage the flow of nutrients within the host causing dieback, wilting, and occasionally tree death (Wang 2017).

Longhorn beetles may oviposit into commercial plants or wood packing material, conferring opportunities to “stowaway” on trade consignments originating within native ranges (Meurisse et al. 2019). International export of live plants, coupled with the use of wood packing material in a wide range of industrial transport practices, increases opportunistic invasion into new regions (Hulme et al. 2008). These pathways have been highlighted by recent invasions of several alien xylophagous longhorn beetles such as the Asian longhorn beetle *Anoplophora glabripennis* (Motschulsky, 1854) from its native range in Southeast Asia into Europe and North America (Hérard and Roques 2009). Once arrived in the new region, Asian longhorn beetle quickly established due to the wide host plant range. Attacks on local trees caused ecological and economic damage. Lengthy eradication efforts have been undertaken in the UK (Straw et al. 2015), USA (Haack et al. 2010), Italy, and in Central Europe (Hérard and Roques 2009; Hérard et al. 2009). In the USA between 2006 and 2013 costs for eradication of Asian longhorn beetles were estimated to be $537 million (Eyre and Haack 2017).

Potentially invasive longhorn beetles are frequently intercepted at ports of entry into the USA (Haack and Cavey 2000). Pest risk analysis is used to gauge the appropriate level of response, such as regulation or monitoring. Guidelines and international standards for phytosanitary measures have been developed for pest risk analysis (FAO 2004, 2007; Devorshak 2012). These standards utilize scientific evidence to determine the threat posed by the organism. Once the risk posed by a pest is quantified in this manner, appropriate responses such as whether it should be regulated, what, if any, measures should be imposed. A transparent, evidence-based approach is critical in determining potential pest status as well as guiding the managed response to biological invasions. A critical initial element of the pest risk assessment process is a literature review and synthesis of scientific data (Baker et al. 2009). This examination process determines the known information for adventive species. Yet, access to the primary data is often limited. Journals, datasets, herbaria, and gray literature can provide conflicting information about an organism or use unverified sources. In addition, language barriers can reduce the accessibility of information on international pests.

Over 36,000 species of longhorn beetle are recognized worldwide with many having little documented natural history. This knowledge gap complicates pest risk assessment as assumptions are made without direct
scientific data. Taxonomic groupings can help to identify pest families. However, this is imprecise. Similarly, host plants and consignment origins can identify an invasion pathway (Eschen et al. 2015). However, plant hosts are only determined based on known examples in the country of origin, while data on suitability of the new hosts usually do not exist. Some xylophagous longhorn beetles, such as *Xylotrechus arvicola* (Olivier, 1800), have shown different host preference in invaded regions (García-Ruiz et al. 2012). Changes in host preferences are the most problematic issue when attempting to quantify the risk posed by a new species. If a host association is known, then a pathway and impacts may be quantified more accurately. For example, the presence or absence of a coevolved congener on a shared host may help predicting impacts of an invasive pest species (Mech et al. 2019). Therefore, knowing host associations may play a key role in accurately predicting invasive capability and impacts of alien longhorn beetles.

We inspected resources from the Institute of Zoology, Chinese Academy of Sciences, Beijing, China (hereafter IZCAS) to expand the range of known host associations. Collection records occasionally contained additional collection information such as the feeding or oviposition host tree. This study focused on potential invasive pests of three groups of tree hosts that are economically and environmentally important in North America, and hence potentially susceptible to invasive Asian Cerambycidae: Fagaceae, the *Citrus* genus, and avocado. A comprehensive host search for all records or all hosts was beyond the boundaries of enquiry of this pilot project. Fagaceae are ecologically and economically important across the world, not just in the target region of the USA. The genus *Citrus* and the species avocado (*Persea americana* (Mill.)) were also selected because recent introductions of alien invasive species have highlighted susceptibility of these plant commodities to invasion and economic damage. The American citrus industry is worth $3.35 billion dollars (Simnitt and Calvin 2019) and the avocado industry $400 million dollars per annum (Perez and Minor 2018). Our target beetle species were xylophagous longhorn beetles, and excluded species feeding on non-woody plants. The specific questions for our survey were: (1) Which Cerambycidae species in the IZCAS collection and related materials have been recorded as feeding on, or associated with, the target plants? (2) For the identified beetle species, what plant associations have already been reported in previous literature? (3) Can this method provide data to support pest risk analysis?

**Materials and methods**

The survey of collection material was undertaken *in situ* at IZCAS. The original records were inspected for each of the more than 40,000 specimens in the collection. Collection notes and supporting documents were examined and explicit references to host trees recorded. Figure 1 shows a typical IZCAS collection specimen.
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Figure 1. An example of the source data. Female *Monochamus guerryi* from the IZCAS collection showing the original labels. This species is an important polyphagous pest. Photo by Mei-Ying Lin.

Table 1. Method of systematic literature review process of identified longhorn species.

| Data Source                                      | Website                                      |
|-------------------------------------------------|----------------------------------------------|
| Integrated Digitized Biocollections             | idigbio.org                                  |
| Encyclopedia of Life                            | eol.org                                      |
| Centre for Agriculture and Biosciences International - Crop Protection Compendium | cabi.org/cpc                                 |
| Centre for Agriculture and Biosciences International - Invasive Species Compendium | cabi.org/isc                                 |
| Titan database on longhorned beetles (in French) | titan.gbif.fr/index                          |
| European Alien Species Information Network (EASIN) | alien.jrc.ec.europa.eu/SpeciesMapper         |
| Global Biodiversity Information Facility       | gbif.org                                     |
| Global Invasive Species Database                | iucngisd.org/gisd/                           |
| Google Scholar Search                           | scholar.google.com                            |
| Google Search                                   | google.com                                   |

Each host label record involving an identified target tree species was recorded. For each beetle species that had an identified host plant, all synonyms were collated using online databases and published information resources (Table 1). Host associations were partly quantitative, we differentiated between singleton records (1–10), occasional records (11–25), and abundant records (26+) (Table 2).

To complement the specimen label survey, a systematic literature review of online resources was then conducted (Table 1). All host interactions were recorded. The records from each database were compared highlighting the previously unpublished host interactions. Novel hosts for these beetles, as well as the previously reported hosts are listed in Table 2. A comprehensive host record analysis is commonly the first step in pest risk analysis as part of a wider systematic literature review process. In addition to the databases listed, a Google Scholar® search was conducted with the first 100 records of all English and Chinese (Mandarin) language results, checked manually. This process was completed for the senior synonym and each junior synonym of each beetle species discovered as part of the scan. Species names were confirmed using the ITIS website (www.itis.gov; retrieved 03/10/2020). Beetles were identified to species and status followed Lin and Yang (2019).
Table 2. Known host interactions of xylophagous longhorn beetles at IZCAS. Examples in bold indicate previously recorded host interactions identified in the literature. Abundance of total sampled specimens in IZCAS is simplified as 1–10 *, 11–25 **, 26+ *** in the Species Name column. Host Species abundance represent the number of specimens recording that host association. When no further information is given in the species column the original literature source identified the plant host to family level. Scientific names of the host trees were revised and confirmed according to the Taxonomic Name Resolution. Service website (http://tnrs.iplantcollaborative.org/TNRSapp.html) and the catalog of life website (http://www.catalogueoflife.org/).

| Cerambycidae Scientific Name | IZCAS Recorded Host Interaction | Host Plants Identified in Literature Review | Literature Source |
|-------------------------------|--------------------------------|--------------------------------------------|-------------------|
| Amarysius sanguinipennis (Blessig, 1872) ** | Quercus sp. * | Betulaceae Betula sp. | Cherepanov 1982 |
|                               |                   | Betulaceae Corylus sp. | Cherepanov 1982 |
|                               |                   | Fabaceae Lespedeza sp. | Cherepanov 1982 |
|                               |                   | Fagaceae Castanea crenata (Siebold & Zuccarini) | Hua 2002 |
|                               |                   | Fagaceae Quercus spp. | Cherepanov 1982; Hua 2002 |
|                               |                   | Lauraceae Lindera obtusiloba (Blume) | Lim et al. 2014 |
|                               |                   | Rosaceae Malus domestica | Hua 2002 |
|                               |                   | Rosaceae Prunus persica | Hua 2002 |
|                               |                   | Salicaceae Salix vulpina | Hua 2002 |
|                               |                   | Sapindaceae Acer pictum (Thuernberg) | Lim et al. 2014 |
|                               |                   | Sapindaceae Acer pictum subsp. mono (Maxim.) H.Ohashi | Lim et al. 2014 |
|                               |                   | Sapindaceae Acer saccharinum (L.) | Cherepanov 1982 |
|                               |                   | Ulmaceae Ulmus americana (L.) | Lim et al. 2014 |
|                               |                   | Ulmaceae Zelkova serrata | Hua 2002 |
|                               |                   | Vitaceae Vitis vinifera (L.) | Lim et al. 2014 |
| Anoplistes halodendri subsp. pirus (Arakawa, 1932) *** | Quercus glauca (Thuernberg, 1784) * | Fagaceae Quercus spp. | Cherepanov 1990 |
|                               |                   | Rosaceae Malus domestica | Chen et al. 1959 |
|                               |                   | Rosaceae Pyrus assuriensis var. Culta | Arakawa 1932 |
|                               |                   | Rosaceae Pyrus sp. | Chen et al. 1959 |
|                               |                   | Rosaceae Ulmus parvifolia | Chen et al. 1959 |
| Anoplophora imitator (White, 1858) * | Quercus sp. * | Altingiaceae Liquidambar formosana | Hua 2002 |
|                               |                   | Betulaceae Betula sp. | Hua 2002 |
|                               |                   | Cupressaceae Cupressaria lanceolata | Hua 2002 |
|                               |                   | Fagaceae Castanea mollissima | DFZJP 1983; Hua et al. 1993 |
|                               |                   | Fagaceae Quercus sp. | Hua 2002 |
|                               |                   | Rutaceae Citrus sp. | DFZJP 1983; Hua 2002 |
|                               |                   | Salicaceae Populus spp. | Li and Wu 1993 |
|                               |                   | Theaceae Schima superba | Hua 2002 |
| Anoplophora lurida (Pascoe, 1856) * | Quercus glauca * | Fabaceae Sophora sp. | Pu 1980; DFZJP 1983; Hua 2002 |
|                               |                   | Fagaceae Castanea crenata | Nakamura and Kojima 1981 |
|                               |                   | Fagaceae Quercus sp. | Hua 2002 |
|                               |                   | Meliaceae Melia azedarach Linné | Hua 2002 |
|                               |                   | Pinaceae Pinus massoniana D. Don | Hua 2002 |
| Aphrodisium gibbicolle (White, 1853) *** | Castanea mollissima * | Apiaceae Foeniculum vulgare | Chiang 1989; Hua 2002 |
|                               |                   | Euphorbiaceae Vernicia fordii | Chiang 1989; Tu et al. 2006 |
|                               |                   | Fagaceae Castanea mollissima | Chiang 1989; Hua 2002; Peverieri et al. 2017 |
|                               |                   | Fagaceae Castanea spp. | Peverieri et al. 2017 |
|                               |                   | Fagaceae Quercus glauca | Chiang 1989; Hua 2002; Zhang et al. 2010 |
|                               |                   | Fagaceae Quercus sp. | Chiang 1989; Hua 2002; Zhang et al. 2010 |
|                               |                   | Juglandaceae Juglans mandshurica Maximowicz | Tu et al. 2006 |
|                               |                   | Juglandaceae | | |
|                               |                   | Pinaceae Pinus armandii Franchet var. amamiana | Chiang 1989; Hua 2002 |
|                               |                   | Pinaceae | | |
|                               |                   | Rutaceae Citrus spp. | Hoffmann 1934; Chen et al. 1959; Chiang 1989; Hua 2002 |
|                               |                   | Rutaceae | | |
|                               |                   | Umbelliferae | | |
Table 2. (continued).

| Common Name | Scientific Name | Family | Synonym | Reference(s) |
|-------------|-----------------|--------|---------|--------------|
| Aromia moschata orientalis | Plavilstshikov, 1933 | Fagaceae | Morus alba L. | Chiang 1989; Hua 2002 |
| Rosaceae | Prunus spp. | DFZJP 1983; | Chiang 1989; Hua 2002 |
| Salicaceae | Salix spp. Populus spp. | Gressitt 1951; | Chiang et al. 1959; DFZJP 1983; Hua 2002 |
| Astynocelis degener (Bates, 1873) | Quercus glauca * Castanea mollissima *** | Asteraceae | Artemisia spp. | Gressitt 1951; Hua 2002 |
| | Betulaceae | Betula spp. | Hua 2002 |
| Cupressaceae | Cunninghamia lanceolata | Hua 2002 |
| Fagaceae | Castanea mollissima | Hua 2002 |
| Salicaceae | Populus spp. | Hua 2002 |
| Simaroubaceae | Ailanthus altissima | Hua 2002; Ding et al. 2006 |
| Cacia cretifera (Hope, 1831) | Citrus reticulata (Blanco, 1837) * | Anacardiaceae | Lannea = Odina sp. | Pu 1980; Chiang 1989; Hua 2002 |
| Berberidaceae | Berberis sp. | Pu 1980; Chiang 1989; Hua 2002 |
| Euphorbiaceae | Mallotus philippensis | Pu 1980; Chiang 1989; Hua 2002 |
| Fabaceae | Albizia julibrissin | Zheng et al 2004 |
| Fabaceae | Albizia odoratissima | Pu 1980; Chiang 1989; Hua 2002 |
| Fabaceae | Bauhinia variegata | Pu 1980; Chiang 1989; Hua 2002 |
| Fabaceae | Dalbergia latifolia | Pu 1980; Chiang 1989; Hua 2002 |
| Magnoliaceae | Magnolia obovata = Magnolia liliflora | Pu 1980; Chiang 1989; Hua 2002 |
| Moraceae | Ficus sp. | Pu 1980; Chiang 1989; Hua 2002 |
| Pinaceae | Pinus yunnanensis | Hua 2002 |
| Castaphrodisium castaneae Gressitt, 1951 * | Castanea mollissima * | Fagaceae | Castanea sp. | Gressitt 1951 |
| Chelidonium argentatum (Dalman, 1817) ** | Citrus reticulata * | Juglandaceae | Juglans regia | Chiang 1989; Hua 2002 |
| Euphorbiaceae | Sapium sebiferum (L.) Roxb. | DFZJP 1983 |
| Moraceae | Alangium lamarckii | Chiang 1989; Hua 2002 |
| Rutaceae | Citrus ssp. | Zhang 1958; Chen et al. 1959; DFZJP 1983; Chiang 1989; Hua 2002 |
| Rutaceae | Fortunella ssp. | Gressitt 1951; Chen et al. 1959 |
| Chelidonium venereum Thomson, 1865 = Chelidonium cinctum (Guérin-Ménéville, 1844) ** | Citrus reticulata * | Rutaceae | Citrus ssp. | Chiang et al. 1985; Chiang 1989 |
| Chloridolum laotium Gressitt & Rondon, 1970* | Quercus sp. * | Pinaceae | Pinus latori | Gressitt et al. 1970; Hua 2002 |
| Chlorophorus annulatus (Hope, 1831) *** | Quercus glacis * Rubiaceae | Coffea sp. | Achrya & Pun 2016 |
| Chlorophorus diadema (Motschulsky, 1854) *** | Quercus sp. * Betulaceae | Betula sp. | Chen et al. 1959; Chiang 1989; Hua 2002 |
| Fabaceae | Robinia pseudoacacia L. | Hua 2002 |
| Fabaceae | Sophora japonica | Chen et al. 1959; Chiang 1989 |
| Lythraceae | Punica granatum | Hua 2002 |
| Rhamnaceae | Ziziphus mauritiana | Cao 2010 |
| Rosaceae | Cerasus sp. | Chen et al. 1959; Chiang 1989 |
| Rosaceae | Malus sp. | Lim et al. 2014 |
| Rosaceae | Prunus spp. | Hua 2002; Lim et al. 2014 |
| Rosaceae | Crataegus pinnatifida | Hua 2002 |
| Salicaceae | Populus sp. | Hua 2002 |
| Salicaceae | Salix spp. | Pu 1980; Cao 2010 |
| Vitaceae | Vitis sp. | Wu 1977; Hua 2002 |
| Dorysthenes granulosus (Thomson, 1861) *** | Citrus maxima (Burm. f.) Merr. * Anacardiaceae | Mangifera sp. | Zhang 1992 |
| Anacardiaceae | Lannea coromandelica | Chiang 1989 |
| Casuarinaceae | Casuarina equisetifolia | Hua 2002 |
| Cupressaceae | Cunninghamia lanceolata | Hua 2002 |
| Euphorbiaceae | Hevea brasiliensis | Chiang 1989; Hua 2002 |
| Euphorbiaceae | Manihot esculenta | Chen et al. 2012 |
| Fagaceae | Quercus spp. | Gressitt 1951; DFZJP 1983; Chiang 1989; Hua 2002 |
| Meliaceae | Melia azedarach | DFZJP 1983; Chiang 1989; Hua 2002 |
Table 2. (continued).

| Family      | Genus          | Species          | Author/Year |
|-------------|----------------|------------------|-------------|
| Moraceae    | Artocarpus     | sp.              | Hua 2002    |
| Myrtaceae   | Corymbia       | citriodora       | Zhu 1995    |
| Myrtaceae   | Eucalyptus     | sp.              | Hua 2002    |
| Palmae      | Areca          | catechu          | Chiang 1989 |
| Palmae      | Cocos          | nucifera         | Chiang 1989 |
| Palmae      | Elaeis         | guineensis       | Chiang 1989 |
| Pinaceae    | Pinus          | sp.              | Wang 1994   |
| Poaceae     | Saccharum      | officinarum     | Wickham et al. 2016 |
| Poaceae     | Saccharum      | sinense          | Pu 1980; Chiang 1989; Hua 2002 |
| Rutaceae    | Citrus         | sp.              | Zhu and Xu 1996 |
| Rutaceae    | Citrus         | grandis          | Hua 2002    |
| Salicaceae  | Salix          | sp.              | DFZJP 1983; Hua 2002 |
| Sapindaceae | Dimocarpus     | longan           | Zhu and Xu 1996 |
|            |                |                  |             |
| Erythresthes bowringii (Pascoe, 1863) * | Castanea mollissima * | Fagaceae | Castanea spp. | Chiang et al. 1985 |
| Glenea cantor (Fabricius, 1787) *** | Quercus sp. * | Bombaceae | Bombax malabaricum | Pu 1980 |
|            |                | Fagaceae         | Castanea mollissima | Hua 2002 |
| Grammographus notabilis subsp. cuneatus (Fairmaire, 1888) *** | Castanea mollissima * | Fagaceae | Quercus sp. | Hua 2002 |
| Ipothalia esmeralda Bates, 1879 * | Citrus reticulata * | Fagaceae | Castanea mollissima | Hua 2002 |
| Ischnostrangalis davidi (Pic, 1934) *** | Quercus sp. * | Fagaceae | Quercus sp. | Hua 2002 |
| Japanostrangalia basiplicata (Fairmaire, 1889) *** | Quercus sp. * | Fagaceae | Broussonetia papyrifera | Hua 2002 |
| Linda femorata (Chevrolat, 1852) *** | Quercus sp. * | Moraceae | Alnus sp. | Hua 2002 |
| Mesosa myops (Dalman, 1817) *** | Castanea mollissima * | Anacardiaceae | Rhus sp. | Chen et al. 1959; Hua 2002; Lim et al. 2014 |
|            |                | Betulaceae       | Alnus sp.   | Lim et al. 2014 |
|            |                | Betulaceae       | Betula sp.  | Hua 2002    |
|            |                | Fabaceae         | Sophora japonica | Hua 2002 |
|            |                | Fagaceae         | Castanea sp. | Hua 2002 |
|            |                | Fagaceae         | Quercus mongolica | Yang et al. 2013 |
|            |                | Fagaceae         | Quercus mongolica subsp. crispula | Yang et al. 2013 |
|            |                | Fagaceae         | Quercus spp. | Hua 2002    |
|            |                | Juglandaceae     | Juglans manshurica | Lim et al. 2014 |
|            |                | Juglandaceae     | Juglans regia | Hua 2002    |
|            |                | Malvaceae        | Tilia cordata | Ehrnström and Holmer 2007 |
|            |                | Pinaceae         | Larix sp.   | Lim et al. 2014 |
|            |                | Pinaceae         | Pinus sp.   | Hua 2002; Lim et al. 2014 |
|            |                | Rosaceae         | Malus sp.   | Chen et al. 1959; Hua 2002 |
|            |                | Rosaceae         | Prunus sp.  | Chen et al. 1959; Lim et al. 2014 |
|            |                | Rosaceae         | Pyrus sp.   | Lim et al. 2014 |
|            |                | Rutaceae         | Citrus sp.  | Lim et al. 2014 |
|            |                | Salicaceae       | Populus sp. | Chen et al. 1959; Hua 2002 |
|            |                | Styracaceae      | Alniphyllum fortunei | Hua 2002 |
|            |                | Ulmaceae         | Ulmus parvifolia Jacquin | Chen et al. 1959; Hua 2002; Lim et al. 2014 |
Table 2. (continued).

| Metastrangalis thibetana (Blanchard, 1871) ** | Castanea mollissima * | Cupressaceae | Metasequoia glyptostroboideae | Chiang et al. 1985; Hua 2002 |
|-----------------------------------------------|-----------------------|-------------|-------------------------------|-------------------------------|
| Monochamus guerryi Pic, 1903 ***             | Castanea mollissima * | Fagaceae    | Castanea mollissima           | Hua 2002; Wan et al. 2010     |
|                                              | Castanopsis hystrix   | Fagaceae    | Quercus glauca                | Pu 1980; Hua 2002             |
|                                              | Castanopsis sp.       | Fagaceae    | Quercus henryi                | Pu 1980; Hua 2002             |
|                                              |                      | Pinaceae    | Pinus kesiyu Royle ex Gordon  | Hua 2002                      |
|                                              |                      | Rosaceae    | Malus pumila                  | Hua 2002                      |
| Monochamus millegranus Bates, 1891 ***       | Quercus sp. *        | Fagaceae    | Castanea mollissima           | Hua 2002                      |
|                                              |                      | Fagaceae    | Quercus sp.                   | Hua 2002                      |
| Nadezhdiella cantori (Hope, 1843) ***        | Citrus reticulata *  | Bromeliaceae| Ananas comosus Merrill        | Chiang 1989; Hua 2002          |
|                                              |                      | Euphorbiaceae| Vernicia fordii               | DFZJP 1983; Hua 2002          |
|                                              |                      | Euphorbiaceae| Sapium sebiferum (L.) Roxb.   | DFZJP 1983; Hua 2002          |
|                                              |                      | Fagaceae    | Quercus spp.                  | DFZJP 1983; Hua 2002          |
|                                              |                      | Lamiaceae   | Tectona grandis               | Hua 2002                      |
|                                              |                      | Moraceae    | Artocarpus sp.                | Hua 2002                      |
|                                              |                      | Oleaceae    | Olea europaea Limnè           | Hua 2002                      |
|                                              |                      | Rutaceae    | Citrus spp.                   | Cheo 1936; Lieu 1945; Gressitt 1951; DFZJP 1983; Hua 2002 |
|                                              |                      | Salicaceae  | Salix sp.                     | Hua 2002                      |
|                                              |                      | Salicaceae  | Populus sp.                   | Hua 2002                      |
|                                              |                      | Vitaceae    | Vitis vinifera                | Chen et al. 1959; Cherepanov 1982; Chiang 1989; Hua 2002 |
| Neocerambyx raddei Blessig, 1872 ***         | Quercus chenii (Nakai, 1924) * | Euphorbiaceae| Sapium sebiferum (L.) Roxb.   | DFZJP 1983; Hua 2002          |
|                                              |                      | Fagaceae    | Castanea spp.                 | Matsushita 1933; Cheo 1936; Gressitt 1951; Chen et al. 1959; DFZJP 1983; Chiang 1989; Lim et al. 2014 |
|                                              |                      | Fagaceae    | Castanopsis spp.              | Lim et al. 2014               |
|                                              |                      | Fagaceae    | Lithocarpus                   | Chen et al. 1959; Chiang 1989; Wu et al. 1995; Hua 2002 |
|                                              |                      | Fagaceae    | Paspisia cuspidata            | Gressitt 1951                  |
|                                              |                      | Fagaceae    | Quercus acutissima            | Gressitt 1951; Chen et al. 1959; DFZJP 1983; Chiang 1989; Wu et al. 1995; Hua 2002 |
|                                              |                      | Fagaceae    | Quercus glandulifera          | Cheo 1936; Gressitt 1951       |
|                                              |                      | Fagaceae    | Quercus liaotungensis         | Cao et al. 2015               |
|                                              |                      | Fagaceae    | Quercus mongolica             | Li et al. 2017                |
|                                              |                      | Fagaceae    | Quercus spp.,                 | Chen et al. 1959; Hua 2002; Lim et al. 2014 |
|                                              |                      | Moraceae    | Morus spp.                    | Li et al. 2017                |
|                                              |                      | Myrtaeaceae | Eucalyptus sp.                | Cheo 1936; Gressitt 1951; Chen et al. 1959; DFZJP 1983; Chiang 1989; Wu et al. 1995; Hua 2002; Lim et al. 2014 |
|                                              |                      | Oleaceae    | Fraxinus mandshurica Ruprecht  | DFZJP 1983; Hua 2002          |
|                                              |                      | Paulowniaceae| Paulownia sp.                 | DFZJP 1983; Wu et al. 1995; Lim et al. 2014 |
|                                              |                      | Pinaceae    | Pinus spp.                    | DFZJP 1983; DFZJP 1983         |
|                                              |                      | Rosaceae    | Armeniaca sp.                 | DFZJP 1983; DFZJP 1983         |
|                                              |                      | Rosaceae    | Malus domestica               | DFZJP 1983; DFZJP 1983         |
|                                              |                      | Rosaceae    | Pyrus sp.                     | DFZJP 1983; DFZJP 1983         |
|                                              |                      | Rutaceae    | Citrus sp.                    | DFZJP 1983; DFZJP 1983         |
| Oberea ferruginea (Thunberg, 1787) ***       | Citrus reticulata *  | Euphorbiaceae| Vernicia fordii               | Hua 2002                      |
|                                              |                      | Poaceae     | Bambusa spp.                  | Hua 2002                      |
|                                              |                      | Salicaceae  | Salix nigra                   | Pitcher and McKnight 1990     |
|                                              |                      | Theaceae    | Schima superba                | Hua 2002                      |
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Table 2. (continued).

| Paraleprodera diaphthalma  
(Pascoe, 1857) *** | Castanea mollissima * | Actinidiaceae | Actinidia sp. | Hua 2002 |
|---------------------|-----------------------|---------------|---------------|----------|
| Betulaceae           | Castaneopsis davidiana Decaisne | Hua 2002 |
| Cornaceae           | Dendrobenothamia sp. | Hua 2002 |
| Cupressaceae        | Cupressus sp. | Hua 2002 |
| Euphorbiaceae       | Vernicia fordii (Hemsley) Airy Shaw | DEZJP 1983; Hua 2002 |
| Fabaceae            | Pueraria montana var. lohata (Willd.) Maesen and S. Almeida | Sun et al. 2006 |
| Fagaceae            | Castanea mollissima | Pu 1980; DEZJP 1983 |
| Fagaceae            | Quercus sp. | DEZJP 1983; Hua 2002 |
| Juglandaceae        | Juglans regia | DEZJP 1983; Hua 2002 |
| Poaceae             | Bambusa sp. | Hua 2002 |

| Plagionotus christophi  
(Kraatz, 1879) ** | Quercus sp. * | Fabaceae | Quercus spps. | Gressitt 1951; Chen et al. 1959; Hua 2002; Hoshino et al. 2009; Lim et al. 2014 |
|--------------------|---------------|-----------|---------------|------------------|
| Saliceae           | Xylosma sp. | Hua 2002 |
| Rosaceae           | Malus pumila | Hua 2002 |

| Purpuricenus lituratus  
Ganglbauer, 1887 ** | Quercus chenii * | Fabaceae | Quercus spps. | Pu 1980; Hua 2002 |
|----------------------|-----------------|-----------|---------------|-----------------|
| Rosaceae            | Malus pumila | Hua 2002; Chen et al. 1959; Lim et al. 2014 |
| Rosaceae            | Malus spps. | Chen et al. 1959; Lim et al. 2014 |
| Rosaceae            | Pyrus pyrifolia | Lim et al. 2014 |

| Purpuricenus sideriger  
Fairmaire, 1888 *** | Quercus chenii * | Fabaceae | Quercus chenii | Pu 1980; Hua 2002 |
|----------------------|-----------------|-----------|---------------|-----------------|
| Rosaceae            | Malus spps. | Chen et al. 1959; Lim et al. 2014 |
| Rosaceae            | Pyrus pyrifolia | Lim et al. 2014 |

| Siniostrangalis ikedai  
(Mitono & Tamanuki, 1939) ** | Quercus sp. * | Fabaceae | Quercus semicarpifolia | Hua 1989 |
|-----------------------------|-----------------|-----------|----------------------|---------|
| Pinaceae                    | Quercus spps. | Hua 2002 |
| Pinaceae                    | Pinus spp. | Hua 1989; Hua 2002 |

| Stenygrinum quadrinotatum  
Bates, 1873 *** | Quercus sp. * | Fabaceae | Acacia confusa | Hua 2002 |
|------------------|---------------|-----------|-----------------|---------|
| Fabaceae         | Castanea mollissima | Cheo 1936; Chen et al. 1959; Hua 2002 |
| Fabaceae         | Quercus spps. | Cheo 1936; Zheng et al. 2005 |
| Fabaceae         | Quercus acutissima | Cheo 1936; Chen et al. 1959; DFZJP 1983; Lim et al. 2014 |
| Lamiaceae        | Tectona grandis Linné fils | Hua 2002 |
| Lauraceae        | Cinnamomum camphora | DFZJP 1983 |
| Moraceae         | Morus spps. or Morus alba | DEZJP 1983; Hua 2002 |
| Pinaceae         | Abies sp. | Hua 2002 |
| Rosaceae         | Malus spps. | Zhang et al. 2017 |
| Ulmaceae         | Zelkova spps. | Hua 2002 |

| Trirachys orientalis  
Hope, 1843 *** | Citrus reticulata * | Fabaceae | Robinia pseudoacacia | Hua 2002 |
|-----------------|---------------------|-----------|---------------------|---------|
| Fabaceae        | Sophora spps. | Hua 2002 |
| Fabaceae        | Quercus spps. | Hua 2002 |
| Rhamnaceae      | Zizyphus sativa Gaertn | Hua 2002 |
| Rosaceae        | Pyrus sp. | Chen et al. 1959; Hua 2002 |
| Rutaceae        | Citrus spp. | Gressitt 1951; Chen et al. 1959; Duffy 1968; Gressitt et al. 1970; Chiang 1989; Hua 2002 |
| Saliceae        | Populus sp. | DFZJP 1983; Hua 2002 |
| Saliceae        | Salix sp. | Chen et al. 1959; DFZJP 1983; Hua 2002 |

| Trirachys sinensis  
(Gahan, 1890) *** | Citrus reticulata * | Ebenaceae | Diospyros spps. | Gressitt 1951; Chen et al. 1959; Duffy 1968; Gressitt et al. 1970; Chiang 1989; Hua 2002 |
|------------------|---------------------|-----------|-----------------|---------|
| Fagaceae         | Quercus sp. | Chiang 1989; Hua 2002 |
| Lauraceae        | Cinnamomum camphora | Hua 2002 |
| Meliaceae        | Cedrela sps. | Gressitt 1951; Chen et al. 1959; Duffy 1968; Gressitt et al. 1970; Chiang 1989; Hua 2002 |
| Rosaceae         | Crataegus sps. | Gressitt 1951; Duffy 1968; Gressitt et al. 1970; Hua 2002 |
| Rutaceae         | Citrus sps. | Gressitt 1951; Chen et al. 1959; Duffy 1968; Gressitt et al. 1970; Chiang 1989; Hua 2002 |
Table 2. (continued).

| Family       | Genus          | Species          | Author          |
|--------------|----------------|------------------|-----------------|
| Salicaceae   | Salix          | sp.              | Hua 2002        |
| Sapindaceae  | Acer           | sp.              | Duffy 1968; Gressitt et al. 1970 |
| Theaceae     | Camellia       | oleifera         | Abel            |
| Xylorhiza pilosipennis |  Castanea mollissima * | Fagaceae | Vives et al. 2019 |
| Breuning, 1943 *** | (Often misidentified as  Xylorhiza adusta (Wiedemann, 1819)) | Lamiaceae | Gmelina hainanensis Oliver | Vives et al. 2019 |
|              | Paulowniaceae  | sp.              | DFZJP 1983      |

Results

We investigated the known records for 40,843 specimens at IZCAS. As a result of our investigation we identified a total of 39 species of xylophagous longhorn beetle associated with Fagaceae, Citrus, and avocado.

The 39 identified beetle species had 43 documented host associations with at least one of the target trees. Some beetle species were recorded on more than one target tree host. By systematically reviewing the known literature we followed a similar process to a preliminary risk assessment and discovered 33 interactions previously documented. The remaining 10 associations were novel and previously unrecorded (Table 2). When a host-interaction was previously recorded on a plant of the same genus (e.g. Quercus sp.), we did not consider this a newly documented host association. No associations of Chinese longhorn beetles with avocado were recorded.

Discussion

The 10 new associations, previously unpublished, may be used to help determine potential pest risk. The remaining 33 associations provide important corroboration of previously recorded single observations. Multiple reported observations increase data reliability (Groom et al. 2017).

Some of the beetles identified in our study have the potential to become an important economic pest and warrant further study. We identified two Anoplophora species, A. imitator (White, 1858) and A. lurida (Pascoe, 1856) on Fagaceae. This genus has two pest species already recognized as being of global concern, A. chinensis (Forester, 1771) and A. glabripennis. Lingafelter and Hoebeke (2002) note that two thirds of the 36 species within this genus have no recorded natural history, so the threat of other Anoplophora is unknown. Another species identified in our study, Anoplistes halodendri subsp. pirus (Arakawa, 1932), has been previously misidentified in the literature as A. halodendri (Pallas, 1776). A. halodendri subsp. pirus had caused mass mortality of sea buckthorn (Hippophae rhamnoides Linné) and sweetvetch (Hedysarum scoparium Linné) in China (Liu et al. 2012). While not definitive, evidence of pest status in other regions can identify potential pest status in adventive regions (Eyre and Haack 2017).

Avocado is native to South and Central America yet it has been planted in China for roughly 100 years (Liu and Zhou 2000). It has sporadically been trialed as a commercial crop. Commercial trials often have higher
levels of vigilance and observation compared to amenity horticulture, and various provenance and pest susceptibility trials have been conducted in China (Luo and Jin 1995; Li 2000). As such, the lack of host-associations identified here are unexpected. Xylophagous longhorn beetles are documented as attacking avocado in other regions. In Hawaii, the invasive longhorn beetle *Acalolepta aesthetica* (Olliff, 1890) is an emerging pest of avocado, despite the beetle being native to Australia (Matsunaga et al. 2019). Similar studies in regions where avocado is longer established may highlight pests and associations that have been previously unrecorded.

Lack of scientific data during the pest risk analysis process could lead to an underestimation of the impacts of invasion, particularly if a species is not considered a threat to a major agricultural crop or commercial plantation (Devorshak 2012). Our two-stage survey method aimed to identify previously unpublished host interactions between xylophagous longhorn beetles and a limited range of commodity tree species that are ecologically or economically important in the USA.

Host associations records may indicate the likely area of risk of understudied alien species. Many longhorn species have little documented ecology making pest risk analysis processes difficult (Eyre and Haack 2017). Three beetle species had no host-associations identified in our systematic literature review prior to this research. In order to perform a risk assessment, the area at risk cannot be assessed without information about the host. Likewise, the level of host-specificity would be unclear. Prior to this study that identified a Fagaceae host (*Quercus* sp.) it could be assumed that a species like *Chloridolum laotium* (Gressitt & Rondon, 1970) is oligophagous on pine trees as *Pinus* spp. were the only previously recorded hosts. Similar results can be seen with *Chlorophorus annulatus* (Hope, 1831) (previously only recorded on *Coffea* sp.) and *Metastrangalis thibetana* (Blanchard, 1871) (previously only recorded on *Metasequoia glyptostroboides* Hu & Cheng). The results indicate a more diverse host association than previously known for these species. This information may be used to determine a longhorn beetles potential area at risk which impacts the pest risk assessment and phytosanitary regulation.

Despite generating useful information, there are still limitations to this study. Many other associations have probably been recorded but are inaccessible. Groom et al. (2017) discuss the difficulties of finding accurate biodiversity data, lack of interoperability and standardization, and paywalls, where access to information requires a subscription service or payment to be made. Language differences can present a special barrier, especially when collection records follow traditional or local plant taxa names, rather than the Latin binomial nomenclature. These issues increase the likelihood of host associations being unusable or incomplete during the pest risk analysis process because regulations are implemented based on species names (FAO 2007).
Previous records can themselves be inaccurate. When using historical data of this nature we cannot verify the accuracy of the host plant identified by the specimen collector in the museum collections. Often, the tree name has been translated and with colloquial or family names used for groups of similar species. As such, identification of hosts can only be made as accurate as the translated local name. Additionally, whether the plant was a feeding host or oviposition host is not recorded. The records in Table 2 identify the number of observations recorded by the original collectors in the IZCAS collection. We can infer that specimens frequently collected on the same plants likely have an association.

Our focus on the tree genus or species in question, but not on its phylogenetic relatives, can be also seen as a limitation. Many insects switch hosts within a higher phylogenetic group, regardless of whether they coevolved with the plant species or not. For example, records at IZCAS do not indicate any Cerambycidae associations on avocado, but many Chinese longhorn beetles exploit native Lauraceae trees and may potentially switch to avocado. However, the strength of our inference is that all studied tree taxa are widely planted in China, and thus served as an analog of sentinel gardens, or living in situ laboratories for new host association studies (Eschen et al. 2019).

This method could be used on other collections and other target groups to highlight species of potential pest status. Equally, documented host feeding evidence is also utilized outside of the pest risk assessment system and could provide ecological information about these organisms in many types of future studies.

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Authors’ contribution

ASE – Original draft, sample design and methodology, investigation and data collection, data analysis and interpretation. MYL – Sample design and methodology, investigation and data collection, review, and editing. YL – Research conceptualization, review and editing. JH – Research conceptualization, ethics approval, funding provision, review and editing.

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