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North American pinewood nematode disease in China

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Abstract

Keywords: *Bursaphelenchus xylophilus,* invasive species, pinewood nematode, *Pinus*, vascular wilt

The pinewood nematode (*Bursaphelenchus xylophilus*) is an important alien invasive species in China. This pinewood nematode poses a serious threat to Chinese forests. It does have an important impact on forestry, including economic, environmental, ecological and social. Here, I summarize the current situation of the occurrence and development of North American pinewood nematode disease, and combine Chinese practices in pinewood nematode control to propose considerations from five aspects: 1) laws, 2) national department, 3) scientific research, 4) technology promotion and application, and 5) Science popularization and public education, but also in terms of scientific and technological support, technology promotion and application, scientific popularization, and public education to consider the management strategy of pinewood nematode disease in China.

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1. Introduction

The harm caused of forestry pests to forests is called “no smoke forest fires”. The pinewood nematode (*Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle) is native to North America and is now an important alien invasive species in China. When the pinewood nematode was introduced from abroad, it posed a serious threat to China's forest resources and ecological environment. The pine wood nematode causes a pine devastating epidemic disease, with the Japanese pine sawyer (*Monochamus alternatus* Hope) as the main vector. Since the pinewood nematode was introduced from abroad, there are no natural enemies in the ecosystem, and there is no effective way to prevent and cure pinewood nematode disease. The spread is extremely fast, and the damage is extensive. The overall function of the original forest ecosystem is seriously damaged in some areas, bringing irreversible ecological disaster. Here, I summarize the development status of pinewood nematode disease in China and propose corresponding management countermeasures. I analyzed the problems existing in the control of pine wood nematode disease in China and propose prevention and control measures for pine wood nematode disease. Finally, I compared the situation of pine wilt disease in Canada with the situation in China to find a more effective way to control Chinese pine wilt.

2. Occurrence status and development trend of North American pinewood nematode disease in China

In mainland China, pine wood nematode disease was first discovered in the black pines(*Pinus thunbergii* Parl.) of Nanjing Sun Yat-sen Mausoleum in 1982. It occurred only in 1 city, with an affected area of 200 m^2 and only 256 dead trees. In just over 30 years, the extent of the epidemic had greatly expanded. Within 30 years, the epidemic area had expanded to 246 counties and cities in 16 provinces, autonomous regions, and municipalities. The current area of occurrence is about 38,000 hectares, resulting in the death of more than 1.4 million pine trees and 50,000 m^3 of lost wood. The accumulated direct economic loss was 2.5 billion yuan ($0.5 billion), resulting in a loss of forest ecological benefits of 25 billion yuan ($5 billion) (Chen, 2010).

Pinewood nematode disease is a pine devastating epidemic disease of pine that is caused by the pinewood nematode, with the Japanese pine sawyer (*M. alternatus*) as the main vector. Since the pinewood nematode was introduced from abroad, there are no natural enemies in the ecosystem, and there is no effective way to prevent and cure. In addition, affected trees have no resistance to the nematode. The spread is extremely rapid and the damage is extensive. The overall function of the original forest ecosystem is seriously damaged in some areas, bringing irreversible ecological disaster.

2.1 Main characteristics of pinewood nematode

(1) The infection rate is quick. Generally, death of black and masson pines

(*Pinus massoniana* Lamb.) occur after a month or two of infection.

(2) It spreads quickly. The distance traveled by vector insects is limited, but long-distance jumps occur because of human factors.

(3) There are many types of symptoms of disease onset. Most of the pines die in the fall, but otherwise only the branches die.

(4) Early diagnosis is difficult. In the early stage of plant disease, the appearance symptoms are often extremely insignificant.

(5) The distribution of newly developed epidemic areas is relatively concentrated. Generally, it is near traffic lines, construction sites, and places where human activities are more frequent.

(6) In the early stages, the epidemic gradually spreads to the surrounding area, and at the same time, the spread of the long-distance, and skip-type dispersal occurred in the vicinity of the epidemic area (Han *et al*, 2007).

2.2 Three stages for the management of pinewood nematode disease in China

According to Han *et al.* (2007), the first pinewood nematode disease management stage occurred from 1982-1990. Prevention was still being explored due to lack of understanding. In the prevention and control, manual cleaning and burning were mainly carried out. However, due to the lack of effective measures in the control and management of infected wood, the epidemic spread rapidly. In 1990, pinewood nematodes occurred in Anhui, Guangdong, Zhejiang, Shandong, and other provinces.

The second stage occurred from 1990-1999. When the national forestry department put forward the overall requirements for greater governance, some epidemics were eradicated, but the number of new epidemics in some provinces increased significantly.

The third management phase occurred from 2000 onwards. According to the requirements of the project management of pinewood nematode disease, the national forestry department proposed a “classification policy” to strengthen the management of infected wood. In the oldest epidemic areas, the number of dead trees are declining, but new epidemics in new provinces have increased significantly. The hazardous areas were basically controlled, and most of the natural forest landscapes in key scenic areas were protected. The control of pinewood nematode disease has achieved significant results.

According to Liang *et al.* (2006), there are two stages to the application of actual control measures: The first stage is the stage of treatment, with the goal of completely eliminating pathogens. The second stage is comprehensive treatment and prevention.

At present, through the control of pine wood nematode disease, the damage is reduced to some extent, and the spread is also controlled. However, the potential danger remains.

2.3 The impact of pinewood nematode on society, economy and environment in China

The pinewood nematode not only has caused huge losses to the Chinese economy, but it also destroys the natural landscape and ecological environment. It poses a serious threat to China's rich pine forest resources. Chinese ports have intercepted such nematodes from timber and wood products imported from Japan and other countries. Pinewood nematodes are mainly distributed in Canada, Mexico, Greece, Portugal, France, North Korea, South Korea and China. The main and potentially harmed host plant species are *P. massoniana* Lamb., *P. thunbergii* Parl., *P. densiflora* Sieb. et. Zucc., *P. yunnanensis* Franch., *P. tabulaeformis* Carr., and *P. medlar.* Plants such as *P. sylvestris var. mongolica*, *P. bungeana* Lindley and Gordon, *Cedrus deodara* Roxb. ex D. Don G. Don, *Abies fabri* (Mast.) Craib, *Larix europaea* Mill., *L. kaempferi.* Lamb.. In addition, artificial inoculation can infect plants such as *P. armandiideng* Franch. (Huang 2017).

Pine wood nematode has an impact on Chinese society and the environment in four aspects:

The first is to cause an ecological disaster. Pine trees are greening trees and are the main trees in forest ecological barriers such as barren hills afforestation and shelter forests and coastal shelter forests in the Yangtze, Pearl River and Huaihe River basins. The soil conditions in these areas are relatively poor. After the pine trees are infected, it is difficult to replant with other tree species. It is difficult to recover after environmental damage, and thus a series of ecological disasters such as soil erosion, flash floods, mudslides and floods can occur. If pine wood nematode disease continues to spread, China's large-scale pine forest will become destroyed, and the achievements of afforestation and greening will be destroyed (Dong *et al.* 2005).

Secondly, it has caused great damage to scenic spots and historical sites, especially scenic spots with natural ecological landscapes. Pine trees are an important part of these natural landscapes. For example, in 1990, UNESCO listed 25 strains of Huangshan Pine (*Pinus taiwanensis* Hayata), including Huangshan and Yingkesong, on the World Natural and Cultural Heritage Protection List. Because Huangshan pine is a susceptible host to the pinewood nematode, once pine wood nematode disease is introduced into an area containing *P. taiwanensis*, Yingke Pine may be destroyed. It will definitely cause a devastating blow to Huangshan's tourism resources, and its losses are incalculable. In addition, there are many religious temples in China, such as Putuo Mountain, one of the four Holy Land of Buddhism. There are ancient pine trees around religious temples. If the pine forests around the temples are destroyed, the natural landscape will suffer on unrecoverable catastrophe (Ning *et al.* 2005).

The third is the impact on international trade. Pine wood nematodes are listed as important phytosanitary objects in many countries in the world, and strict quarantine measures are taken to prevent their introduction. With the further development of the Chinese economy, foreign trade has become more frequent, with the packaging of the goods utilizing pine. At present, due to the pine wood nematode, the EU has imposed strict quarantine requirements on Chinese exports. If pine wood nematode disease spreads widely in China, countries around the world will impose more stringent requirements on Chinese pine packaging exports, which will seriously affect China's export trade (Ning *et al.* 2004).

The fourth is the loss of ecological benefits. The most important role of forests is to regulate the climate and maintain soil and water. Each hectare of forest land can store 300 m^3 of water, 96,700 m^2 of pine forest can store 2,900 m^3 of water. The transpiration of forest land can regulate the climate and increase rainfall. Forests can reduce soil erosion and generally reduce the annual runoff by 30% to 60%. The amount of sediment loss in forest-damaged areas is 6-8 times higher than that in areas with good forest vegetation. Forests can purify the air and eliminate noise. Due to industrial development, the atmospheric CO_2 content has increased by 14%, while 60% of the atmospheric oxygen comes from terrestrial plants, of which 2/3 come from forests. Pine forests can absorb 20 mg of SO_2 from 1 m^3 of air per day. Indirect losses caused by pine wood nematode disease cannot be measured (Yang *et al.* 2003).

3. Pinewood nematode in North America

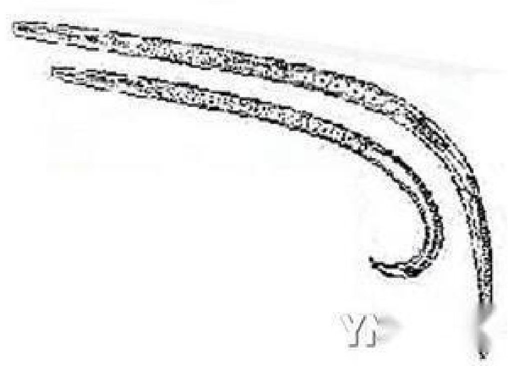
Pinewood nematode has been found in at least 36 states in the United States. There are also reports of pine wood nematode in the southern provinces of Canada, but no reports from Mexico or the southern coast of the United States. Most reports of pine wilt disease in North America come from trees that grow as ornamental plants, especially *Pinus sylvestris* L., but trees in natural forests, plantations, Christmas tree plantations, windbreaks and coniferous seed orchards are also included. Pine wood nematode is native to North America, but the nematode does not cause large-scale conifer deaths in forests anywhere on the continent. It could be that North American conifer species co-evolved with the pinewood nematode and tolerate infections. This situation is contrary to the epidemic in Chinese pine forests.

Monochamus alternates is a very effective carrier in China, but is not known to have occurred in forests in North America. It it has been intercepted several times at US ports of entry, and *M. alternatus* is an effective carrier that does not occur in the United States, it is imperative to prevent accidental introduction of this beetles to forests in North America (Bergdahl 1988), in case it causes more affective vectoring of the pinewood nematode.

4. Biological characteristics

4.1.1 Biological characteristics of pinewood nematode

Pinewood nematode (Figure 1) is parasitic on dead wood or weak wood caused by other factors. The pinewood nematode has a typical nematode life cycle, with four juvenile stages and an adult stage with both male and female individuals that reproduce sexually. The distribution of pinewood nematodes in different species of hosts and different occurrence areas is regular and different. The vertical distribution on the diseased tree is mainly in the trunk, branches, roots, and pine needles, but have not been found in cones. For horizontal distribution, the number of nematodes in the general heartwood is more than in the sapwood at the chest height of the trunk (Pan 2011). The larvae of the pinewood nematode have an instinctive response to carbon dioxide. When the beetle's adult worms produce a large amount of carbon dioxide, the pinewood nematode is attracted to the trachea for lodging. A beetle can carry tens of thousands of pine wood nematodes up to nearly 300,000. When the *M. alternatus* feeds on the bark, the pine wood nematode larva invades into the pine tree from the wound of the trunk (Kanzaki *et al.*2016).



Source: Amy & Mark 2008

Figure 1. North American Pinewood Nematode

4.1.2 Biological characteristics of M. alternatus (Fig. 2)

At the end of the winter, pupation occurs, and adults emerge in spring and feed on foliage of hosts. This feeding is important because it provides a place for nematodes to invade living healthy trees. The natural diffusion ability of *M. alternatus* is not strong, and its lifetime diffusion distance does not exceed 200 m. The temperature has a significant effect on the activity of the beetle. When the temperature drops below 18 °C, the adult is latent (Han *et al.* 2007).

Source: Thomas Schoch

Figure 2. *M. alternatus*

5. Host of Pinewood Nematode

Pine wood nematodes can parasitize 70 species of conifers, including 57 species of *Pinus* and 13 species of non-pine (Table 1).

Table 1. Pine wood nematode host tree species in China

Scientific name	Scientific name
Pinus cembra Linn.	*P. thunbergii or P. massoniana*
P. engelmannii Carr.	*P. echinata* Mill.
P. caribeaa Morelet	*P. densiflora var. umberaclifora*
P. bungeana Zucc ex Endl	*P. laricio(P. nigra)* Arnold
P. virginiana Mill.	*P. strobus* Linn.
P. ponderosa Dougl． et Laws	*P. yunnanensis* Franch.
P. pinaster Ait.	*P. jeffreyi*
P. radiata Mill.	*P. lambertiana*
P. mugo Turra	*P. strobiformis*
P. kesiya Ｒoyle ex Gordn．	*P. fenzeliana*
P. muricata D. Don	*P. griffithii* Engelm.
P. rudis Endl	*P. tabulaeformis* Carr.
P. oocarpa Schiede	*P. hinekomatus*
P. parviflora Sieb. ＆ Zucc．	*P. glabra*
P. sylvestris Linn.	*P. pungens*
P. clausa Sarg.	*P. armandii* Franch.
P. elliottii Engelm.	*P. serotina*
P. michoacana Martinez	*P. morrisonicola*
P. montana Mill.	*P. koraiensis*

P. taeda Linn.	*P. monticola*
P. resinosa Ait.	*P. sylvestris var. mongolica* Martinez
P. halepensis Mill.	*P. flexilis*
P. greggii Engelm.	*Pseudotsuga mexzeizii* Franco
P. massoniana Lamb.	*Cedrus deodora* (Roxb. ex D. Don) G. Don
P. pseudostrobus Lindl.	*C. atlantica* Manetti
P. thunbergii Parl.	*Picea glauca* Karst.
P. leiophylla	*P. canadensis* (Mill.)
P. densiflora Sieb. et. Zucc.	*P. abies* Karst.
P. luchuensis Mayr	*P. pungens* Engelm
P. kwangtungensis Chun ex Tsiang	*Abies sachalinensis*
P. taiwanensis Hayata	*A. balsamea* Mill.
P. banksiana Lamb.	*A. homolepis*
P. palusris Mill.	*Larix europaea* Mill.
P. rigida Mill.	*L. leptolepis*
P. contorta Loud.	*L. laricina* (Du Roi) K. Koch

Source: (Wang *et al.* 2018)

6. Geographical distribution of pinewood nematodes

Pine wood nematode is endemic to the North American continent, and the disease (Fig. 3) is currently distributed in North America(including the United States, Canada, and Mexico), Northeast Asia(Japan, North Korea, South Korea and China) and parts of Europe (Portugal and France) (Figueiredo *et al.* 2013) (Table 2). Huge populations of the nematode develop throughout the tree which impedes water transport and causes the wilt symptoms. Highly susceptible pines usually die within three months of infection. Adult females lay eggs in trees weakened or killed by the pinewood nematode and the disease cycle is repeated (Fite n. d.).

Table 2. Geographical distribution of pinewood nematode

Country	distribution range	First report
Canada		
America	All states east of the Mississippi River are distributed, with at least 36 states, and all states with pine trees in the continental United States are considered to have a distribution of pine wood nematodes (with the exception of Hawaii).	1979
China	In some areas, the southern part is more serious	1983
Japan	45 of the 47 capitals, provinces, prefectures and counties in Japan, only Aomori and Hokkaido in the north	early 1900s
Mexico	16 provinces	1982
Portugal	La Botella	
France	some areas	
North Korea	some areas	1990s
South Korea	some areas	1990s

Source: European and Mediterranean Plant Protection Organization (EPPO) plant quarantine information retrieval system

Soucre: Amy & Mark 2008

Figure 3. North American Pinewood Nematode Disease

7. Route of transmission of pinewood nematode disease

According to Ning *et al.* (2004), due to the poor mobility of nematodes and the limited ability of *M. alternatus* to fly, the pinewood nematode primarily spreads through human transmission through two ways: (1) in import and export trade and material exchange, the diseased wood is used for packaging of goods, causing long-distance transmission of pine wood nematodes across the sea; (2) Close transportation along traffic routes.

Additionally (Ning *et al.* 2004) mentions, there are three natural transmission routes: (1) the main mode is by vector insects; (2) the movement of the nematodes themselves; and (3) the contact between the diseased plants and the roots of healthy plants in the pine forest, but this method is rare.

Vector insects are important in the natural route of nematode transmission. More than 28 species of insects can carry pine wood nematodes (Estay *et al.* 2014) (Table 3).

Table 3. Pine wood nematode carrier insect species

Name	Range
M. carolinensis(Olivier)*	America, Canada
M . titillator(Fabricius)*	America, Canada
M.scutellatus(Say)*	America, Canada
M .obtusus Csy.	America, Canada
M.alternatus Hope*	Japan, China, South Korea
M.saltuarius Gebler*	Japan, China, Nouth Korea
M.nitens Bates	Japan
M.marmorator (Kirby)	America, Canada
M.mutator LeConte*	America, Canada
M.notatus (Drurry)	Mexico
M.rubigineus Bates	Mexico
M.sutor (L.)	Scandinavia,Finland,China
M.grandis Waterhouse	Japan
Acanthocinus griseus(Fabricius)	Japan, China
A.clavipes Schrank	Japan

A .taiwanensis	China
Arthopalus rusticus L .	America, Japan, China, North Korea
A .rusticus obsoletus (R.)	America
Neacanthocinus obsoletus (Olivier)	America
N .pusillus (Kirby)	America
Asemum striatum (L .)	America, Japan, China, North Korea
Spodylis buprestoides L.	Japan, China, North Korea
Acalolepta fraudatric fraudatrix Bates	Japan
Uraecha bimaculata Thomson	Japan, China
Phymatodes macki Kraatz	Japan
Corymbia succedanea (Lewis)	Japan, North Korea
Astylopsis sexguttata(Say)	America
Xylotrechus sagittatus (Germ)	America
Hylobius pales Herbst	America
Hylobitelus abirtis haroldi Faust	Japan
Chrysobothris spp.	America
Pissodes approximates Hopkins	Japan
Shirahoshizo sp.	America, China
Paracalais berus	Japan
Tenebroides mauritanicus (L.)	Japan
Blastophagus piniperda L.	China
Odontotermes formosanus Shiraki	China

* = Major Vector

Source: European and Mediterranean Plant Protection Organization (EPPO) plant quarantine information retrieval system

8. Problems and suggestions

8.1 Laws

The diffusion ability of *M. alternatus* is limited. In healthy forests, the spread of *M. alternatus* adults is within 60 m. After the debilitated trees appear in the forest, the spread of adult *M. alternatus* is significantly reduced, so the pine wood nematode is spread mainly by human activities.

The spread of pine wood nematode disease is largely caused by the human transport of infected wood and its products, and pine wood nematode disease tends to occur locally in the world. Therefore, strengthening the quarantine management of human activities in accordance with the law is an important part of the comprehensive management of pine wood nematode disease.

Biological invasion is a common problem throughout the world. According to Cai (2017), Nordic countries such as Finland ban the import of US and Canadian pine chips and logs. The European Plant Protection Organization (EPPO) recommends that EU countries ban the import of pine products from the pine wood nematode countries except for kiln dried wood. Currently, more than 40 countries in the world have listed pine wood nematodes as quarantine objects. The United States has established a National Invasive Species Commission, which is chaired by the President. Similar institutions have been established in Canada, Australia, New Zealand, Japan, India, Thailand, Malaysia, and South Africa. In these countries, national plans are formulated to strengthen the prevention and management of alien invasive organisms through the legal system.

The main reason for the successful invasion and rapid spread of alien species in China is that legislation on the invasion of alien species is relatively backward and poorly managed. In order to solve and control the damage caused by invasive alien species to the ecological environment and economy, it is urgent to establish a special law to control the invasion of alien species. There is no specific national law on the prevention and control of alien invasions. Due to the lack of special laws, the provisions in the regulations are not clear enough. To establish a legal control system for invasive alien species, a comprehensive assessment of the relevant legal systems in China is required. Research on the existing problems of relevant laws and regulations, improve the existing legislation to protect biodiversity, and increase the content base to prevent invasion of alien organisms. It is necessary to provide a legal basis for effective prevention and control of alien species invasion (Zhang *et al.* 2017).

There are also many problems involved in the management of exotic pests such as the pine wood nematode. For example, quarantine of pine wood nematodes, the identification of infected areas, prevention and control funds after the occurrence, the logging indicators of diseased wood, treatment and circulation of infected wood (including products) and restoration of vegetation after disasters are just some of the problems encountered. For alien species such as the pine wood nematode, which have a huge impact and potential for spread, it is necessary to legally clarify that the state and local governments are responsible for prevention and control, and the entire prevention and treatment process must have a special agency to implement and supervise (Huang 2017).

8.2 National department

The increase in international trade has created conditions for the exchange of living things around the world; pests have been intentionally or unintentionally brought to various places, and their threat has become a global problem.

Pine wood nematode is endemic and widely distributed in North America, and generally does not cause harm to pine tree species there. However, it has caused great harm after invading China. At present, China lacks comprehensive and systematic investigations and statistics on the types of pest invasion, the area of damage, the economic losses caused, and the extent of damage to the ecological environment. The epidemic monitoring work lags behind, and the damage of pine wood nematodes is discovered only when a large area has been affected. It is extremely difficult to block and extinguish the epidemic. There is no special funding for preventing the invasion of alien pests, and the forest phytosanitary funds are obviously insufficient, and has affected the development of early warning, control and research work on exotic pests (Dong *et al.* 2005).

China's management system for invasive pests such as the pine wood nematode is very flawed. The management responsibilities for the prevention and control of the pine wood nematode are scattered in different departments, and some management responsibilities are not implemented in specific departments. The lack of a unified coordination mechanism in various departments has resulted in unclear responsibilities and ineffective measures, which is not conducive to the continued control of pine wood nematode disease. Although China has established the National Collaborative Group on Biological Control, and established the Alien Species Management Office in 2004 to specifically address the problem of invasive alien species, the sector involved in the control of pine wood nematode involves far more than this (Ning *et al.* 2005).

In general, it is recommended to implement quarantine system reform as soon as possible, integrate China's existing quarantine resources, establish and improve the risk warning mechanism for inbound plants and their products, and establish the National Invasive Biology Committee to organize and lead the nation's invasive species management. At the same time, establish an information network for the establishment of invasive species in different fields and be responsible for international exchange. The invasive alien species are extremely harmful and the local finances are inadequate. The state should invest special funds to prevent and control invasive species(Pan 2011).

8.3 Scientific research

Chinese technological development cannot meet the major needs for the prevention, control and ecological restoration due to pinewood nematode disease. The reasons for the successful invasion of the pinewood nematode and how to solve it are not clear, and there is no basic research being done. Due to the lack of research on the biological and ecological mechanisms of pinewood nematode, there is no objective assessment of the risk of invasion of pine wood nematode. Because of a lack of detection and monitoring techniques for pine wood nematodes, lack of effective and safe techniques for the control of invasive pinewood nematodes and the restoration of damaged ecosystems, it is difficult to carry out quarantine inspection of pine wood nematodes due to the backwardness of the technology being used by the relevant departments (Huang 2017).

Insufficient research funding and low levels of repetition has contributed to the problem of little available technology to solve pine wood nematode problems. China discovered pine wood nematodes in 1982 and they were not listed as an important subject until 1994. For example, the Ministry of Science and Technology had made insufficient investments in the addressing of pine wood nematode (such as in 1985 was invested 300,000 yuan, in 1995 was invested 500,000 yuan), but there is no pine wood nematode research project, but only as a small part of exotic pests research (Liang *et al.* 2006).

Although there are many invasive alien species in China, only a small number of them are very harmful. Therefore, the state should focus on the species that are most harmful, especially those associated with plant diseases, and not all species. Simple research will result in a reduction in reality; at the same time, due to the limitations of funding, the research is carried out on a small scale, and no demonstrations are carried out. Therefore, it is difficult to directly apply the research results to forestry production, resulting in insufficient scientific research support. Correspondingly, the state is spending a lot of money on the engineering management of pine wood nematode disease, and there is no funding for scientific problems that need to be solved in the process of engineering governance. Ultimately, the state should concentrate its efforts on the practice of invasive species prevention and control (Liang *et al.* 2006).

8.4 Technology promotion and application

Current goals are to establish a series of technical regulations for early warning and prevention of pine wood nematode disease. Such early warning technical regulations including investigating technical regulations, disease management methods for diseased areas, and technical regulations for diseased wood treatment in infected areas. The technical regulations formulated are scientific, highly operational, practical, and simple. Pine wood nematode is universal like other pests and has its own particularity (Pan 2011). Applying the general forest pest control target to the control of pine wood nematode disease will inevitably bring many limitations.

8.5 Science popularization and public education

Wang *et al.* (2018) outlines the necessity of strengthening publicity and raising public awareness to prevent biological invasion. Relevant departments should explain the morphological characteristics, biological characteristics, degree of danger, and methods of removal of pine wood nematodes to the public in the form of wall charts. Pine wood nematode disease spreads quickly and is harmful. Newspapers and television can be used to publicize, increase investment, create favorable conditions for prevention and control work, strengthen technical training for technical workers and management personnel engaged in pine wood nematode disease, and improve the quality of professionals. The promotion and scientific popularization of the prevention of pine wood nematode disease will help raise awareness among the people to actively cooperate with the forestry department to prevent pine wood nematode disease.

9. Conclusions

In summary, this thesis mainly discusses the problems existing in the control of North America pine wood nematode disease in China and the current situation of pine wood nematode disease in North America.

9.1 Problems in the control of pine wood nematode

9.1.1 The control of pine wood nematode is difficult

Science-based phytosanitary measures are very important in the prevention and control of plant diseases. As a serious pest, it’s very difficult to work on pine wood nematode during the testing process. First, because China's quarantine work started late, the law was not complete, and some plant diseases continued to spread. In addition, in the transportation and quarantine of timber and wood products of major projects, there is no strict inspection of wood. The detection of small parasites requires sophisticated instruments. However, due to the lack of funds, the equipment cannot reach every forest area in time, which greatly increases the difficulty in detecting and controlling pine wood nematode. Pine wood nematode spreads extremely fast, not only because it has a very strong reproductive capacity and breeding speed, but also inseparable from its vectors. Once an epidemic occurs, it is difficult to control within a short period of time.

9.1.2 The control technology of pine wood nematode disease is backward

In 1982, pine wood nematode disease was first discovered in China. After decades of research, the technology for controlling pine wood nematode disease has also made great progress. However, no scientific method has been found to treat nematodes. Due to the limitations in the process of pine wood nematode prevention and control, only some relatively low-level technical means can be adopted. The main reason is that grassroots forestry technicians do not have timely and effective professional mastery of new technologies, and new methods. The application ability is also very poor. In addition, the enthusiasm for engaging in forestry has not been effectively improved, and the learning ability of grassroots technicians has been affected by many factors, resulting in backward control technologies.

9.1.3 Lack of funds in the control of pine wood nematode

In the process of prevention and control of pine wood nematode disease, the development of new technologies is generally carried out by scientific research units, and a large amount of financial support is needed in the process of prevention and control. However, it is difficult to control pine wood nematode disease in areas where certain funds are lacking. The establishment of a strict pine wood nematode control system requires huge capital investment and the application of scientific research results. However, due to the lack of funds, there will occasionally be a phenomenon of theoretical research and actual disconnection.In the actual control of pine wood nematode disease, regular cleaning of disease trees and spraying of chemicals to control pine wood nematodes will require a large amount of labor and funds. Once a funding gap occurs, it will lead to repeated epidemics. Therefore, the funds of the people who have invested before are not used reasonably.

9.2 Current situation of pine wood nematode disease in North America

The vector insects of the pine wood nematode are widely distributed in North America. However, pine wood nematode disease is less harmful, the main reason is that the host is resistant, the ability of vector insects to carry pine wood nematodes is not strong, and these insects themselves have more natural enemies. Although pine wood nematode disease has become a regular forest pest, it has not caused serious damage to North American forests.

9.3 Scientific prevention and control of pine wood nematode

9.3.1 Establish a sound outbreak detection system

In order to solve the harm caused by pine wood nematode disease in time, it is the key to accurately grasp the epidemic situation by establishing an epidemic monitoring system, and achieve the effect of early detection, early prevention and early elimination.

Specific monitoring measures can be carried out in the following ways:

First, take effective and targeted measures. A test station is set up at the entrance and exits of a forest to detect vehicles transporting timber to and from the forest. It is forbidden to bring wood with pests and diseases into the forest.

Secondly, regular inspection of trees in the forest, strengthening the procedural force of quarantine, timely destruction of trees that have been affected by pests and diseases, and prohibiting the use of infected pine trees for commercial activities.

Finally, as soon as possible, some reasonable laws and regulations should be formulated to ensure that the control measures for pine wood nematode disease can be carried out smoothly, thereby improving the effectiveness of prevention and control.

9.3.2 Control of infectious sources

Pine wood nematode disease is caused by the pine wood nematode that exists in the vector from the wound to the pine tree. Cutting down the diseased pine trees in the presence of *M. alternatus* before the vector adult can attack them, and moving these diseased trees out of the forest will have a good effect, although this has resulted in the loss of a lot of pine trees. Once the disease occurs, it will cause a large number of pine trees to die in the surrounding area.

9.3.3 Preventing the spread

The vector of pine wood nematode is mainly *M. alternatus*, so strengthening the control of *M. alternatus* can greatly enhance the control effect of pine wood nematode. The activity time of *M. alternatus* is generally from the end of April to the middle of October each year. Installing traps in the pine forest can reduce the number of pine sawyers in the forest, thus effectively reducing the number of pine wood nematodes in *M. alternatus*.

9.3.4 Improve the resistance of the forest

Adjust the structure of forests to enhance the disease resistance of pine trees. For example, artificial afforestation and replanting are good choices. Or build a mixed forest of broad needles or broadleaf forests.

9.3.5 Biological control of pine wood nematode

In the biological control of pine wood nematode disease, research in China has progressed. Rotenone can effectively prevent pine wood nematode disease. Amygdalin can inhibit the reproduction of pine wood nematodes and even kill pine wood nematodes. Finally, electricity can slow the breathing rate of pine trees, so electricity can affect the activity of pine wood nematodes (Cai 2017).

When controlling forest pests, it is necessary to adapt to local conditions, and different species in different regions require different treatment methods. In order to protect and improve the ecological environment, we aim to achieve sustainable control and follow the principle of prevention. Based on the ecological environment, supplemented by chemical control, coordinated use of artificial and physical measures for comprehensive prevention and control. In this way, forest pests and diseases can be better managed, forestry development can be promoted, and pine wood nematode disease prevention and control work can be done well.

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