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Review

Review

Insect wood borers on commercial North American tree species growing in China: review of Chinese peer-review and grey literature

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Invasive insect wood borers are a threat to global forests and tree-related industries as they can damage trees and spread plant pathogens. Reports of damages by wood borers on plants that were planted overseas may facilitate the identification of potential invaders and speed up risk assessment. However, much of this information remains unavailable to the international plant protection community due to language barriers, lack of digitization, or limited circulation of regional literature. Here, we investigated reports of wood borers on 7 important North American commercial tree species planted in China (*Carya illinoinensis*, *Liquidambar styraciflua*, *Pinus elliottii*, *Pinus taeda*, *Quercus texana*, *Quercus rubra*, and *Quercus virginiana*) in peer-reviewed as well as "grey" (nonpeer-reviewed) Chinese literature. A total of 60 unique wood borer records were found, yielding reports of 4 orders, 39 genera, and 44 species of insect wood borers. Among Coleoptera, longhorned beetles (Cerambycidae) were the most commonly reported colonizers of North American trees in China. Chinese peer-reviewed reports of pests on alien plants are a valuable tool to survey for potential wood-boring invaders of North America, and wherever North American trees are planted and have the potential to encounter Asian invasive insects. Digitization and dissemination of non-English literature are essential for contemporary risk assessment. On the other hand, the nonpeer reviewed "grey" literature, primarily agency reports and student theses, provided only 5% of the records; many incidental observations were unreliable.

Key words: Chinese literature, grey literature, wood borer, potential invader, North American tree

Introduction

Forest ecosystems are threatened by increasing disturbances, including fire, diseases, insect pests, and drought (Parker et al. 2006, Hicke et al. 2012, Jenkins et al. 2014) . One of the most significant threats is the increased impact of insect pests (van Lierop et al. 2015), which cause ecological and economic damages (Mosquera et al. 2015, van Lierop et al. 2015). An increasing threat is the increasing incidence of invasive pests [invasive is defined as any alien species that threaten plants in the nonnative region (FAO 2017)], some of which can eliminate entire tree species from ecosystems. For instance, the hemlock woolly adelgid, *Adelges tsugae* Annand (Hemiptera: Adelgidae), was introduced into the United States of America from Japan and caused a dramatic decline of eastern hemlock, *Tsuga canadensis* (Linn.) Carr. (Pinaceae) (Orwig and Foster 1998, Orwig et al. 2002). Invasive pests also threaten commercial tree commodities. The brown marmorated stink bug, *Halyomorpha halys* Stal (Heteroptera: Pentatomidae), seriously damages fruits and seeds of plants in Europe and North America (Wiman et al. 2015, Bariselli et al. 2016). The Asian longhorned beetle, *Anoplophora glabripennis* Motschulsky (Coleoptera: Cerambycidae), attacks healthy trees in Europe, North America, South Korea, and Japan (Cavey et al. 1998, Smith et al. 2009, Lee et al. 2020, Akita et al. 2021).

Among the most damaging tree pests are invasive insect wood borers (Brockerhoff et al. 2006, Linnakoski and Forbes 2019). Some wood borers are vectors of plant pathogens. For instance, *Xyleborus glabratus* Eichhoff (Coleoptera: Curculionidae), an Asian ambrosia beetle invasive in North America, carries the fungus *Harringtonia* *lauricola,* which is highly pathogenic to New World species of family Lauraceae (Harrington et al. 2008). The joint beetle-fungus introduction resulted in the laurel wilt disease, which devastated native lauraceous trees and planted avocados in the Southeastern U.S., totaling losses of over $100 million (Mosquera et al. 2015). Many wood borers damage trees without the aid of a pathogen. The larvae of the invasive emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), for example, kill American ash trees (*Fraxinus* spp., Oleaceae) via consuming the phloem (Poland and McCullough 2006, Dietze and Matthes 2014, Dang et al. 2022).

Many cases of new invasive insects may appear unexpected, but some had been predictable because clear evidence of damage already existed in their native environment. The Asian longhorned beetle, for example, became notorious in the invasion literature after its establishment in Europe and North America (Haack et al. 2010, Meng et al. 2015). However, its devastating effect on planted maples and poplars was already known to entomologists in China and Korea long before the invasion (Huang et al. 1992, Hu et al. 2009). When attention to wood borers in their native forests is insufficient, researchers and agencies may fail to register signs of invasion potential (Nair 2007, Bilski et al. 2017).

A large amount of data regarding wood-boring pests has been produced due to increased observation of insects (Kolle et al. 2015). Some were published in different languages other than English, or published as reports outside of peer-reviewed scientific articles, such as in news, agency reports, or student theses. Nonpeer-reviewed literature is often referred to as "grey literature". Significantly, the grey literature includes resources that are valuable but not widely shared (Adams et al. 2016, 2017). One of the major barriers preventing the information from reaching key audiences is the publication language. For instance, a government agency in China reported *Acanthotomicus suncei* Cognato (Coleoptera: Curculionidae) as a new species specific to sweetgum (*Liquidambar*) in 2013, but this information was lost until recent research described the beetle's destructive effect on American sweetgum (*Liquidambar styraciflua* Linn., Altingiaceae) in English articles (Gao et al. 2017, Gao and Cognato 2018). *Agrilus planipennis* attacking ash tree (*Fraxinus americana* Linn.) was first reported in Chinese in 1964 (Yu 1992, Wei et al. 2004) but it received little attention until the beetle's accidental introduction to North America (Cappaert et al. 2005, Klooster et al. 2014). Chinese literature includes so much information on nonnative pests that it is sufficient for pest prediction models and for models to predict existing pest occurrence (Bebber et al. 2019). Thus, extracting wood borer pest information from grey literature may significantly contribute to the knowledge of insects that would otherwise remain unnoticed.

The "grey literature", which is typically not peer-reviewed and may not be based on confirmed observations, could be similarly useful for pest prediction, but its reliability has not been empirically assessed. Nonpeer reviewed reports on insect pests often include data on tree hosts. This information can improve pest distribution or invasion models. Most pest modeling literature is limited to data on geographic distribution, and host-use data are often missing. That is unfortunate because invasive pest damage is well predicted by the evolutionary relatedness of native and nonnative host plants (Gilbert et al. 2012, Hulcr et al. 2017, Mech et al. 2019). Predictions from models based solely on occurrence data decrease model robustness, because distribution data of little-known pests are often incomplete in the mainstream, English literature (Ernstsons et al. 2021).

A more sensitive approach may be the reporting of pest interactions with plants that have been planted in the region of the pest origin, including in botanical gardens (Kirichenko and Kenis 2016) or research sentinel gardens (Vettraino et al. 2017, Kenis et al. 2018). This perspective has been supported by an increasing number of recent studies (White et al. 2010, Roques 2015, Roques et al. 2015, Mansfield et al. 2019). For instance, 4 yr of observations of 7 European tree species planted in China were used to identify potential pests threatening European trees. The authors reported 104 Asian insect taxa on European plants, including 38 insect taxa that could be major pests if introduced to Europe (Roques et al. 2015). Aside from this direct monitoring, predictions using statistical models for potential insect invaders generally rely on data on pests' historical occurrences. The damage by insect invaders in their native region is difficult to extrapolate to nontraditional hosts, until such hosts are empirically tested or until the insect occurs in a nonnative region. Direct observations on native hosts in the native region, as well as biology-informed modeling, may improve the risk assessment. Thus, investigating insects on introduced plants in the region of concern allows for identifying pests before damage in the adventive area occurs (Fagan et al. 2008, Roques 2015).

Many North American tree species were introduced into China as part of the ornamental tree trade or for afforestation purposes. Researchers in China explored the insects attacking these trees, but much of that research has been published in Chinese. Our report summarizes the wood borer information on 7 North American commercial tree species introduced into China in literature sources often neglected or missed in standard research projects.

Materials and Methods

Tree Species

We focused our survey of literature on papers containing records of wood borers associated with commercial trees native to North America which have a long history of planting in China, as well as considerable value in their native North America. These tree species consisted of: pecan (*Carya illinoinensis* (Wangenh) K. Koch, Juglandaceae), sweetgum (*Liquidambar styraciflua* Linn., Altingiaceae), slash pine (*Pinus elliottii* Engelm, Pinaceae), loblolly pine (*Pinus taeda* Linn., Pinaceae), nuttall oak (*Quercus texana* Buckley, Fagaceae), northern red oak (*Quercus rubra* Linn., Fagaceae), and live oak (*Quercus virginiana* Mill, Fagaceae).

Those North American tree species with high-quality timber or desirable fruit have been imported and widely planted in multiple provinces in China (such as Anhui, Beijing, Fujian, Guangxi, Hunan, Jiangsu, Jiangxi, Nanjing, Shandong, Shanghai, Sichuan, and Yunnan; Fig. 1, Table 1) since the beginning of the twentieth century; they are now common urban trees or commercial plants (Wu 1983, Jiang et al. 1997, Chen 2010, Lin et al. 2022, Catalogue of Life China: 2022 Annual Checklist: http://www.sp2000.org.cn/).

Data Collection and Management

Data were obtained from peer-reviewed research literature written exclusively in Chinese, as well as from nonpeer-reviewed Chinese sources, including books, news reports, inspection records, and unpublished studies. For the academic papers, we searched the pest items in Google Scholar (https://scholar.google.com/) and Chinese online publishing platforms (http://www.cnki.net/, http://www.chaoxing.com/, and http://wanfang.pdf68.com/). These platforms cover research papers, student theses, and dissertations. News reports and inspection records mentioning pests on the targeted host trees were located in forestry-specific websites (China National Forestry and Grassland Administration: http://www.forestry.gov.cn/, provincial Forestry Administration) and web search engines (https://www.google.com/, https://www.baidu.com/, and https://www.so.com/). Books were searched in 4 extensive libraries (http://www.nlc.cn/,

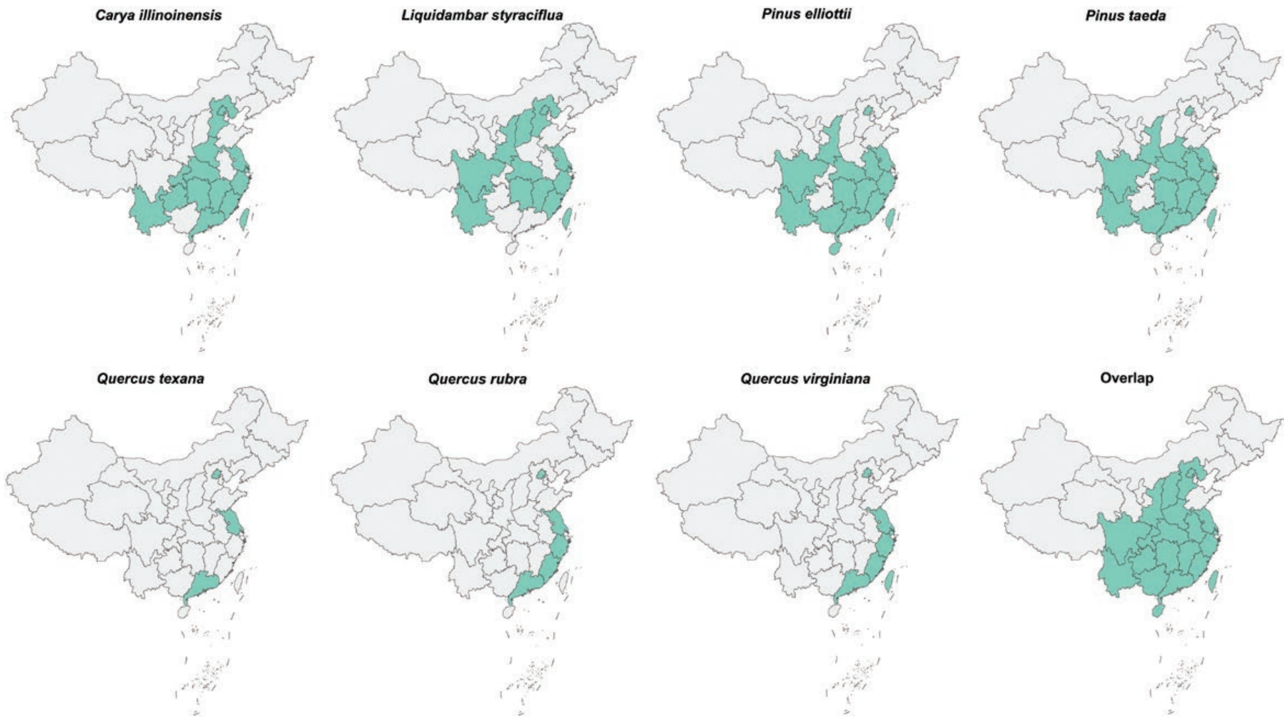

Fig. 1. The distribution map of selected North American-origin trees in China. The last graph is the distribution overlap of all selected North American-origin tree species.

Table 1. The introduction and cultivation details of selected North American tree species in China

Species	Introduction	Cultivation area	Cultivation	Sources
Carya illinoinensis (Wangenh) K. Koch	Year 1900	66,700 ha.	Plantation	(Wu 1983, Zhang et al. 2022)
Liquidambar styraciflua Linn.	Year 1956	No report, broad	Urban tree/plantation	(Shen 1981)
Pinus elliottii Engelm	Year 1930	150,000 ha[a]	Plantation	(Wu 1983, Chen 2006)
Pinus taeda Linn.	Year 1933	150,000 ha[a]	Plantation	(Wu 1983, Chen 2006)
Quercus texana Buckley	Year 2001	No report	Urban tree/Plantation	(Teng et al. 2016)
Quercus rubra Linn.	Year 1998	No report	Urban tree/Plantation	(Huang et al. 2005)
Quercus virginiana Mill	Year 2001	No report	Urban tree/Plantation	(Teng et al. 2016)

[a]The value represents the hectares of forest. Note: *Quercus* spp. are planted on nearly 18 million ha in China (Wang et al. 2022).

http://www.ucdrs.superlib.net/, https://libweb.zju.edu.cn/, and http://libsvr.xtbg.ac.cn:8080/). We searched for insect records by combining the scientific or common names of the plants, plus the keywords “wood borer”, “stem borer”, “pest”, “bug”, and “insect”. The keywords were variously combined to maximize the query power in each tree species. The data sources used here do not specify the time range covered in their databases. We did not set any time range limit for each search, to maximize record retrieval. Fortunately, time range of the data sources appears to precede the time when the tree species in question started to be imported to China.

We curated the records from the first search results as follows.

1) In some pest records, the damage type was not reported, and we surmised the wood borer feature based on the insect’s biology or other scientific reports about the species.
2) initially, reports regarding all feeding guilds were collected, including leaf chewing, sap-sucking, wood boring, and seed feeding (this unfiltered search yielded 265 items) and the nonwood borers were removed.
3) Then, we compared the records and merged duplicate records. Finally, 60 wood borer records were present in the list.
4) Last, some insect records were only documented by species name, so the orders, families, and genera information of these insect species were filled in according to contemporary systematics.

We summarized the numbers of pest orders, families, genera, and species of insects associated with each tree species. The packages bipartite and networkD3 in R (R Development Core Team 2018) were employed to graph the recorded associations between host plants and woodborer at the family level (Dormann et al. 2008, Allaire et al. 2017). To evaluate which insect species tends to attack the same host plants repeatedly, Pearson correlation coefficients were computed via the corr.test function in the R package psych (Revelle 2022). The frequency of each wood borer species on its respective tree host was summarized from the presence/absence matrix of the insect species on the host plants.

Results

The Chinese literature search and the subsequent curation resulted in 60 unique wood borer records (44 species) on North American trees. These insects belonged to 4 orders, 17 families, and 39 genera (Table 2, Fig. 2). Some wood borer species were associated with

Table 2. The records of wood borers of 7 plant species were gathered from Chinese peer-reviewed and grey literature from selected tree commodities of North American origin. Damage and mortality in some reports are not included, since they are often difficult to interpret with high confidence

Order	Family	Species	Host plant	Damage or mortality	Sources	Native regions	Reported in English literature
Blattodea	Termitidae	*Odontotermes formosanus* Shiraki	*Carya illinoinensis*	Infests and can kill live trees	(Chen et al. 2015, Qi et al. 2016)	Unknown	Not yet
Coleoptera	Buprestidae	*Agrilus lewisiellus* Kere	*Carya illinoinensis*	Not reported	(Qin and Qin 2016)	Unknown	Not yet
Coleoptera	Cerambycidae	*Aeolesthes induta* Newman	*Carya illinoinensis*	Not reported	(Chen et al. 2015, Qi et al. 2016)	Unknown	Not yet
Coleoptera	Cerambycidae	*Anoplophora chinensis* Forster	*Carya illinoinensis*	Infests and can kill live trees	(Ju et al. 2014, Chen et al. 2015, Qi et al. 2016, Xia 2016)	Eastern Asia	Not yet
Coleoptera	Cerambycidae	*Anoplophora glabripennis* Motschulsky	*Carya illinoinensis*	Not reported	(Ju et al. 2014, Qi et al. 2016)	Eastern Asia	Not yet
Coleoptera	Cerambycidae	*Aphrodisium sauteri* Matsushita	*Carya illinoinensis*	Infests and can kill live trees	(Ju et al. 2014, Qi et al. 2016)	Unknown	Not yet
Coleoptera	Cerambycidae	*Apriona germari* Hope	*Carya illinoinensis*	Not reported	(Ju et al. 2014)	Unknown	(Singh et al. 2016)
Coleoptera	Cerambycidae	*Apriona rugicollis* Chevrolat	*Carya illinoinensis*	Infests and can kill live trees	(Yang et al. 2010a, Qi et al. 2016)	Asia	Not yet
Coleoptera	Cerambycidae	*Batocera horsfieldi* Hope	*Carya illinoinensis*	Infests and can kill live trees	(Yang et al. 2010a, Ju et al. 2014, Qi et al. 2016, Qin and Qin 2016)	Unknown	(Singh et al. 2016)
Coleoptera	Cerambycidae	*Batocera lineolata* Chevrolat	*Carya illinoinensis*	Infests and can kill live trees	(Jiao et al. 2011, Chen et al. 2015, Qi et al. 2016)	Unknown	Not yet
Coleoptera	Cerambycidae	*Megopis sinica* White	*Carya illinoinensis*	Infests and can kill live trees	(Ju et al. 2014, Qi et al. 2016)	Unknown	Not yet
Coleoptera	Coccinellidae	*Aiolocaria hexaspilota* Hope	*Carya illinoinensis*	Infests and can kill live trees	(Ju et al. 2014, Chen et al. 2015)	Unknown	Not yet
Coleoptera	Curculionidae	*Hypothenemus erectus* LeConte	*Carya illinoinensis*	Not reported	(Chen et al. 2015)	Unknown	Not yet
Coleoptera	Elateridae	*Campsosternus auratus* Drury	*Carya illinoinensis*	Not reported	(Chen et al. 2015)	Unknown	Not yet
Coleoptera	Lucanidae	*Aegus laevicollis* Saunders	*Carya illinoinensis*	Not reported	(Chen et al. 2015)	Unknown	Not yet
Coleoptera	Lucanidae	*Lucanus maculifemoratus* Motschulsky	*Carya illinoinensis*	Not reported	(Chen et al. 2015)	Unknown	Not yet
Lepidoptera	Cossidae	*Cossus cossus* Linnaeus	*Carya illinoinensis*	Infests and can kill live trees	(Ju et al. 2014)	Unknown	Not yet
Lepidoptera	Cossidae	*Zeuzera coffeae* Nietner	*Carya illinoinensis*	Infests and can kill live trees	(Chen et al. 2015, Xia 2016)	Unknown	Not yet
Lepidoptera	Cossidae	*Zeuzera leuconotum* Butler	*Carya illinoinensis*	Infests and can kill live trees	(Yang et al. 2007, 2010a, Jiao et al. 2011, Ju et al. 2014)	China	(Singh et al. 2016)
Lepidoptera	Hepialidae	*Phassus excrescens* Butler	*Carya illinoinensis*	Not reported	(Chen et al. 2015)	Unknown	Not yet

Table 2. Continued

Order	Family	Species	Host plant	Damage or mortality	Sources	Native regions	Reported in English literature
Lepidoptera	Limacodidae	*Latoia consocia* Walker	*Carya illinoinensis*	Not reported	(Ju et al. 2014)	Unknown	Not yet
Lepidoptera	Limacodidae	*Setora postornata* Hampson	*Carya illinoinensis*	not reported	(Ju et al. 2014)	Unknown	Not yet
Lepidoptera	Metarbelidae	*Arbela dea* Swinhoe	*Carya illinoinensis*	not reported	(Yang et al. 2012, Ju et al. 2014)	Unknown	Not yet
Lepidoptera	Metarbelidae	*Lepidarbela dea* Swinhoe	*Carya illinoinensis*	Infests and can kill live trees	(Yang et al. 2007)	Unknown	Not yet
Lepidoptera	Pyralidae	*Tryporyza incertulas* Walker	*Carya illinoinensis*	not reported	(Ju et al. 2014)	Unknown	Not yet
Lepidoptera	Sesiidae	*Aegeria molybdoceps* Hampson	*Carya illinoinensis*	Infests and can kill live trees	(Chen et al. 2015)	Unknown	Not yet
Hymenoptera	Formicidae	*Formica* sp.	*Carya illinoinensis*	not reported	(Ju et al. 2014)	Unknown	Not yet
Hymenoptera	Tenthredinidae	*Tenthredo* sp.	*Carya illinoinensis*	not reported	(Ju et al. 2014)	Unknown	Not yet
Coleoptera	Curculionidae	*Acanthotomicus suncei* Cognato	*Liquidambar styraciflua*	Infests and can kill live trees	(Gao et al. 2020, Yu et al. 2020, Zhao et al. 2021)	China	(Gao and Cognato 2018)
Blattodea	Termitidae	*Macrotermes barmeyi* Light	*Pinus elliottii*	Not reported	(Zhao et al. 2000)	Unknown	Not yet
Blattodea	Termitidae	*Odontotermes formosanus* Shiraki	*Pinus elliottii*	Not reported	(Zhao et al. 2000, Chen 2010)	Unknown	(Li et al. 2010)
Coleoptera	Buprestidae	*Chalcophora yunnana* Fairmaire	*Pinus elliottii*	Not reported	(Wang and Lu 1996)	Unknown	Not yet
Coleoptera	Cerambycidae	*Dorysthenes granulosus* Thomson	*Pinus elliottii*	Not reported	(Wang and Lu 1996)	Unknown	Not yet
Coleoptera	Cerambycidae	*Monochamus alternatus* Hope	*Pinus elliottii*	Infests and can kill live trees	(Zhao et al. 2000, Yang 2008)	Unknown	(Nan et al. 2023)
Coleoptera	Cerambycidae	*Philus antennatus* Gyllenhal	*Pinus elliottii*	Infests and can kill live trees	(Wang 1989, Wang and Lu 1996)	Unknown	Not yet
Coleoptera	Curculionidae	*Hylobitelus xiaoi* Zhang	*Pinus elliottii*	Infests and can kill live trees	(Qiu 1999, Zhao et al. 2000, Huang 2008, Zhao 2009)	China	(Yin et al. 2015)
Coleoptera	Curculionidae	*Niphades verrucosus* Voss	*Pinus elliottii*	Not reported	(Zhao et al. 2000)	Unknown	Not yet
Coleoptera	Curculionidae	*Shirahoshizo patruelis* Voss	*Pinus elliottii*	Not reported	(Zhao et al. 2000)	Unknown	Not yet
Coleoptera	Curculionidae	*Tomicus piniperda* Linnaeus	*Pinus elliottii*	Infests and can kill live trees	(Zhao et al. 2000)	Europe and Asia	(Eager et al. 2004)
Lepidoptera	Crambidae	*Dichocrocis punctiferalis* Guenee	*Pinus elliottii*	Not reported	(Huang 2003)	Unknown	Not yet
Lepidoptera	Pyralidae	*Dioryctria rubella* Hampson	*Pinus elliottii*	Not reported	(Zhao et al. 1988, 2000, Xu and Li 1992, Huang 2003, Wang 2010, Tan 2017)	Unknown	(Zhang and Zhang 2019)

Table 2. Continued

Order	Family	Species	Host plant	Damage or mortality	Sources	Native regions	Reported in English literature
Lepidoptera	Pyralidae	*Dioryctria splendidella* Herrich-Shaeffer	*Pinus elliottii*	Not reported	(Jin 1998)	Unknown	Not yet
Lepidoptera	Tortricidae	*Petrova cristata* Walsingham	*Pinus elliottii*	Infests and can kill live trees	(Jin 1998, Huang 2003)	Unknown	Not yet
Blattodea	Termitidae	*Macrotermes barmeyi* Light	*Pinus taeda*	Not reported	(Zhao et al. 2000)	Unknown	Not yet
Blattodea	Termitidae	*Odontotermes formosanus* Shiraki	*Pinus taeda*	Not reported	(Zhao et al. 2000)	Unknown	(Li et al. 2010)
Coleoptera	Cerambycidae	*Monochamus alternatus* Hope	*Pinus taeda*	Infests and can kill live trees	(Zhao et al. 2000, Yang 2008)	Unknown	Not yet
Coleoptera	Curculionidae	*Hylobitelus xiaoi* Zhang	*Pinus taeda*	Infests and can kill live trees	(Qiu 1999, Zhao et al. 2000, Huang 2008, Zhao 2009)	Unknown	Not yet
Coleoptera	Curculionidae	*Niphades verrucosus* Voss	*Pinus taeda*	Not reported	(Zhao et al. 2000)	Unknown	Not yet
Coleoptera	Curculionidae	*Shirahoshizo patruelis* Voss	*Pinus taeda*	Not reported	(Zhao et al. 2000)	Unknown	Not yet
Coleoptera	Curculionidae	*Tomicus piniperda* Linnaeus	*Pinus taeda*	Infests and can kill live trees	(Zhao et al. 2000)	Europe and Asia	(Eager et al. 2004)
Lepidoptera	Crambidae	*Dichocrocis punctiferalis* Guenee	*Pinus taeda*	Not reported	(Zhao et al. 2000, Huang 2003)	Unknown	Not yet
Lepidoptera	Pyralidae	*Dioryctria rubella* Hampson	*Pinus taeda*	Not reported	(Xu et al. 1986, Zhao et al. 2000, Huang 2003, Chen 2010, Wang 2010, Tan 2017)	Unknown	Not yet
Lepidoptera	Pyralidae	*Dioryctria splendidella* Herrich-Shaeffer	*Pinus taeda*	Not reported	(Jin 1998)	Unknown	Not yet
Lepidoptera	Tortricidae	*Petrova cristata* Walsingham	*Pinus taeda*	Infests and can kill live trees	(Jin 1998, Huang 2003)	Unknown	Not yet
Coleoptera	Cerambycidae	*Anoplophora chinensis* Forster	*Quercus texana*	Infests and can kill live trees	(Hu 2009)	Eastern Asia	(Ernstsons et al. 2022)
Coleoptera	Cerambycidae	*Batocera horsfieldi* Hope	*Quercus texana*	Not reported	(Chen et al. 2013)	Unknown	Not yet
Coleoptera	Cerambycidae	*Aromia bungii* Fald	*Quercus rubra*	Infests and can kill live trees	(Xue and Li 2007)	South-eastern Palearctic and Oriental	Not yet
Lepidoptera	Cossidae	*Streltzoviella insularis* Staudinger	*Quercus rubra*	Not reported	(Xue and Li 2007)	Unknown	Not yet
Coleoptera	Cerambycidae	*Anoplophora chinensis* Forster	*Quercus virginiana*	Infests and can kill live trees	(Hu 2009)	Eastern Asia	Not yet
Coleoptera	Cerambycidae	*Batocera horsfieldi* Hope	*Quercus virginiana*	Not reported	(Chen et al. 2013)	Unknown	Not yet

a given host tree repeatedly, and reported in different observation resources. For example, *Anoplophora chinensis* Forster (Coleoptera: Cerambycidae), *Batocera horsfieldi* Hope (Coleoptera: Cerambycidae), *Zeuzera leuconotum* Butler (Lepidoptera: Cossidae), and *Dioryctria rubella* Hampson (Lepidoptera: Pyralidae) were recorded at least 4 times each. The pecan tree *Carya illinoinensis* yielded the greatest number of wood borer records (28 species, 63.6% of 44 species). The tree species with the lowest number of wood borer species records was *L. styraciflua* (1 insect species). Coleoptera was the most commonly reported order (33 records, 55% of all records) in the wood borer record list, with the most common family being Cerambycidae (18 records, 30% of all records), the longhorned beetles.

Some noteworthy discoveries included, for example, *Anoplophora chinensis* and *Batocera horsfieldi* sharing 3 host plant species (*C. illinoinensis*, *Q. texana*, and *Q. virginiana*, the correlation coefficient $r = 1$, *P-value* = 0, Supplementary Tables S1 and S2). *Odontotermes formosanus* Shiraki (Blattodea: Termitidae) was also observed on 3 host plant species, *C. illinoinensis*, *P. elliottii*, and *P. taeda*. *Dichocrocis punctiferalis* Guenee (Lepidoptera: Crambidae), *Dioryctria rubella*, and *D. splendidella* Herrich-Shaeffer were all recorded on *P. elliottii* and *P. taeda*. There were 12 of 60 associations between wood borers and plants that have been recorded in English literature (Table 2).

Almost all usable records (95% of all records) originated from original Chinese peer-reviewed literature. Very few usable records were retrieved from the "grey literature", such as news, nonpeer-reviewed agency reports, student theses, and incidental observation. The CNKI platform, as the largest Chinese publishing database, contributed the most records.

Few reports documented the damage and tree mortality details (Table 2). In the original Chinese papers included in this review, these insects were reported as pests on trees, but most publications only indicated the occurrence of the insect species on the host tree, or a simple description of feeding.

Discussion

Chinese wood boring insect damage to 7 different North American commercial tree species in original Chinese records is summarized. There are abundant incidences of wood borers on these tree species, when planted in China. Some borer groups, such as the longhorned beetles, deserve special attention in future research because of their potential for mortality of host trees. Our summary provides a resource for predictions of potential invasive wood borers and improves the dissemination of "cryptic" data on wood borers.

Singleton records of insects from a host plant may be ecological aberrations, but repeated wood borer records may be considered a potential warning and a reason for further investigation of the specific pest. For instance, we confirm the reports of previous studies that the polyphagous longhorned beetles, *Anoplophora chinensis* and *Batocera horsfieldi*, are able to attack many plant species and cause the death of trees (Hérard and Maspero 2019, Lin et al. 2020). Larvae of *Dioryctria rubella*, the pine shoot moth, can tunnel and feed within branches, reducing the health of pine trees (Lapis 1987, Xu et al. 2021). These insect species were documented as having outbreaks in other regions (Sjöman et al. 2014, Zhou et al. 2016, Hérard, Maspero 2019).

Longhorned beetles pose a potential threat to these North American tree species. *Anoplophora chinensis*, *Batocera horsfieldi*, and *Monochamus alternatus* Hope were observed frequently. They are a major pest of *Citrus*, *Populus*, and *Pinus*, respectively (Ikeda et al. 1980, Haack et al. 2010, Zheng et al. 2016, Hérard and Maspero 2019). *Anoplophora chinensis* and *Batocera horsfieldi* are both notorious for tunneling holes into trees and causing the death of living xylem (MacLeod et al. 2002, Straw et al. 2015, 2016). The former lays eggs near the trunk and roots of trees after which larvae bore into the wood and remain inside of trees until adulthood (Sjöman et al. 2014). The latter can attack *Juglans regia* Linn. and *Populus* spp. in China (Wang et al. 2004, Yang et al. 2010b). Besides the tunneling damage, *M. alternatus* can vector the

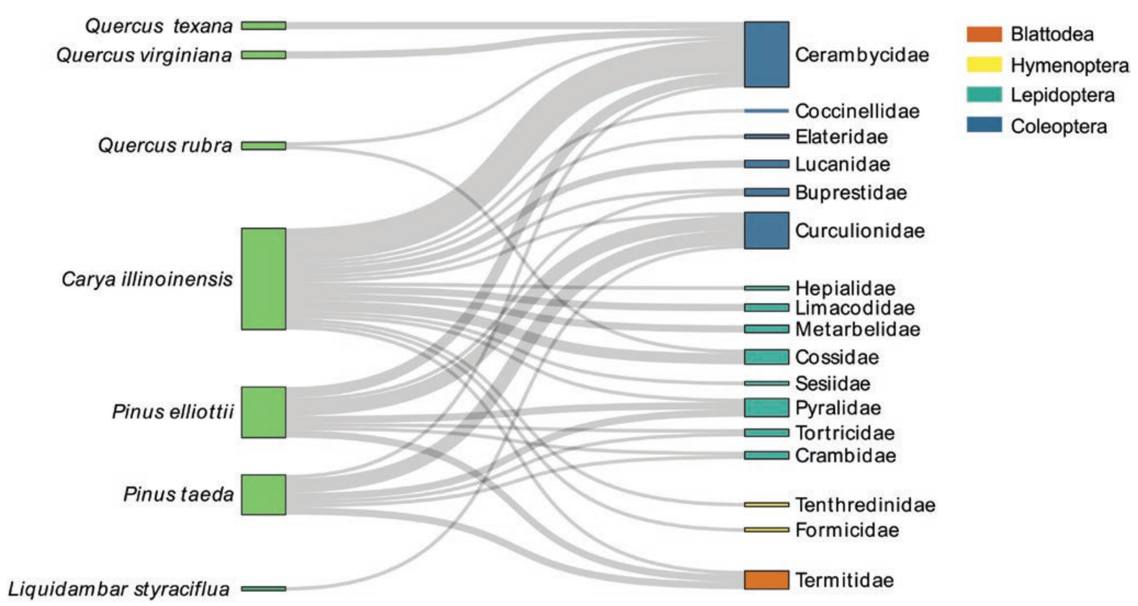

Fig. 2. Records of host plants and their insects at the insect family level. The left bars represent the host plant species, and the right color bars represent the families and orders of wood borers. The width of the grey link reflects the number of times the insect species reported on the corresponding host plant in the dataset from our literature survey. The linkages between the host plants and pest families indicate that the insects attacked those specific host plants.

pinewood nematode, *Bursaphelenchus xylophilus* Steiner and Buhrer (Nematoda: Aphelenchoididae), which causes wilting of pines (Zhao et al. 2007). Even though the nematode is native to North America, this *Monochamus* beetle species is not, and their joint damage may synergistically increase damage if the beetle is introduced to North America or elsewhere.

Zeuzera leuconotum attacking pecan trees was recorded in multiple Chinese literature in various years, showing this species may be considered a priority pest. Ning et al. (2020) reported that *Z. leuconotum* can excavate and exploit the stem of salt marsh bush, *Tamarix chinensis* Lour. (Tamaricaceae), and listed it as a novel wood borer on salt marsh bush. The fact that this moth is also apparently capable of attacking a nontypical host, such as *Carya*, is only described in multiple records in nonmainstream, grey literature.

We noted a paucity of reports of tree mortality caused by bark and ambrosia beetles (Curculionidae: Scolytinae). These insects are among the most invasive as well as most damaging insect pests worldwide. Therefore, their absence in the Chinese regional literature is probably not a representation of true reality, but instead a result of underreporting. Bark and ambrosia beetles are much smaller than longhorned beetles, and their entrance holes can be difficult to notice for nonspecialists. Similarly, tree death by scolytine-vectored fungi may be underreported because they are notoriously difficult to verify (Fraedrich et al. 2008, Hulcr et al. 2020).

Individual wood borer species tend to attack closely related plant species. For example, all wood borers of *P. taeda* were also observed on *P. elliottii* in our list. The 2 pine species (*Pinus,* Pinaceae) are common and dominant species in Southeastern and North American forest ecosystems, and as such, potentially invasive wood borers should be of concern. Closely related plant species generally possess more similar volatile and nonvolatile compounds and environmental preferences (Schaal and Olsen 2000, Courtois et al. 2016, Carvalho et al. 2019, Wang et al. 2021), which leads to them being used by the same insects (Weiblen et al. 2006, Nyman 2010). Evolutionary relatedness of native and adventive host plants is a major factor in predicting invasive pest damage (Mech et al. 2019).

Our results showed that compared to pecan and pine trees, oaks and American sweetgum were overlooked in past pest monitoring research in China. For example, the beetle genus *Acanthotomicus* (Curculionidae, Scolytinae) used to be thought to only colonize dead trees, but the Asian *A. suncei* Cognato was shown to kill live American sweetgum (Gao et al. 2017). Oak and sweetgum are widely distributed urban and forest trees across North America, and reliable background information on potential pests is needed to prepare a response strategy.

Recovering data from grey literature faces several challenges and barriers. In the process of investigating insect data, we infer that many insect records may not have been published or digitized. A substantial proportion of entomological literature is still available only as physical copies in libraries or archives (Osayande and Ukpebor 2012). Another recurring problem has been uncertain insect identification, especially in older literature where insects were frequently identified only at the family level. Some insects are not easily identifiable at the species level using solely morphological characters, but more importantly, species-level identification has not always been the target of the studies reviewed here. Another challenge is incomplete records of damage by insects. Some investigations only reported the presence of insects without any details of damage or mortality. These challenges limit further application of the information from grey literature, because at least minimal information on the degree of damage is required for reliable pest risk assessment.

One of the significant drawbacks of grey literature is the accuracy of information. News reports, in particular, may not meet the criteria of a scientific publication (Pappas and Williams 2011), and as such, it is not always easy to distinguish evidence from opinions. Yet, some experts share professional knowledge and accurate information with public audiences (Hopewell et al. 2007, Pappas and Williams 2011). Thus, even though each instance may require a careful credibility assessment, grey literature is a plausible data source.

Information on potential invasive species is increasingly present in publicly accessible databases. For instance, in 1980, the System for Information on Grey Literature in Europe was established as an open-access database (OpenGrey, http://www.greynet.org/opengreyrepository.html) to leverage the value of grey literature. Compared to the Grey Literature Report (http://www.greylit.org/) that only focuses on urban health literature, the OpenGrey database covers various subjects and allows users to export full-text for free. OpenGrey has been found to contain information on apple pests, for example, that was absent in standard research papers (Kertesz et al. 2020). The European and Mediterranean Plant Protection Organization Global Database (https://gd.eppo.int/) includes thousands of records of the association between insect pest and host plants. It provides identification details of several insect pests. The Invasive Species Specialist Group developed the Global Invasive Species Database (http://www.iucngisd.org/gisd/) to share alien species information. Additional countries and regions have developed invasive species response strategies and provide regional risk assessments. These databases include invader taxonomy, biological information, detection, and control methods, which may facilitate integration of pest data from grey literature (Guisan et al. 2013).

Conclusion

Peer-reviewed and grey Chinese literature analyzed here showed that at least 44 insect species attack North American tree species planted in China. Among these insect species, a total of 12 associations between insect species and hosts have been reported in English literature before (such as *Tomicus piniperda* Linnaeus, *Anoplophora chinensis*, *Acanthotomicus suncei*, *Odontotermes formosanus*, and *Zeuzera leuconotum*), indicating that Chinese literature could provide valuable information for pest risk analysis. Meanwhile, drawbacks such as variable information accuracy, require careful interpretation of grey literature.

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Data Availability

All data and figures in this study are included in this article and Supplemental Materials.

Author Contributions

Yiyi Dong (Data curation-Equal, Investigation-Equal, Visualization-Equal, Writing – original draft-Equal, Writing – review & editing-Equal), Jie Gao (Data curation-Equal, Investigation-Equal), Jiri Hulcr (Conceptualization-Equal, Funding acquisition-Equal, Writing – review & editing-Equal)

Supplementary Material

Supplementary material is available at *Environmental Entomology* online.

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