

Forest Bio-disaster Status and its Basic Research in China

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This review outlines the characteristics and developmental trends of forest bio-disasters (including disease, insect and rodent pests) of recent years in China, summarizes the achievements of the basic researches supported by the National Natural Science Foundation of China, defines the main drawbacks, and proposes some important issues to be highlighted in the basic research in the future in order to integrate research resources, concentrate research objectives and to accelerate the development of forest bio-disaster basic research in China.

Key words forest, disease, insect pest, integrated management, basic research, research progress

China has a wide territory with various forest vegetations and so many kinds of harmful organisms. The forest ecosystem is like a whole concordant super-organism in the long period of confliction between plants and pests. Recently, as the change of global climates, the increase of demands on forest products brought by the development of population and economy, especially the improper management, the forest biological structures have been influenced evidently. On the one hand, destruction and degradation of the natural forests were very serious, and many patch forest areas with low quality and low levels were produced, so that the functions of forest biodiversity would be heavily damaged. On the other hand, despite of the great achievements of artificial forestations, usually the man-made forests were monoculture with relatively simple tree species and structure, i.e. narrow genes, so the forest ecosystem was terribly unstable which helped the outbreak of bio-disasters. In addition, along with the increase of international trades, exotic dangerous species were imported frequently, then dispersed and spread further, which induced increasingly severe occurrence of forest bio-disasters in China^[1]. According to recent statistical re-

suits, the yearly infestation areas of forest disease and insect pests were around 8,000, 000 hm² in the whole country, losing stem volume 17, 000, 000 m³ with direct economic loss about RMB 5 billion yuan^[2]. Bio-disasters seriously damaged our forest resources, landscapes and biodiversity, threatened the ecological safety of mankind, and became one of the outstanding problems in the development of national economy^[1-3].

1 Characteristics and Developmental Trends of Forest Bio-disasters in China

In general, there are more than 8000 species of forest disease and insect pests in China, in which around 200 species are severely damaged agro-forest plants, but only appropriate 100 pests would occur frequently^[1]. At present, outbreaks of the forest bio-disasters in China had the following traits: Firstly, the invasive alien species (IAS) caused huge damages^[4]. The occurrence areas induced by IAS were over 1, 300, 000 hm² every year in China. So it has become the No. 1 problem endangering our forests. The fall webworm, *Hyphantria cunea* (Drury) (Lepidoptera: Arctiidae) was first found in Dandong, Liaoning Province in 1979 and now it has spread into Shandong, Shaanxi, Hebei, Tianjin, and Shanghai successively. Since the pinewood wilt disease caused by *Bursaphelenchus xylophilus* was found in 1982 in Nanjing, it has dispersed to Jiangsu, Zhejiang, Anhui, Guangdong, and Shandong Provinces. This disease has attacked 730, 000 hm² forests and killed more than 20, 000, 000 pine trees. Secondly, the area of frequent occurrence bio-disasters was large and increasingly aggravating. The pine caterpillar was a big problem nearly every year. The infestation area has exceeded 1, 300, 000 hm² in China and losing about 2, 000, 000 m³ stem volume. The ecological canker diseases mainly caused by *Valsa sordida* and *Botryosphaeria dothidea*, and trunk borers dominat-

ed as longhorn beetles destructively damaged the poplar man-made forest ecosystem in the "Three-North" regions, and further threatened the recovery and reconstruction. In addition, rodents infested forests more than 660, 000 hm² yearly in the north-eastern and northwestern of China. Thirdly, outbreaks of some occasional occurrence forest disease and insect pests in a wide range caused huge loss. In 1998, more than half of the 200, 000, 000 poplar trees in Henan Province suffered from defoliating insect pests so that about RMB 300,000,000 yuan was lost directly. A severe *Cytospora* canker disease of trees arose in dozens of middle-large size cities of northeastern China in succession and excess of 150,000 trees died of it. *Apocheima cinerarius* Erschoff (Lepidoptera: Geometridae) in Qinghai Province and *Aphrodisium* sp. in Guangxi Province broke out successively, the pest population increased sharply. Infestations of *Parocneriu orientalis* in Jiangsu Province, *A. cinerarius* in Shandong Province, *Drosicha contrahens* in Shaanxi Province, *Nymphalis xanthomelas* in Qinghai Province were also very serious. The cypress trees in protection forest of the Yangtze River in Hubei region became vulnerable after attacked by sawflies, inducing outbreaks of bark beetles and longhorn beetles. Currently, such pests as pine caterpillars, pinewood wilt disease, poplar trunk borers, red turpentine beetle (*Dendroctonus valens*), pine scale (*Hemiberlesia pitysochila*), *Oracella acuta*, *Clania variegata*, pine sawflies, and rodents, has become the most severe forest bio-disasters^[1,4].

In the future, risks from invasive pests will be more and more serious following increase of foreign exchanges. Those bio-disasters induced by the change of climates and deterioration of ecological environments will arise frequently. Some secondary pests will grow up to major bio-disasters gradually and the urban forest bio-disasters will become more dangerous.

2 Basic Research on the Forest Bio-disasters in China

The National Natural Science Foundation of China (NSFC) always concerned the basic research on forest bio-disasters. Since its foundation in 1987, many related basic research activities have been supported in the form of programs and included in "Directed Research Projects", "Encouraged Research Fields", and "Key Projects", financing more than

120 projects in total. Especially since the year of 2000, as the spread and worsening of forest disasters, NSFC enhanced the support for the "General Programs" as well as set "Special Funds in favor of forest bio-disasters". Funding for basic research on pinewood nematode, longhorn beetles, pine caterpillars and forest rodents were emphasized. Thanks to the powerful support from NSFC and associated organizations, recently basic research for the forest disasters in China has been developed greatly and the entire research levels improved evidently. On the aspects of study profundities, researches have been changed from survey on pest species and their distributions in the early stage to exploration on the developmental principles and damage mechanisms of bio-disasters; and from the individual plant or organic levels to cellular, physiological, biochemical and even molecular levels. While on the aspects of study scope, researches and regulations on a single pest have been expanded to multi-directional and 3 dimensional managements on host trees-pests-natural enemies-habitats. The effective integrated management patterns on some particularly destructive insect pests such as pine caterpillars and pine scales were developed successfully. Increasingly frequent crossing among disciplines, successive emergence of new techniques and new methods, especially those techniques from aeronautics, remote sensing, information, and biology were successfully applied in the monitoring on population dynamics of some key forest insect pests and in the studies on their outbreak mechanisms. The gene engineering technology aimed at improving the resistances of trees to diseases and insect pests became more and more mature. Particularly, outstanding progresses were obtained in the following aspects.

(1) Life cycles and behaviors of more than 800 forest insect pests, especially the biology, ecology and damage habits of around 170 insect pests in which were studied in detail. The pathogens, epidemic patterns, and resistances of host plant to diseases of about 60 important forest diseases were clarified.

(2) On the research of outbreak mechanism and management of rodent population, it was found that incidence of some rodent populations was highly related to El Nino-Southern Oscillation (ENSO), and an ENSO-hypothesis on the outbreak of rodent population was proposed. Anal sac secretion of the natural enemy Siberian weasel *Mustelia sibirica* (principal component was 2, 2-Dimethylthietane) heavily influ-

enced the aggressive behavior, colony structure, and mate choice of Rat-like hamster *Cricetulus triton*. On the population management, a sustainable control theory about the fertility control caused by competitive reproduction interference and marry system was proposed.

(3) Early diagnosis on pine wilt disease was studied and many kinds of early diagnosis techniques were developed, in which the sap-diagnosis method showed high accuracy. The incidence mechanism of pine wilt disease induced by the combined infection of pinewood nematode and its attached bacteria was further evaluated. The contamination damage from combined infection of pinewood nematode proved to be derived from certain toxic chemical using a self-made device named "hot-brake". A wilting toxic substance, 2-methoxycinnamic acid was identified recently. These important findings on the mechanism of pine wilt disease provided theoretical basis for management of this disease through controlling the infection bacteria. An approach against the pinewood wilt disease by controlling longhorn beetle *Monochamus alternatus* Hope to cut off its spread ways was proposed. Bio-control technique for the sustainable management of *M. alternatus* was also developed via pheromone attractant chemicals plus cloth bands containing *Beauveria bassiana*. A new pesticide formulation, contact-broken microcapsules was developed successfully. This product not only had the characteristics of long effectiveness duration, low dosage, and low contamination as well as those of common microcapsules, but also could break and release insecticidal components rapidly when longhorn beetles contacted it, so that the control effects were enhanced greatly.

(4) The natural enemies of the fall webworm, *Hyphantria cunea* (Drury) (Lepidoptera: Arctiidae) were investigated carefully. A total of 27 species of natural enemies was discovered, including 2 predators and 2 parasitoids in host larval stage, 18 pupal or larval-pupal parasitoids. Parasitic enemy *Chouioia cunea* Yang (Hymenoptera: Eulophidae), a new genus and new species to science, was found. And an effective strategy was developed for the bio-control of fall webworm mainly using *C. cunea*. Natural enemy *Dastarcus helophoroides* was found on Asian longhorn beetle (ALB), *Anoplophora glabripennis* Motschulsky, Japanese pine sawyer, *Monochamus alternatus*, and oak trunk borer, *Mallambyx raddei*, parasitizing larvae and pupae of longhorn beetles respectively. Important progress has been achieved in the taxono-

my and artificial mass rearing of *Dastarcus helophoroides*. By releasing eggs and adults of *D. helophoroides* against *A. glabripennis*, results revealed the control effects via release of eggs were much better, mortality of Asian longhorn beetle larvae was up to 96%, which suggested its excellent utilization potentials.

(5) On the aspect of forest management measures, the ecological control theory was proposed for the first time against longhorn beetles using a rational integrated system composed as multiple species of trees including non-host trees, resistant trees (objective trees), and lure trees. The ecological regulation theory and technology for forest bio-disasters have been established and developed, making the bio-disaster management upgraded from control only to pests to an integrated regulation mainly exploring the relationships among host trees-pests-natural enemies-habitats, taking components, structures, and stability of trees (shrubs and grass), and pest population dynamics as the frame route.

(6) There were many outstanding achievements in the monitoring of pine caterpillars, pine bark beetles, longhorn beetles, sawflies, utilizations of sex ectohormones, acrasins, and attractants, etc. Methods of using aviation video and GPS navigation system to monitor the pine wilt disease have been put into probation.

(7) On the research of genetic engineering of forest trees resistance to diseases and insect pests, after solutions of those key technical problems on the transduction, regeneration, screening, and identification, subsequently *Bacillus thuringiensis* (Bt) toxin protein (*cryIAC3*) gene, Cowpea trypsin inhibitor (*CpTI*) gene, 35S- Ω -Bt-NOS chimeric gene, Bt + API double genes, Bt + scorpion toxin (*AaIt*) insecticidal genes, and defensin gene (*NP-I*) were successfully transferred into poplar tree. Transgenic poplar trees with resistances to diseases and insect pests were obtained, and some transgenic poplar trees were authorized to release and extend in field.

Although some valuable results have been achieved in the basic researches of forest bio-disasters in China, most of those studies were still tracking cases with poor research foundation, lacking of research outcomes and academic viewpoints with distinct innovations. Comparing with the serious forest diseases and insect pests, investments for basic research are insufficient, and the lack of senior scientific researchers is still a big problem. According to the principle of finite goals but predominant emphases,

fund from NSFC should aim at those outstanding problems in forest bio-disasters in China, and choose critical issues to conduct research combining international advanced fields in the coming years. It is hopeful to promote the development of the basic research on forest bio-disasters in China, and provide theoretical foundation for guiding the control of forest bio-disaster.

3 Several Important Basic Issues in Forest Bio-disaster in China

Recently, as the rise of theory of near natural forest, research and managements on forest bio-disasters have changed greatly. People were gradually aware of the difficulties to solve problems ultimately if only research into a single pest. The traditional chemical control could get half the result with twice the effort, but often brought serious pollution to our environment, and re-rampancy of the bio-disasters. Thus, the forest bio-disaster management must be improved along the way of integrated and sustainable development. At the end of 20th century, scientists developed theories of integrated pest management (IPM), sustainable pest management (SPM) and integrated biology^[6,7]. In these theories, forest pests were comprised in the entire forest ecosystem, and the "pests-host trees-natural enemies-habitats" were studied synthetically as a system in order to find out the outbreak mechanisms of bio-disasters. The relationships between population dynamics, occurrence of pests and changes of environment should be emphasized, enhancing the sustainable control of forest itself to pest populations, and regulating forest pests using applied ecological and bioengineering measures.

The aspects listed below about basic research on forest bio-disaster should be paid more attention to according to the research status of forest bio-disasters in China.

3.1 Research on the occurrence and damage mechanisms of important forest bio-disasters

Due to the huge damage caused by IAS in China, some important forest bio-disasters broke out every year and became increasingly serious, basic research on the important forest bio-disasters should be focused on in the future. The mechanisms of pest dispersal, and outbreak must be made clear as guidelines of scientific and effective control. Several important academic issues on the infestation and attack mechanism of forest bio-disasters were listed as follows.

(1) Dispersal and outbreak mechanisms of IAS, including the ecological procedures of invasion and the mechanisms of genetic "*pre-adaptation*" in the course of planting and population establishment, integrated research on the infection stress of IAS, relationships between adjustment ability of ecological adaptation and outbreak mechanisms of IAS, process of bursting into disasters, and importable causes of ecosystems, etc; (2) Relationships between bio-disasters and influences of global climate changes and environment pollutions on the population fluctuations of pests and their natural enemies; (3) Effects of landscape degradation and biodiversity decrease on the forest insects and microorganisms fauna, and the relations with bio-disasters; (4) Population dynamics of important insect pests and disease epidemic ecology, and their damage mechanisms; (5) Adaptation characters of pests to environment changes and mechanism of their population differentiation; (6) Mechanisms of seasonal outbreaks of pests.

3.2 Research on the sustainable control of major forest pest populations

The natural regulation actions of forest ecosystems should be treated as the key factor of sustainable control for those important forest pests. Utilizations of the natural and induced resistances of forests, natural enemies, ecological management, and ecological engineering measures, would effectively control pests in the long-term. These scientific issues are very important in the basic research on sustainable control of forest pest population: (1) Producing mechanisms of natural resistances and induced resistances of host trees; (2) Natural regulation abilities and mechanisms of forest ecosystem; (3) Mechanisms of maintaining the stability of ecosystem services by insect functional groups; (4) Mechanisms and regulations of insect pest migration and diapause; (5) Information communications and interaction mechanisms in the systems of "hosts-pests-natural enemies"; (6) Ecological management theories and patterns of pests; (7) Natural enemy systematics of important insect pests, and the succession of natural populations.

3.3 Developments and innovations of forest biological resistant natural resources

Forest biological resistant natural resources consist of two parts; one is the inherent resistance of tree species themselves, the other is chemical and biological

cal resources associated with pest control, including biological pheromone resources, natural enemy resources, pathogenic microorganism resources, and biological pesticide resources. Developing and utilizing forest resistant natural resources, and creating new germplasm, are the important foundation for the realization of forest pest sustainable control. As the rapid development of modern genetic technology, forest pest bio-control has entered genetic engineering transformation or internal genetic expression phases. The modern genetic techniques must hold wonderful prospects in the application of resistant breeding of forest trees following the technical breakthroughs in plant trypsin inhibitor gene, Bt endotoxin gene, and insect sex hormone genes. Currently, the main research directions in this field include: (1) Identifications and systematic studies on natural resources of biological pheromones, natural enemies, pathogenic microorganisms, biological pesticides; (2) Genetic analysis of resistant resources; (3) Molecular mechanisms of tree durable resistances; (4) Gene recombinant techniques of high-effective natural enemies and pathogenic microorganisms; (5) Directed and virtual breeding of resistant tree species to diseases and insect pests; (6) Safety evaluation techniques of transgenic resistant trees.

3.4 Research and development on the quarantine, monitoring and precautionary systems of IAS

Preventing the rise of pest populations is a positive strategy against IAS. Through establishing and developing an early precautionary system (risk recognition, damage recognition, region recognition, variation recognition) to forecast IAS scientifically. Then the rapid detecting and quarantine techniques can be developed under guidance of forecast, and an associated quick and effective response system is established against IAS successfully^[5]. The main scientific issues in this field are: (1) Research on the risk assessment of potential pests and epidemiology of potential IAS, forecasting the possible distribution range and damage of introduced species based on those limiting factors for phylogeny of species, including life cycle characters, climate comparability between the native and imported regions of introduced pests, differentiation traits of biology and genetic biodiversity of IAS in native and invasive areas, differences between populations of invasive and native/related species, and the spread patterns of invasive species, etc.; (2) Adapta-

tion and safety assessment techniques for importation of alien tree species; (3) Research on the information management systems of disaster dynamics detection and forecasting and precaution technology with freedom scale and high precision; (4) Rapid, sensitive and specific detection and quarantine techniques; (5) Research on the fast and high-effective emergency technology of disasters, through biological control, ecological regulation, and ecological restoration measures to cut off and eradicate invasive pests, establishing an integrated preventive and control system for the sustainable management of exotic organisms.

It can be anticipated that the future forest pest control would energetically develop biological and information technology, actualize a highly-efficient, low-consumed, and sustainable management, and establish an integrated forest bio-disaster management pattern which will contribute to the sustainable development of society and economy, as goals of the regional biological resources, and means of the ecological regulation and ecological engineering.

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