

# Disentangling Environmental and Anthropogenic Impacts on the Distribution of Unintentionally Introduced Invasive Alien Insects in Mainland China

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## Abstract

Globalization increases the opportunities for unintentionally introduced invasive alien species, especially for insects, and most of these species could damage ecosystems and cause economic loss in China. In this study, we analyzed drivers of the distribution of unintentionally introduced invasive alien insects. Based on the number of unintentionally introduced invasive alien insects and their presence/absence records in each province in mainland China, regression trees were built to elucidate the roles of environmental and anthropogenic factors on the number distribution and similarity of species composition of these insects. Classification and regression trees indicated climatic suitability (the mean temperature in January) and human economic activity (sum of total freight) are primary drivers for the number distribution pattern of unintentionally introduced invasive alien insects at provincial scale, while only environmental factors (the mean January temperature, the annual precipitation and the areas of provinces) significantly affect the similarity of them based on the multivariate regression trees.

**Key words:** distribution pattern, invasive alien insects, mainland China, unintentional introduction

Biological invasion can cause enormous economic and ecological damage (Reichard and White 2003, Liu et al. 2005, Pimentel et al. 2005), and lead to decrease of global biodiversity, even result in extinction of some species (Mack et al. 2000, Dextrase and Mandrak 2005; Gallardo et al. 2016), so invasive alien species (IAS) have drawn more attention in the worldwide. Describing the distribution pattern and understanding the drivers of IAS are very important to predict where and when invasions will occur (Higgins et al. 1996, Vilà and Pujadas 2001, Sax 2002, Myers and Bazely 2003, Liu et al. 2005, Lin et al. 2007, Ding et al. 2008, Boulant et al. 2009, Huang et al. 2012).

Biotic and abiotic factors all can impact the distribution pattern of IAS. Abiotic factors, such as suitable temperature and humidity, can influence the distribution of IAS and shape community structure of IAS (Casasayas 1990, di Castri 1990, Lin et al. 2007, Menke et al. 2009, Hartley et al. 2010). Biotic factors, such as human activity, clearly influences the distribution pattern during the initial stage of the invasion process (Roura-pascual et al. 2011).

Recently, more and more studies elucidated the relative roles of biotic and abiotic factors on the distribution pattern of biological invasion at regional or global scales. For example, Westphal et al. (2008) analyzed the global invasive species and found that the

merchandise imports were the most important explanatory variable for the number of invasive species. Pyšek et al. (2010) identified general predictors of the alien species from a variety of taxa across Europe, and they found the anthropogenic factors (i.e., wealth and demography) determined the distribution of alien species. In China, Huang et al. (2012) also indicated that introduction pressure [i.e., number of international tourists, gross domestic product (GDP)] was the driver for the numbers of IAS in first detection locations. When environmental and anthropogenic factors were integrated in the same model, the relative effects of determinant variables shaping the individual taxonomic groups also are related to the introduced pathway or taxonomic groups (Pyšek et al. 2010). Some studies also demonstrated that intentionally and unintentionally introductions can influence subsequent invasions (Reichard and White 2001, Kowarik 2003). For example, Roques et al. (2016) found unintentionally introduced insects spread faster than intentionally introduced insects.

In this study, we try to analyze the determined factors on the distribution pattern of 105 unintentionally introduced invasive alien insects in mainland China. Previous studies reported the lists or described the distribution (Li et al. 2005, Wan et al. 2008, Xie 2008, Zhang et al. 2008, Xu and Qiang 2011) or management

practices (Zhang et al. 2009, Wan and Yang 2016) of invasive alien insects in China. However, most of these studies described the current distribution of invasive alien insects, and determined factors of the distribution pattern were seldom examined. In our study, we combined 105 unintentionally introduced invasive alien insects and selected 14 potential variables, e.g., 4 environmental variables and 10 anthropogenic variables to analyze the effects of environmental and anthropogenic factors on unintentionally introduced invasive alien insects in mainland China. We try to clarify 1) which factor is the main driver for the number distribution of unintentionally introduced invasive alien insects in mainland China? 2) which factor is more important for determining similarity of species composition of unintentionally introduced invasive alien insects at provincial scales?

## Materials and Methods

### Data Collection

A list of unintentionally introduced invasive alien insects was compiled based on previous studies on alien insects in China. Li et al. (2005) evaluated 160 invasive alien insects in mainland China, including some quarantine pests that had not been previously occurred in China. Xie (2008) listed 71 invasive insects, which comprised native species that invaded Taiwan from mainland China. Zhang et al. (2008) described the distribution of 11 important international pests recorded in Global Invasive Species Database. Wan et al. (2008) reported the checklist of 80 invasive alien insects and Xu and Qiang (2011) published a list included 93 insect species. Wan and Yang (2016) also list 125 insect pests in China. And we integrated all of these data, removed the duplications, and extracted the invasive alien insects based on five criteria: (1) invasive alien insects recorded as established in China, (2) recorded as non-native to China, (3) recorded as unintentionally introduced into China, (4) detailed distributed records were available, (5) economical or ecological loss had been reported. One hundred and five insect species were listed as unintentionally introduced invasive alien insects (Supp Appendix S1 [online only]). The distribution data of these insects in provincial administrative units were compiled based on previously published literature (Wan et al. 2008, Xie 2008, Xu and Qiang 2011, Zhang et al. 2008). Although some of the "absence" records of unintentionally introduced invasive alien insects in different province due to insufficient sampling effort, we decided to use them because all these data were compiled from the published data and provide a more reliable set of absences than pseudoabsences created at random from areas where the species is not known to occur.

### Explanatory Variables

To test on determined factors for the species diversity and species composition of unintentionally introduced invasive alien insects, four environmental factors (1–2) and 10 anthropogenic factors (3–V) were selected in our study. 1) Geography: total area of each Province. 2) Climate, based on the data from 2006 to 2011 at 1-km pixel resolution for the province: i) mean annual precipitation; II) mean temperature in January; and iii) mean temperature in July. 3) Conservation status: i) the area of nature reserve and ii) the percentage of areas protected occupied the total area of province. 4) Demographic variables: the population density. 5) Economic factors: i) GDP; ii) transport density; iii) sum of total passengers; iv) international tourism income; v) sum of inbound tourisms; vi) total imported goods; and vii) sum of total freight (STF) (Table 1). Socioeconomic data and protected areas were compiled based on

**Table 1.** Variables reflecting environmental features and anthropogenic factors in province, China

Variables	Code (units)	Data transformation
<b>Environmental factors</b>		
Area of province	AP (ten thousands ha.)	log
Mean temperature in January during 2006–2011	MT1 (°C)	
Mean temperature in July during 2006–2011	MT7 (°C)	
Annual mean precipitation during 2006–2011	APP (mm)	
<b>Anthropogenic factors</b>		
Population density	PLD (person/ha.)	log
Gross domestic production	GDP (a hundred million Yuan)	
Area of nature reserves	ANR (ten thousands ha.)	log
Percentage of areas protected	PAP (%)	
Transport density (the total of all kinds of transports in province/area of province)	TPD (kilometre/ten thousands ha.)	
Sum of total passenger	STP (ten thousands persons)	
STF	STF (ten thousands tons)	
International tourism income	ITI (million dollar)	log
Sum of inbound tourisms	SIT (ten thousands person-times)	log
total imported goods	TIG (ten thousands dollar)	log

the official statistical data published on the website of the National Bureau of Statistics People's Republic of China (NBSC 2013).

Normal characters of 14 variables were tested using Kolmogorov–Smirnov. If  $P < 0.05$ , then the values of variables were transformed with  $\log(x + 1)$  (Table 1).

### Pattern Analysis

The number of recorded unintentionally introduced invasive alien insects in each province represents the province's species diversity. The diversity distribution pattern of unintentionally introduced invasive alien insects was analyzed at the provincial level using ArcGIS 9.3 produced by Environmental Systems Research Institute. Data matrix (0, 1) was built based on the absence/presence data of 105 unintentionally introduced invasive alien insects in 31 provincial administrative units. We used nonmetric multidimensional scaling (NMDS) to compare species composition of these insects among these provinces with Bray–Curtis dissimilarity coefficient (Clarke 1993). Using stress levels obtained by fitting the dissimilarities to distance, a two-dimensional solution was chosen as the best representation of the dissimilarities among tree types. NMDS was performed using the PAST software package (Hammer et al. 2001).

### Regression Trees

CART were often used to explore the single response variables by several explanatory variables, including being able to deal with non-linear relationships, non-normality (Breiman et al. 1984, De'ath and Fabricius 2000). We try to reveal determinant factors of province's species diversity by CART. Trees were constructed by repeatedly splitting the number of unintentionally introduced invasive alien

insects in each province using binary recursive partitioning in rpart (John and Trevor 1992). We employed the 1-standard error rule to select trees with the best number of splits and avoid over-fitting (Breiman et al. 1984). CART was computed using R 2.15.1 (R Development Core Team 2012) and the rpart packages (John and Trevor 1992, Westphal et al. 2008).

In order to evaluate the determined factors on the species composition of unintentionally introduced invasive alien insects among different provinces, multivariate regression trees (MRT) (De'ath 2002) were used to build regression trees based on explanatory variables. It is a hierarchical technique, where each split is chosen to minimize the dissimilarity in the sites within the clusters. Bray–Curtis pairwise similarities measure and the cross-validated relative errors were applied for the predictive power of the resultant regression trees (De'ath 2002). Insect composition structure was compared with four environmental factors and ten anthropological factors. 100 trees were built used MRT, the best tree was chosen based on the minimum of cross-validated relative error. MRT were computed using R 2.15.1 (R Development Core Team 2012) and the mvpart packages (Therneau and Atkinson 2005).

## Results

### Spatial Pattern

Spatial diversity pattern of unintentionally introduced invasive alien insects in each province indicated most of them distributed in southern China and coastal parts of eastern China (Fig. 1). The maximum

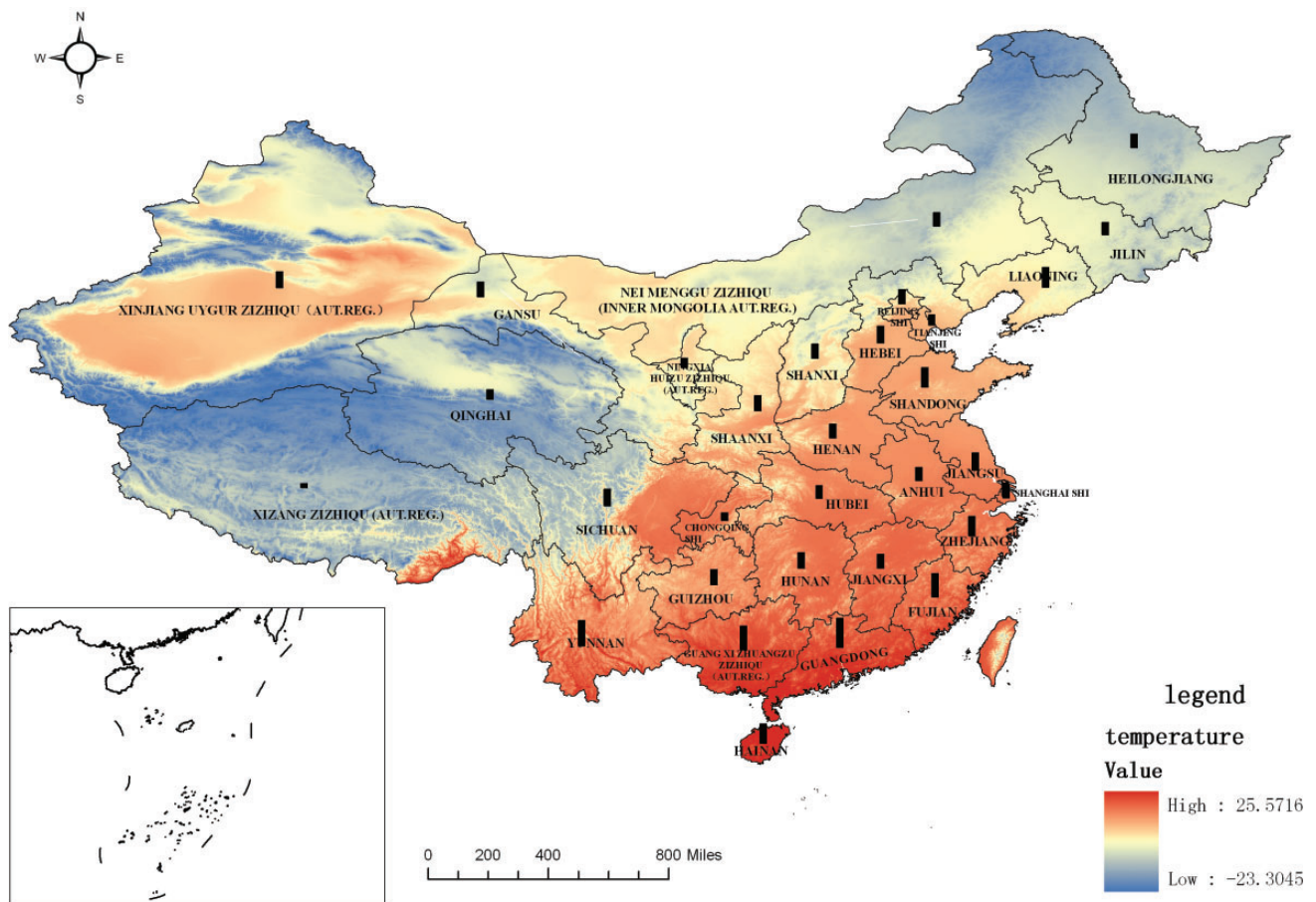
number of unintentionally introduced invasive alien insects was observed in Guangdong province (60; Fig.1), followed by Yunnan (52), Guangxi (49), and Fujian (48). The minimum number of them was found in central and western part of China, e.g. only 9 unintentionally introduced invasive alien insects were found in Tibet (Fig. 1).

Based on NMDS ordination, unintentionally introduced invasive alien insects assemblages were clustered into three categories: (1) coastal provinces in southern China and Yunnan Province, (2) central China, southwestern China (Sichuan and Guizhou), and almost all of eastern China, and (3) northern, northeastern, northwestern, and southwestern China (Chongqing and Xizang) and Shandong Province (Fig. 2).

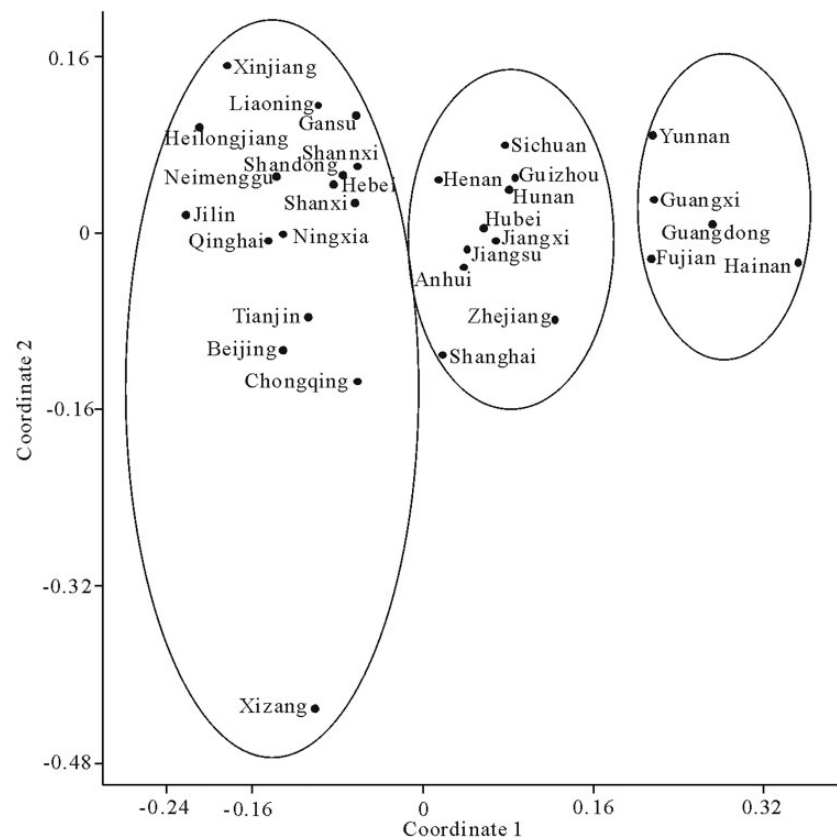
### Determinant Factors

CART supported that mean temperature in January (MT1) and STF had overwhelming effects on the numbers of unintentionally introduced invasive alien insects. The regression tree explained almost half of the variance ( $R^2$  value of 0.47) (Fig. 3). MT1 and STF were the dependent variables in the best tree and explained 34.4% and 12.3% of variation, respectively.

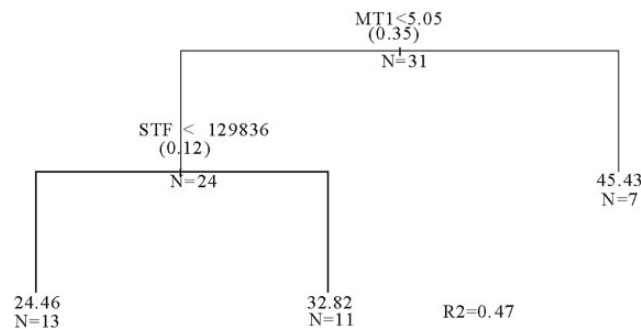
The MRT indicated that the environmental factors (MT1, APP, and AP) are the more important determinants of the species composition of unintentionally introduced invasive alien insects at provincial scales (Fig. 4). The first split based on the mean temperature in January explained 36% of variation in the similarity matrix. Yunnan, Fujian, Guangdong, Guangxi, and Hainnan provinces were separated from other provinces. The second split explained 20% of variation and was



**Fig. 1.** The number distribution of unintentionally introduced invasive alien insects and mean temperature at provincial scale in mainland China. Black bars are the numbers of IAS insects in each province. Different colors represent the change of mean temperature.



**Fig. 2.** Assemblage similarity of unintentionally introduced invasive alien insects in 31 provinces based on the NMDS analysis. The right of axis 1 represents the warmer and moister regions while the left of axis 1 are the colder and drier regions.



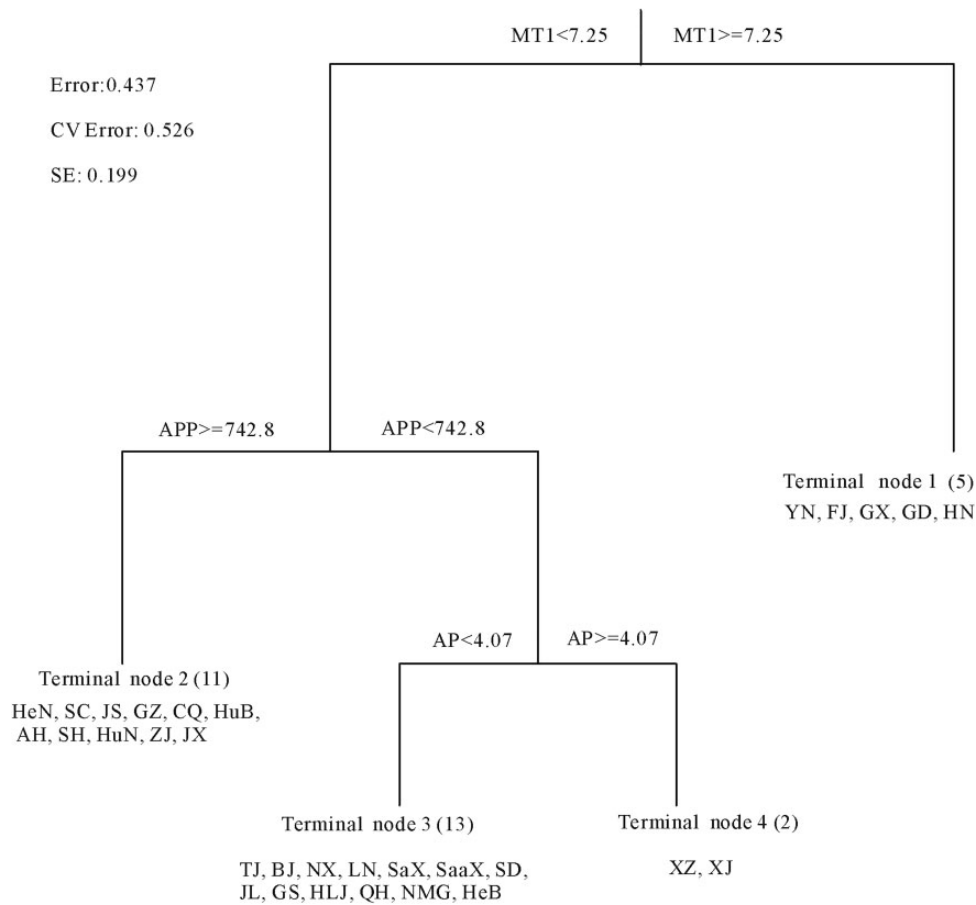
**Fig. 3.** Classification and regression tree was used to identify the roles of environmental and anthropogenic factors in explaining the distribution of the number of invasive alien insects in mainland China. Only the most influential variables were used to construct tree: MT1 and STF. Each split (non-terminal node) is labeled with the explanatory variable, the value that determines the split, for example, mean temperature of January <5.05 and mean temperature of January  $\geq$  0.05 split the first node, and the proportion of the total null deviance that the variable explains (in parentheses). N values indicate the total number of provinces assigned to the terminal nodes. The  $R^2$  value is the amount of variance that the model explains.

based on the annual precipitation. High precipitation provinces such as Sichuan, Henan, Jiangsu, Guizhou, Chongqing, Hubei, Anhui, Shanghai, Hunan, Zhejiang, and Jiangxi were separated. The last split explained 13% of variation based on the areas of provinces. The entire MRT explained 69% of the variation and had CV error  $0.437 (\pm 0.20 \text{ SE})$ , indicating a strong predictive power for a new dataset.

## Discussion

Climate was often identified as the key abiotic factor for invasion of many invasive species (Thuiller et al. 2005, Ulrichs and Hopper

2009). In this study, we also found the climate factors, such as mean temperature in January and annual precipitation, distinguished influenced the distribution pattern of unintentionally introduced invasive alien insect in mainland China. Our results showed that most of unintentionally introduced invasive alien insects distributed in southern China, and high similarity of species composition was observed in the similar climate provinces. Lin et al. (2007) also found that higher temperatures and abundant rainfall in southern China may contributed to great abundance of invasions in this area. Kowarik (1990) and Dukes and Mooney (1999) also proved the warmer climates could be positively related with representation of alien species in temperature latitudes. Lester (2005) found that



**Fig. 4.** Multivariate regression tree was used to identify the roles of environmental and anthropogenic factors in explaining the assemblages of invasive alien insects in 31 provinces, mainland China. The variables and provinces used to split the records are indicated at each split. For example, the terminal node 4 corresponds to province with a mean temperature of January  $<7.25$  and annual precipitation  $<742.8$  and area of provinces  $\geq 4.07$ , and (2) represents two provinces assigned to this terminal nodes including XiZang and XinJiang.

mean temperature played an important role for successful establishment of exotic ants in New Zealand. Temperature can impact the distribution patterns of unintentionally introduced invasive alien insects mainly because insects are poikilothermic organisms, their growth, reproduction, the survival ratio and population density of overwintering individuals are all related to temperature (Musolin 2007, Bale and Hayward 2010, Johnson et al. 2010, Luedeling et al. 2010, Pöyry et al. 2011). In addition, warmer temperatures can increase establishment of alien insects (Huang et al. 2011), also benefit to spread of established invasive insects (Spark et al. 2005). According to previous studies (Casasayas 1990, di Castri 1990), environmental constraints could limit the invasion process in Mediterranean region. Unsuitable precipitation presumably impacted on the community of insects, such as dry areas could resist to the invasion of red fire ants (*Solenopsis invicta*) (Hu et al. 2008). The occurrence of Argentine ant was also highly constrained by temperature and humidity (Menke et al. 2009, Hartley et al. 2010).

Moreover, this study also proved that anthropogenic activity can impact the number distribution pattern of unintentionally introduced invasive alien insects based on the CART analysis. Previous studies also found that the GDP (Lin et al. 2007), the introduction pressure (e.g., number of international tourists and number of water ports of entry) (Huang et al. 2011), or propagule pressure (e.g., imported goods) (Westphal et al. 2008) influenced the number of IAS at regional or national scales. Our result indicated that STF can

determine the number of unintentionally introduced invasive alien insects, just as previous studies showed that domestic transports may have accelerated the spread of IAS in China (Ding et al. 2008, Wan and Yang 2016). Our results found unintentionally introduced invasive alien insects mainly distributed in developed regions, where the intentional or unintentional introduction of IAS had increased due to frequent economic activity (Jenkins 1996, McKinney 2001, Levine and D'Antonio 2003, Yang et al. 2009). In addition, containers and transport vector can provide a convenient way for alien species to enter new places (Hulme et al. 2008), so a large number of transported freights are beneficial for the entering and spreading of unintentionally introduced invasive alien insects. Reports on the insects showed that many species were intercepted on imported wood, such as Scolytidae (46 species), Bostrychidae (10 species), Cerambycidae (19 species), and Burprestidae (4 species) (Wan and Yang 2016). Lin et al. (2007) showed that large amounts of traffic not only increased the risk of invasive alien insect diffusion but also seriously damaged existing habitats, thereby benefited the establishment of invasive alien insects. Several other authors also predicted dire future scenarios of biological invasion for rapidly growing national economies such as China (Jenkins and Mooney 2006, Lin et al. 2007, Ding et al. 2008, Weber and Li 2008, Roques et al. 2009, Urban et al. 2008, Huang et al. 2012).

No evidence that human activity impacted on the assemblage similarity of unintentionally introduced invasive alien insects was

found in this study, similar as results of separating the climatic suitability and anthropogenic influence in determining the pattern of Argentine ant (*Linepithema humile*) (Roura-pascual et al. 2011). Maybe human activity clearly influences the distribution pattern during the initial stage of the invasion process (Roura-pascual et al. 2011), and the environmental factors can play more roles on the community similarity after their establishment. In fact, results in this paper should be interpreted with caution because they do not necessarily imply cause–effect relationships between the independent variables and insects invasion. On the other hand, all relevant variables explaining the alien representation are hard to enclose in one paper. For example, the distribution of invasive plants or native plants also can impact the invasive insects (Engelkes and Mills 2013, Sugiura et al. 2013). Besides the native insects and ecological habitat also could effect on the invasion of insects. All these factors are not considered in this analysis.

In China, in order to effectively manage on the IAS, Ministry of Environmental Protection issued four lists of IAS, including 21 insect species. Our results indicated when we going to advise that policies and management practices related with biological invasions, several aspects for future research should be conducted: 1) concentrating on other unintentionally introduced organisms group; 2) focusing on the distribution pattern or spread ratio or characteristics of invasive insects under the future scenario of climate change; 3) majoring on relationship between the number changes of invasive insects and the progress of domestic transports in different regions or nations. Collaboration between different regions or nations is required to control biological invasions in the future.

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## Supplementary Data

Supplementary data are available at *Journal of Insect Science* online.

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