IL A ~f- M Ada Enlornologica Sinica , February 2002, 45 (1): 121-130 ISSN- 0454-6296

综述 Review Articles *

Unwelcome Guests: Exotic Forest Pests

Kerry 0. BRITTON[1] , SUN Jiang-Hua[2]

(1. USDA Forest Service, Southern Research Station, Athens, GA, USA 30602-2044;

2. Institute of Zoology, Chinese Academy of Sciences, Beijing, CHINA 100080)

Abstract: Exotic forest pests cost China and the United States billions of dollars each year. Current regulatory systems worldwide are overwhelmed with the increasing volume of international trade. Trade in nursery stock, wood products, pallets and dunnage have proven the most common means of transport for exotic forest pests. Despite our best efforts, pests such as chestnut blight, gypsy moth, Dutch elm disease, and Asian longhorned beetle (ALB) have caused major changes in the structure and function of American forests, as well as urban landscapes. China' s natural resources are likewise under attack, and many of the pests come from the United States, such as the pinewood nematode and the red turpentine beetle. ALB is acting like an exotic pest in China, attacking over 100 host species, and killing many of the trees planted in the Three-North Belt project. The biological basis of the invasiveness of exotic pests, and what can be done about them, are discussed.

Key words: Exotic pest; forest; invasion; gypsy moth; pinewood nematode; Asian longhorned beetle; red turpentine beetle

1 INTRODUCTION

As the global economy grows, the risk of importing exotic pests is also increasing. Organisms are carried, intentionally or unintentionally, on trade goods and by travelers. Disturbances in the natural habitat increase the opportunity for establishment of many pests, and, particularly in the United States, environmental disturbance has increased in recent years. A 1993 report by the United States Congress Office of Technology Assessment found several thousand non-native invasive species in the United States (Table 1). They estimated the accumulated economic cost of just 79 well-known exotic pests at 9.7 billion USD. Environmental costs are harder to evaluate, but recently Pimental *et al.* (1999) estimated environmental costs and losses of a broader spectrum of exotic pests at 138 billion USD per year.

The exotic pest problem is much broader than insects alone (Table 2). Many other organisms have become expensive " biopollutants". Unfortunately, once pests are established, this type of pollution is much harder to clean up than chemical pollution. As exotic pests replace native flora and fauna, ecosystems lose biodiversity. Once lost, the differences between continents that make each ecosystem unique can never be recovered.

Table 1 Exotic species in the United States, and their proportion of group biodiversity

Number of Exotic Species by Category	Percent of total species in group
> 2 000 insects and arachnids	2%
239 plant pathogens	Unknown
> 2 000 plants	Unknown
142 terrestrial invertebrates	6%
70 fish	8%
91 mollusks	4%

Table 2 Estimated cumulative losses (1906-1991) from a few well-known exotic pests

Exotic pest category	Number of species analyzed	Cumulative loss (millions USD)
Plants (excluding agricultural weeds)	15	603
Invertebrates		
Terrestrial	6	225
Aquatic	3	1 207
Insects	43	92 658
Plant Pathogens	5	867
Fish	3	467
Others	4	917
Total analyzed	79	96 944

There is growing concern among the scientific community as we observe the destructive behavior of exotic pests in forests. Yet it is difficult to persuade those who

收稿日期 Received: 2002-01-07; SS H M Accepted: 2002-02-04

ship cargoes abroad to adopt sanitation measures, such as methyl bromide fumigation, which raise the price of pallets from 0.5 - 1.50 USD each. The World Trade Organization has established a Phytosanitary Agreement to provide guidance to importing countries as they try to regulate materials that carry pests once a definite risk has been shown. Complex trade implications make these negotiations intricate; no agreement on harmonious standards has yet been reached.

Our goal with this paper is to show how important this issue can be, using only a few examples of the exotic forest pests in the United States and China. We as scientists must all work to help bring this issue to the attention of government officials who have the power to stop the tide of exotic pests which flows in both directions across the oceans.

2 WAYS THE EXOTIC PESTS OCCUR

2.1 Intentional introductions

Many exotics we now consider pests were introduced intentionally, and escaped from cultivation. This is particularly true of plants and animals originally imported for agriculture, horticulture, or aquaculture. In the United States, kudzu, multiflora rose, scotch broom, Chinese privet, and Japanese honeysuckle are examples of ornamental plants that escaped and became troublesome weeds. Common carp were introduced in the 19th century, but now reduce water clarity and habitat quality for other fish. Most countries are only now slowly awakening to these hazards, and very few have developed risk assessment methods for intentional introductions. The United States, for example, inspects and quarantines incoming nursery stock only for the presence of insect pests and pathogens; it does nothing to assess potential weediness.

2.2 Non-intentional introductions

Every type of trade goods can serve as a carrier for non-intentional introductions. Container freight from Russia brought the Asian strain of gypsy moth to the United States. Tires from Japan that were brought to Texas for recycling carried the Asian tiger mosquito, an efficient vector of many viral human and animal diseases. Zebra mussels that now choke the Great Lakes and associated water systems were carried in ship ballast water from the Caspian sea region of Asia. Pine shoot beetle (*Tomicus piniperda*) also arrived through the shipping industry of the Great Lakes, and became established near Cleveland, Ohio. Peanut breeding stock from China harbored peanut stripe virus. Asian longhorned beetle reached Chicago in wooden pallets.

2.3 Introduction of forest exotic pests

Forest insect pests and diseases are usually introduced non-intentionally. They lie hidden in soil, seed, bonsai and other nursery stock, logs, pallets, and many wood products. Consumption and trade in forest products alone has increased 400% worldwide over the last 30 years. In 1999, the United Nations Food and Agriculture Organization estimated the annual value of trade in wood and wood products worldwide at 250 billion USD. Furniture and wooden objects represent only a very small part of the wood crossing international borders. In the United States, only 30% of the softwood lumber we use is imported, but 70% of all imported goods arrive on wooden pallets and spools, or wedged into metal cargo boxes with pieces of wood. Such wood is usually inferior in grade, and may contain many insects and disease organisms.

Wooden spools carrying wire from China were examined by the Canadian Forest Service in 1997. They found live wood borers in 24% of the spools, and tunnels indicating wood borer activity in 31% of the 50 spools they examined. Six species of Cerambycidae and one Anobiidae were reared from these spools. There was often no visible external evidence of borer activity until the spools were taken apart (Allen, 2001). Obviously, normal port inspections cannot probe this deeply into every shipment of spools. A similar study found live beetles in green spruce bolts that were used to brace large blocks of granite rock inside shipping containers from Norway. More than 2 500 live insects were found from only 29 log bolts. These represent more than 40 species, including several of quarantine significance (Table 3). Bluestain fungi and nematodes were also present (Allen, 2001).

A system of regulation and inspection has been established in most developed countries to safeguard against pest introduction, but it is so overcome with the volume of trade, that in the United States, we can inspect only 1% of incoming freight. The current system is clearly not working. More than 205 new exotic pests were introduced or first detected in the United States between 1980 and 1993.

Table 3 Wasps and beetles reared from 29 intercepted spruce bolts from Norway used as dunnage for granite shipped to Canada (By permission of Dr. Eric Allen, Cnadian Forest Service, Victoria, British Columbia)

Family	Species	Number of individuals
Anobiidae	*Anobium* sp.	10
	Ernobius explanatus	4
Cerambycidae	*Tetropium fuscum*	44
	Callidium coriaceum	3
	Molorchus minor	1
	Pogonocherus fasciculatus	1
	Semanotus undatus	1
Cucurlionidae	*Rhyncholus* sp.	1
Melandryidae	*Serropalpus barbatus*	7
Scolytidae	*Pityophthorus micrographus*	942
	Pityogenes chalcographus	284
	Ips typographic	27
	Crypturgus hispidulus	16
	Pityophthorus pityographus	1
Siricidae	*Sirex juvencus*	21

2.4 The reasons for their devastating impacts

Exotic pests can be particularly devastating because the native host species have not evolved under selection pressure for resistance to the pest. They will be defenseless, unless by sheer luck a general resistance mechanism that they developed to fight off other native pests is effective against the newcomer. Another reason exotic pests can be so destructive is they often arrive in a new land without their natural enemies. This is particularly true of insects and other animal life. Without predators and parasites to keep them in balance, the pest population can skyrocket.

3 EXAMPLES OF EXOTIC FOREST PESTS IN THE UNITED STATES AND CHINA

3.1 Chestnut blight

American chestnut (*Castanea dentata*) once composed 25 % of most hardwood forests in the eastern United States. These were magnificent trees, up to 30 m tall, and averaging 1.5 m in diameter when fully mature. They were very drought-resistant, and tolerated poor soils. Their wood quality was excellent, and rot resistant. The nuts were used for food and supplied valuable nutrition for livestock, as well as wildlife such as deer, turkey, grouse, squirrel, and bear.

Then in 1904, a forester in New York noticed chestnut trees were dying. At first, he thought it was from drought stress, but soon it was learned the trees were infected with a fungal disease. The fungus, *Cryphonectria parasitica* , probably arrived on nursery stock from China. Chinese chestnuts planted nearby were resistant. The fungus spread throughout the eastern forests, causing girdling cankers that killed every chestnut on some 3.6 million hectares. The stumps still sprout to this day, producing small trees that also become infected and die. The fungus survives on these sprouts and on several oak species (Liebhold *et al.* , 1995)

Although great strides have been made toward resistance by genetic crosses with Chinese chestnut (*C. mollissirna*), repeated backcrosses have been necessary to restore the popular form and size of the American chestnut, while maintaining the Chinese resistance genes.

Use of marker-assisted selection for the resistance trait has greatly reduced the time and cost required for these efforts. The American Chestnut Foundation has selected third generation backcrosses, containing 94% American chestnut genes and possessing high levels of resistance. These were developed mainly from three Chinese cultivars. Their intention now is to broaden their breeding program by incorporating more Chinese sources of resistance, and out-crossing to locally adapted American parents. However, it is doubtful that chestnut can be planted on such a large scale as to restore its place in the ecosystem. Indeed, its niche has been taken over by other species, notably oak.

3.2 Gypsy moth

Even as the oak component of eastern hardwood forests expanded into the openings left by the dying chestnut, another invader was already quietly munching the leaves of an expanding circle of eastern oak species. The European strain of gypsy moth *{Lymantria dispar)* was accidentally released in Boston, Massachusetts, in 1869. The moth was brought to the United States from France for scientific study by an amateur entomologist and silk worm enthusiast named E. Leopold Trouvelot. Defoliation in the vicinity of his home did not become evident until

1892. It look about 20 years to attract government attention. In 1906, the first federal funds were appropriated by the United States Congress to control the gypsy moth, but it was too late to achieve eradication. Pesticide applications (usually Dimilin) and biocontrol efforts have only succeeded in reducing the rate of spread of the insect about 50% (from 20 - 40 km/yr to 9 - 14 km/yr) .

The consequences of defoliation by gypsy moth depend largely upon the health status of the tree, the season of defoliation, and larval population dynamics. Trees under stress from drought or crowding have fewer stored carbohydrate reserves. If severe defoliation occurs in the spring, the trees will produce new leaves, exhausting their limited energy reserves. In the short growing season that remains, the trees cannot make up the carbohydrate deficit through photosynthesis. Such trees enter the dormant season with greatly depleted energy reserves to resist cold injury, and begin the next growing season with less productive leaves and mineral imbalances. Trees in this weakened state are much more susceptible to other insects, diseases, and environmental stress. Healthy hardwoods have more energy reserves, and can withstand several seasons of defoliation before dieback occurs. Defoliation that occurs in the fall is less damaging because the trees do not refoliate until the next growing season.

Areas newly invaded by the gypsy moth show little defoliation in the first few years, as populations grow. Gradually, repeated defoliation predisposes the trees to secondary diseases, such as Armillaria root rot, and pests such as the two-lined chestnut borer (*Agrilus bilineatus*) .

Population dynamics of the gypsy moth have recently been affected by an epidemic of a fungal pathogen, *Entomophaga maimaga* . This fungus was first released in the early 1900s, with little apparent success. Later biocontrol efforts focused on *Bacillus thuringensis* (Bt) , which has been used extensively. However, lack of host specificity of Bt led to concerns about non-target impacts on other Lepidoptera. A viral biocontrol agent called Gypchek has also been widely used. The virus is very host specific, but more difficult to produce, since it can only be grown in live caterpillars. In 1985, scientists reintroduced *E. maimaga* (Hajek *et al.* , 1996), but larvae at the release site became heavily infected with the virus, and so researchers could not determine whether or not the fungus had become established. Then, in 1989, *E. maimaga* became widely active across the entire range of gypsy moth, achieving spectacular control in some areas.

Over the years, efforts to control the European strain of gypsy moth have cost billions of USD, but slowing the spread is also estimated to save 22 million USD/yr. But an even more dreaded variety of gypsy moth, the Asian strain, reached the western United States on grain ships from Siberia in 1991 . The European strain females cannot fly, so for dispersal, this strain depends upon larvae dangling from silken threads to be caught and transported in wind. Conveniently, the larvae produced in a dense population are much smaller and lighter, so they can be carried long distances in this passive manner.

Because the Asian strain females are active flyers, the potential for spread is much greater. Concern for the disastrous results which might be expected, should the Asian strain become established, prompted a swift eradication program near the western port cities. This project cost 17 million USD over four years.

Military vehicles and containers shipped to North Carolina from Germany were also infested with the Asian strain. When the infestation was detected, the insects had already established in the forests surrounding the military shipping terminal. The three-year program to eradicate this small outbreak in the eastern United States cost 6 million USD. Fortunately, the Asian strain was not found in any of the 48 locations to which containers had been forwarded. Needless to say, these locations remain under sharp scrutiny for evidence of further establishment.

One special difficulty in eradicating the Asian strain is that the two strains are very similar morphologically. Adult males of both strains are attracted to the Gyplure pheromone traps deployed by tens of thousands in the United States each year. Because the two strains are very difficult to distinguish, a computer system comparing landmark wing venation coordinates has been developed to discriminate between the two strains This may prove a useful screening tool, in combination with more costly molecular techniques.

3.3 Dutch elm disease

In the 1930s, a ship from the Netherlands brought veneer logs to the United States. In the logs were beetles, *Scolytis multistriatus* , carrying a devastating fungus. The fungus, *Ophiostoma ulmi,* had already killed millions of elms in the Netherlands and Northern France. It was probably of Himalayan origin, and reached Holland by way of the Dutch East Indies. All North American elm species were susceptible, and particularly the extremely popular *Ulmus americana* , which was widely planted to provide a graceful canopy of green over streets in many American cities and towns. The fungus spread by means of native bark beetles, *Hylurgopinus rufipes* , as well as *Scolytis multistriatus* , and by root grafts. Leaves on infected trees wilted, curled, turned yellow and died. Sometimes the tree died within a few weeks, its vascular tissue plugged with fungal mycelium, tyloses, and gums. Sometimes the tree died one limb at a time, over a period of a year or more.

There have been two separate epidemics of this vascular wilt in North America, Europe and Asia. It serves as a good example of the need for more precise taxonomic information at international borders (Fig. 1) . Current United States quarantine regulations prevent entry only of pests that are:

1) not present in the United States, or

2) present, but of limited distribution, and subject to an active eradication/control program.

The story of Dutch elm disease (DED) clearly illustrates the "loophole" in this policy.

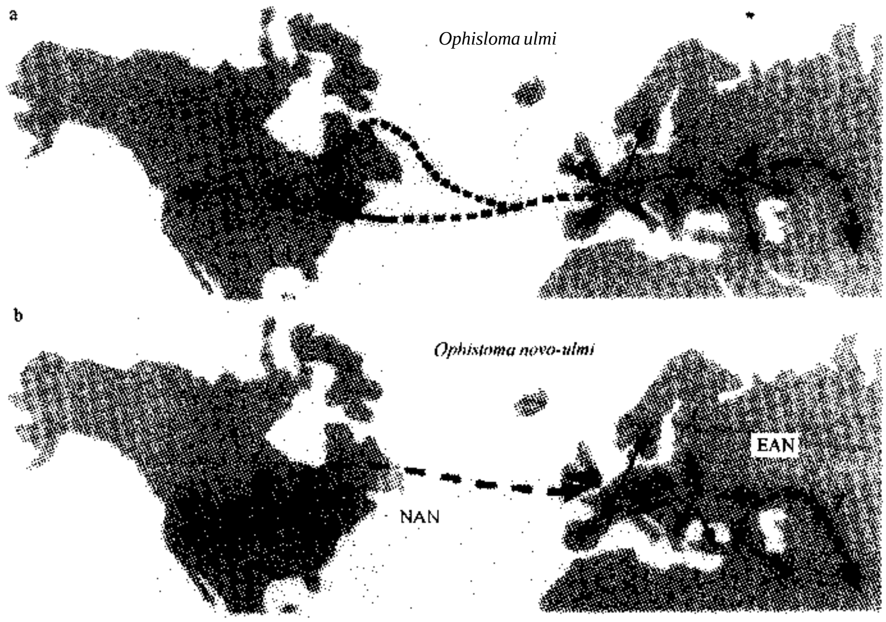

Fig. 1 International transport of the Dutch elm disease fungi (Adapted from Brasier, 1990)

Because DED was present in both the United States and Europe, elm logs containing what appeared to be the same fungus were imported and exported without concern for the possible increase in pathogenicity, which might result from increased biodiversity and possible genetic recombination. Today, scientists worldwide are concerned about the biodiversity issue, and taxonomists are working to help regulators determine how much individual genetic differences might limit the effectiveness of existing quarantine regulations, which generally function at the species level.

What happened with DED clearly shows how limited understanding of taxonomy, and the worldwide shortage of trained taxonomists, can cause a regulatory failure. Because of a lack of necessary taxonomic information, a second, much more aggressive species, *0 . novo-ulmi,* was introduced (no one knows where from) into North America. It was not until the new fungus was shipped on elm logs from North America to Europe, and began killing elms that had survived the original epidemic, that the new species was identified. In Britain alone, the new species is estimated to have killed 30 million elm trees.

3.4 Asian longhorned beetle

The recent introductions of Asian longhorned beetle (ALB), *Anoplophora glabripennis* (Motsch.), into the United States have caused quite a regulatory furor. The USDA Animal and Plant Health Inspection Service (APHIS) considers ALB has "the potential to cause more damage than Dutch elm disease, chestnut blight and gypsy moth combined" . The beetle is known to attack 29 species of American host trees. Estimates of potential damage to lumber, maple syrup, nurseries, commercial fruit orchards, and tourism accumulate to 41 billion USD.

The first beetles were discovered in New York in 1996. Removal of felled trees for firewood resulted in a second infestation just outside the city. In 1998, a third infestation was found in Chicago, which originated in pallets from China. All three outbreaks have resulted in intensive survey, quarantine, and chipping of all infested trees. By the end of 1998, 8 million USD had been spent trying to eradicate these outbreaks. As of November, 2001 , more than 5 000 infested trees have been destroyed in New York, and 1 500 trees in Chicago. Non-infested trees within the quarantine zone are being injected with imidacloprid. The quarantine areas were recently expanded, as new infestations were discovered near the original three. In addition, ALB has been intercepted in 26 warehouses in 14 different states, but none of these interceptions has yet resulted in the pest establishing trees.

Preventative measures have been taken to reduce the risk of additional introductions. In 1998, APHIS posted an "interim rule" requiring all solid wood packing materials (SWPM) from China to be heat treated, fumigated, or treated with preservatives prior to shipping. A risk assessment was recently conducted by APHIS, and in addition to *Arwplophora* , it focused on three other genera frequently intercepted on SWPM from China: *Ceresium*, *Monochamus* , and *Hesperophanes* . Based on their biological characteristics and likelihood of introduction, they concluded that each of these taxa represent a significant and immediate threat to the United States. APHIS is developing a proposed rule for regulatory options for the general problem of SWPM from all countries, and particularly how these requirements will be affected by the scheduled phase-out of methyl bromide fumigation.

Although ALB is native to China, and distributed in most parts of the country, it recently began behaving in some regions like an exotic pest. It has a wide range of hosts, reportedly over 100 species of broadleaf trees. Its primary preferred hosts are maples, poplar, willow, and box elder trees (Xiao, 1992; Luo *et al.* , 1999) . In the past, ALB was a secondary pest. However, its pest status has increased dramatically in recent years, due largely to massive reforestation programs initiated in early 1980s. One such example is the well-known Three-North Belt project, the largest reforestation project in the world. Various non-native species, particularly poplars (*Populus* spp.) from Europe and North America, were planted. These species have proved highly susceptible to attack by ALB, thereby providing an active breeding ground for beetle populations. Only incomplete statistics are available, but the State Forestry Administration (unpublished data) estimates that about one third of trees planted in the Three-North Belt Project have been killed by ALB so far.

ALB has also reached outbreak status in other parts of China in the last ten years. Large numbers of maple and poplars were killed. This beetle poses a serious threat to poplar plantations in China, and it is causing serious problems on ornamental trees, especially in northern cities where maple, poplar, and willow trees were widely planted as ornamentals. Since ALB is of great concern to both China and the United States, it seems prudent for us to work together to tackle this pest. Successful outcomes will demonstrate the importance of international cooperation in dealing with exotic pests.

Research in the United States on ALB has focused on chemical and acoustic detection, and modeling dispersal behavior to improve quarantine efficacy. Collaborations with Chinese scientists to date have focused on the areas of biological and chemical control, host selection and colonization, pest biology, and behavior.

3.5 Pinewood nematode

The pinewood nematode (PWN) is a good example of how an exotic pest can prove costly to the exporting country (the United States, in this case), as well as the importing country. Although the nematode (*Bursaphelenchus xylophilus*) is causing serious damage to the forests of China including Taiwan, Japan and Korea, the damage it has caused in the United States has been in lost exports. PWN generally does no damage to pines native to North America, because they are not susceptible. It is vectored by cerambycid beetles in the genus *Monochamus* , which are opportunistic, largely saprophytic insects. When the beetle oviposits on logs or on weakened, dead or dying trees, the nematodes exit the beetles' spiracles and colonize the weak tree. The nematode lives saprophytically in the tree and forms a special quiescent stage called dauer-larvae, for its journey in the beetle. They enter the spiracles on the thorax of callow adult beetles before they emerge. Adult beetles conduct maturation feeding for 14 - 20 days. As adults, they feed on young pine shoots, and the nematodes leave the spiracles and enter the feeding wounds. If the host is susceptible, PWN can invade such tissues and cause pine wilt disease. Because PWN cannot colonize fresh healthy growing tips of North American pine species, it cannot cause disease. This seems to be the critical difference between the situation in North America and elsewhere (Dwinell 1987)

The known susceptible hosts to PWN are Japanese red pine (*P. densiflora*) , Japanese black pine (*P. thunbergii*) , Mason pine (*P. massonia*) , and Scots pine (*P. sylvestris)* . Japan suspects PWN arrived there in the early 1900s. It displaced their native *Bursaphelenchus mucronatus* , which had co-evolved with their native *Monochamus* spp. *B . mucronatus* did no damage to their native pines. Losses to PWN in the early 90s were over 1 million m^3/yr. Since 1995, losses have slowly dropped, but still in 1999 exceeded 600 000 m^3 . Japan now requires quarantine and a phytosanitary certificate from the exporting country for all imported logs. Still, in 1999 alone, Japan intercepted more than 13 000 log shipments contaminated with dangerous beetles such as *Dendroctonus* , *Hylastes* , *Ips* , *Monochamus* , *Platypus* , *Scolytus* , and *Tomicus* . These interceptions show that the risk of pests, even in certified logs, is very real (Kaneko and Sharma, 2001)

Finland intercepted PWN in unprocessed wood chips from the United States and Canada in 1984. The European Union now requires heat treatment certification or a phytosanitary certificate. The added cost of these treatments proved too great a burden to an already depressed market; United States exports to the European Union dropped 70 million USD the first year. Despite these regulations, PWN was discovered in Portugal in 1999. It arrived in SWPM.

Many pines in China are susceptible to PWN. Infested trees can be killed in 40 days, and most die within 2 - 3 months. The nematode was first found in 1982 in Nanjiang, Jiangsu Province, and ever since, its range in China has spread steadily. As the population grows, its rate of spread has even increased. Between 1995 and 2000, the PWN infested area has doubled from 40 000 hm^2 to 80 000 hm^2. In five provinces, over 15 million pines have been killed. To make things even worse, PWN is closing in on some very well-known national parks such as Huangshan Mountains and Zhangjiajie National Parks, which is causing great concern nationwide. There are no effective control measures for PWN, except to cut and replant, which is currently practiced in PWN infested areas in China. An effective trap baited with volatile lures is being used to manage its vector, *Monochamus.* Some parasites are also being explored to control these beetles (Wang *et al.,* 2001; He, 2000). Millions have been spent to control the spread of this pest, but with only limited success so far. PWN remains the number one forest pest in China and poses a devastating threat to pine forests in southern China.

3.6 **Red turpentine beetle**

The red turpentine beetle (RTB) , *Dendroctonus valens* LeConte (Coleoptera: Scolytidae) , is a common pest in North America, yet, despite the abundance and wide distribution of this beetle, outbreaks have not been extensive or severe. It has been recorded from at least 40 species of domestic and foreign conifers. The beetle usually attacks trees of reduced vigor or those infested with other bark beetles, but it can attack apparently healthy trees. (Smith, 1971; Cibrian *et al.* , 1995). Only recently, it has been reported causing some tree mortalities in a thinned, subsoiled ponderosa pine plantation near Pondosa, California, and in Mexico (Rappaport *et al.* , in press) .

In China, however, since its first outbreak in 1999, this exotic pest has spread rapidly from Shanxi Province to three other adjacent provinces (Hebei, Henan, and Shaanxi) and infested over half a million ha of pine stands, and it is causing severe mortality. More than 6 million *Pinus tabulaeformis* Carr have been killed so far, as well as some other pines such as *P. bungeana* Bucc (Li *et al.,* 2001; Miao *et al.* , 2001) . The historical record has shown that the RTB was introduced into China in early 1980s when unprocessed logs were imported from the west coast of the United States. Several consecutive years of drought conditions have also severely stressed its primary host, *P. tabulaeformis* and contributed greatly to the sudden outbreak (Li *et al.*, 2001). With pines as a major reforestation species in China, and *P. tabulaeformis* widely planted across a large portion of the country, the potential range and damage by this exotic beetle is overwhelming (Li *et al.*, 2001).

The mechanism of beetle attack is different in China than in the United States. Smith (1961) reported that attacks by this beetle frequently occur on injured or stressed trees in the United States, where it is not considered a primary pine killer. In the United States, it is reported to initiate attack at the ground line and then colonize a short distance both up and down under the bark, i. e., to the upper roots and lower bole (Owen, 1985; Smith, 1971). However, in China RTB has been found colonizing roots extensively and it overwinters inside roots.

Overlapping generations make it hard to treat RTB effectively with chemicals, because there are larvae inside the roots year around (Miao *et al.*, 2001). Insecticide applications to the basal portion of tree boles have shown to be effective in reducing damage by *D. valens* in the United States (Koehler, 1990; Hall, 1984). Therefore, an alternative, and more environmental friendly method of control has to be studied. For exotic pests such as *D. valens*, the need for effective monitoring and detection techniques is even more urgent.

Semiochemical techniques naturally come into consideration because bark beetles are considered very good candidates for the development of semiochemical-based management strategies (Borden, 1997). *D. valens* is known to be attracted to diseased or wounded pines, and relies more on host odors or kairomones to locate and select its host. It is specifically attracted to the resin of its preferred host, ponderosa pine, *Pinus ponderosa Laivwon* (Vite and Cara, 1962; Owen, 1985; Hobson *et al.*, 1993). The well-documented response of RTB to host volatiles and specific components indicates that volatiles play a major role in the host selection process and could play a major role in RTB management (Hobson *et al.*, 1993; Rappaport *et al.*, 2002). However, little is known about these roles in RTB attacking *P. tabulaeformis*, or this host's response to stress, and consequently, the management potential of semiochemicals in China remain to be learned. Collaborative work on this beetle between the USDA Forest Service and China is currently underway and is making good progress.

RTB is a vector of *Leptographium terebrantis*, one of the most pathogenic blue stain fungi. On a new and unadapted host, as is the case in Shanxi, China, it may be particularly lethal. RTB's extensive colonization of roots of *P. tabulaeformis* may favor the action of *L. terebrantis*. Several other *Leptographium* spp. are significant root pathogens of pine as well (Owen, 1985).

4 DISCUSSION

What is the role of the scientist who recognizes the threat posed by exotic pests? It is difficult sometimes to walk the tightrope between advocacy and science. Because of our specialized training, entomologists, pathologists, ecologists, and weed scientists are among the few who recognize the magnitude of the threat that exotic pests pose to agriculture and to natural ecosystems. We might wish to awaken the concern of administrators charged with the protection of these systems. Yet scientists must remain objective to retain credibility.

4.1 Improve detection methods

We must provide good biological information that can be used to guide decision-making. Monitoring techniques need to be developed that can help improve detection at port facilities. Inspectors simply cannot keep up with the flow of trade using existing techniques. New advances in the field of molecular biology look promising, but need work to become practical for large-scale implementation. One such example under development is "real-time" multiplex detection microarray technology, which allows a single sample to be tested for 30 000 organisms/cm^2 grid, in just minutes.

Broad-spectrum insect traps for port facilities are needed because it is impossible to identify and build individual traps for all the possible threats. Development of lures attractive to broad groups of Coleoptera would be very beneficial. And of course, trained taxonomists will be needed to identify the insects captured in such traps.

4.2 Study biology of pests

Regulators cannot make reasonable judgements about pest risk without basic information about the biology of the pests of regulatory concern. We must also provide good data that can be used to weigh the value of specific mitigation measures against the costs. In our April, 2001 Online Workshop on Exotic Forest Pests and Their Impact on Trade in Wood and Wood Products, many data gaps were discovered and discussed. The text of the workshop papers is available at www. exoticpests. apsnet. org. A particularly important topic at present is mitigation measures for solid wood packing material (SWPM), which has proved to be a very significant pathway for forest pests. Presently the United States requires treatment of all SWPM that retain any bark. One of the most commonly used acceptable treatments is methyl bromide fumigation, but this ozone-depleting chemical is scheduled for phase-out in 2005 . Heat treatment regimes need to be studied more closely, as the killing temperature will be affected by percent moisture. The effectiveness of pressure treatments and chemical protectants also need further evaluation.

4.3 Quantify losses

It is essential to provide decision makers with loss estimates, so they can compare the costs and benefits of regulatory and control options. Today it is difficult to obtain funding to provide scientific information that demonstrates the importance of exotic pests. But as we accumulate data that document their ecological and economic impact, this task will become easier.

4.4 Collaborate internationally

Once exotic pests become established beyond the reach of eradication efforts, biological control may be desired as part of an integrated pest management strategy. It is encouraging to see the development of collaborative projects, such as the US-sponsored kudzu biocontrol project (Britton *et al.* , 2001) , and the China-sponsored Oracella mealybug project (Sun *et al.* , 1996). Asian longhorned beetle collaborations have moved even further, into the arena of jointly beneficial research .

4.5 Share information

The International Plant Protection Convention offers common ground for regulators worldwide to work together to develop global strategies that can help protect ecosystems across political boundaries. Global distribution maps are extremely valuable, and international sharing of biological information could greatly improve the quality of regulatory decisions. Immediate information on detection and eradication measures is particularly critical, and such information is often not available within the country where a pest is not yet established. The proliferation of online journals is greatly assisting this cause. However, we lack a central repository or organized structure for this information . Web search results invariably leave out many useful references, regardless of which search engine is used. The ephemeral nature of websites leaves questions about the future accessibility of some very good information. International databases, such as that provided by the non-profit CAB International should offer common ground for the scientific information that can be used as a basis for such decisions. The Pest CABweb site offers members taxonomic guides, as well as pest identification and diagnostic services for nematodes, fungi, and bacteria. Similar information should be available for insect pests. Firmer governmental support is also needed to reduce the price of such services to individual scientists. Political barriers to free trade are crumbling, but it is our business to ensure that trade is conducted in a manner that safeguards our global food and fiber supply, as well as natural ecosystems .

References

Allen E, 2001. Solid wood packing material as a pathway for non-indigenous species (www. exoticpests. apsnet. org) .

Borden J H, 1997. Disruption of semiochemical mediated aggregation in bark beetles . In: Carde R T, Minks A K, eds. Insect Pheromone Research, New Directions. New York: Chapman and Hall. 421 ~438.

Brasier C M, 1990. China and the origins of Dutch Elm Disease. *Plant Pathology* , 39: 5-16.

Britton K 0, Sun J, Orr D, Yang Z-Q, Ping C, Tian M-Y, Jiang Z, 2001 . Potential biocontrol agents for kudzu from China. Pp 24 ~ 27. In: Proc. USDA Interagency Research Forum on Gypsy Moth and Other Invasive Organisms. Annapolis, MD. Jan 16- 19, 2001.

Cibrian Tovar, D. J. Tulio Mendez Monliel, R. Campos Bolanos, H, O Yates HI, and J. Fiores, Lara. 1995. Forest insects of Mexico. Universidad Autonoma Chapingo. 453 .

Dwinell L D, 1987. Pine wood nematode in southern pine chips exported from Georgia. In: Pathogenicity of the Pine Wood Nematode. Mike Wingfield , ed. American Phytopathological Society Press. 50 - 58 .

Dwinell L D, Nickle W R, 1989. An overview of the pine wood nematode ban in North America. Gen Tech. Rep. SE - 55. Asheville NC. Us Dept. of Agriculture Forest Service 13 pp.

Hall M R W, 1984. Effectiveness of insecticides for protecting ponderosa pines from attack by red turpentine beetle (Coleoplera: Scolytidae) . /. *Entomal.* , 77: 446 - 448 .

He R Q, 2000. Pest status of pine wood nematode and its management. Forestry Science and Technology, 4: 5 - 7 .

Hobson K R, Wood D L, Coo] L G, White P R, Ostsuka T, Kubo I, Zavarin E, 1993. Chiral specificity in responses by the bark beetle *Dendroctonus valens* to host kairomones. *J. Chem. Eco.*, 19 (9): 1 837 ~ 1 846.

Kaneko S, Sharma J K, 2001. Risks of exotic forest pests and their impact on trade in Asia (http: //www. exoticpests. apsnet. org).

Koehler C S, 1990. Red turpentine beetle control on pines. 77: 446-448. California Cooperative Extension, San Rafael, CA.

Li J S, Chang G B, Song Y S, Wang Y W, Chang B S, 2001. Management of red turpentine beetle. *Forest Pest and Disease*, 20 (4): 41-44.

Liebhold A M, MacDonald W L, Bergdahl D, Mastro V C, 1995. Invasion by exotic forest pests: a threat to forest ecosystems. *Forest Science*, 41; *I*-49.

Luo Y Q, Song GW, Liu Y G, Li J G, 1999. Preliminary study on ecological threshold of poplar longhorned beetle. *Journal of Beijing Forestry University*, 21 (6): 45-51.

Miao Z W, Zhou W M, Huo F Y, Wang X L, Fan Z X, 2001. Biology of red turpentine beetle. *Shanxi Forestry Science and Technology*, (1): 34-37.

Owen D R, 1985. The role of *Dendroctonus valens* and its vectored fungi in the mortality of ponderosa pine. Ph. D. Dissertation, Unversity of California, Berkeley. 64.

Pimental D, Lach L, Zuniga R, Morrison D, 1999. Enviromental and economic costs associated with non-indigenous species in the United States, www. news. Cornell. edu/releases/Jan99/species_costs. html.

Rappaprot G N, Owen D R, Stein J D, Disruption of semiochemical-mediated attraction of *Dendroctonus valens* (Coleoptera: Scolytidae) and selected nontarget insect by microencapsulated verbenone and verbenone bubblecaps. *Environ. Entomol.*, in press. Smith R. H. 1971. Red Turpentine Beetle. Forest Pest Leaflet 55, USDA Forest Service. 9.

Sun J, DeBarr G L, Liu T-X, Berisford W C, Clarke S R, 1996. An unwelcome guest in China: a pine-feeding mealybug. *Journal of Forestry*, 94: 27 ~ 32.

Wang M X, Cheng L C, Song Y S, 2001. Pest risk analysis of pine wood nematode (*Bwsaphelenchus xylophilus)* on Hunan forestry and ecological environment. *Forest Pest and Disease*, 20 (2): 42 ~ 45.

Xiao G Y, 1992. Forest Insects of China. Beijing: Forestry Publishing House. 1 362.

Vite J P, Cara R I, 1962. Volatile attractants from ponderosa pine attacked by bark beetles (Coleoptera: Scolytidae). *Contrib. Boyce Thomopson Inst.*, 21 (5): 251-274.

不速之客：林业外来有害生物

Kerry 0. BRITTON[1], 孙江华[2]

(1. 美国林务局南方试验站，雅典，佐治亚州，美国 30602-2044; 2. 中国科学院动物研究所，北*M* 100080)

摘要：结合与中美两国林业有关的重要外来入侵性病虫害实例，包括板栗疫病、荷兰榆树病、松材线虫、光肩星天牛，*il* 脂大小蠹和舞毒蛾等，对外来有害生物的危害严重程度、发生途径和控制对策进行了讨论，提出了入侵种监测，*Wit*, 科学研究、国际合作和信息共享等方面的具体建议。

关键词：外来有害生物；林业；Aft; 舞毒蛾；松材线虫；光肩星天牛；红脂大小蠹

中图分类号：S763 **文献标iR«5: A** **文章编号**：0454-6296 (2002) 01-0121-10