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Field research in China and Korea by the EMEA group and some implications for Japanese Oak Wilt

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Abstract.
Our EMEA group conducted field research in China and Korea for the second term of the EMEA project (FY2002-2005). In 2002, we visited northern parts of a forested area in South Korea in August and northern China in September. In China, vegetation deterioration was observed in relation to mahuang (*Ephedra* spp.) distribution. In August 2003, we visited Liaoning and Jilin Provinces in northeastern China to study *Quercus* vegetation with special reference to Japanese Oak Wilt. In October 2004 at the EMEA meeting in Mokpo, we got information on massive oak mortality in Korea from Korean EMEA members. Therefore, we visited Korea again in the end of July 2005 to see oak wilt disease in Korea through the courtesy of Dr. Joon-Hwan Shin. In August and November 2005, we visited Liaoning and Jilin Provinces, and Taiwan to compare forest composition and Platypus fauna among northeastern China, Taiwan and Korea. Since late 1980, in Japan, Japanese Oak Wilt (JOW) caused by an ascomycetous fungus, *Raffaelea quercivora*, carried by an ambrosia beetle, *Platypus quercivorus*, has been prevalent and spreading. Mortality is known to be high (40-70%) in *Quercus crispula*. In Korea in 2004, massive oak mortality similar to JOW was first observed in *Quercus mongolica*. The pathogen is thought to be a congeneric species belonging to the genus *Raffaelea*. The vector insect is *Platypus koryoensis*. It is highly suggestive that similar pests have become epidemic in both Japan and Korea during almost the same period although all the constituents differ from each other. In the first year of incidence of massive oak mortality in Korea, all dead trees and even living trees with much insect frass were eliminated and treated with chemical insecticide in the same way as in Japan. However, a greater number of *Q. mongolica* trees were killed in the second year. The result suggests that it is impossible to stop JOW even if all dead trees are eliminated in the traditional way. Other control tactics must be incorporated into a control strategy for JOW. In both Korea and Japan, tree mortality tends to be greater in trees with larger diameter. In Jilin Province in China, massive oak mortality has not been recorded despite the fact that in Jilin there are many forest stands that consist of *Q. mongolica* trees of larger diameter (sometimes > 60 cm DBH) than in Korea. The vector insect, *P. koryoensis,* has not been recorded in Jilin but it is likely that *P. koryoensis* is distributed in the area because the

insect was recorded both from Korea and Siberia. In Taiwan, *P. quercivorus*, *P. koryoensi*, and *P. taiheizanensis* are distributed, but no massive mortalities were recorded. It is speculated that evolutionarily stable relationships developed between host trees and fungi in a long coevolutionary process. Factors other than tree size must be related to the incidence of massive oak mortality in both Korea and Japan.

1. Introduction

Since the late 1980s, Japanese Oak Wilt (JOW) has been prevalent in Japan (Ito and Yamada 1998). Both deciduous and evergreen tree species belonging to the family Fagaceae start wilting and then die within a few weeks after becoming infested by *Platypus quercivorus* (Murayama). The number of trees killed by JOW has been increasing, and the range of JOW occurrence has been expanding since the late 1980s. An ascomycetous fungus, *Raffaelea quercivora*, is the causal agent of this disease (Ito et al. 1998, Kubono and Ito 2002). *Platypus quercivorus* is the vector insect in this system. It is important for developing control strategies for JOW to clarify the cause of the sudden increase of this disease since the late 1980s.

Some researchers hypothesized that both *P. quericovorus* and *R. quercivora* are native in the regions of JOW incidence (the native hypothesis) because JOW is similar to massive mortalities of coniferous trees in many regions of the northern hemisphere, which are caused by a native bark beetle-blue stain fungus complex (Kobayashi 2004). On the other hand, others hypothesized that *P. quericovorus* and/or *R. quericovora* are invasive species to regions of JOW incidence (the invasive hypothesis) (Yoshida 1994, Kamata et al. 2002). JOW has been spreading from four different loci (Kamata et al. 2002), which is known as the typical spreading pattern of invasive species (Elton 1958, Shigesada 1992). There are no known examples of a bark beetle-blue stain fungus complex of which epidemics have continued for > 20 years with range expansion.

JOW has been recorded in several locations since the 1950s (Kabe 1955, 1960, Matsumoto 1955). According to these records, similar massive mortalities of deciduous and evergreen oaks occurred in the 1930s in Yamagata Prefecture and Kyushu. These old records of JOW form part of the basis for the native hypothesis. However, records of incidence in the early 20th century do not prove the native hypothesis because many important forest and agricultural pests were introduced after the Meiji revolution, such as a pine wilt disease caused by a pinewood nematode.

Knowing whether JOW is native or invasive is important in determining a control strategy for JOW. Invasive species sometimes cause serious damage to ecosystems because of many years of intense outbreaks or causing high mortality to their host, which derive from a lack of natural enemies and/or high susceptibility of the host to the invasive creatures because of a lack of coevolutionary processes. In the former case, some examples are known in which the introduction of a natural enemy has succeeded in depressing invasive pest populations. In the latter case, however, introduction of natural enemies cannot control invasive populations effectively. Other control tactics, such as an additive resistance are necessary. An example of this is trunk injection of nemtiacide to pine trees against pinewood nematode.

This synthesis is aimed to propose some implications for control strategies of JOW through comparison of JOW with massive oak mortalities in other parts of East Asia.

2. Massive mortalities of *Quercus mongolica* in the Russian Far East (Mikhail Gromyko, personal communication)

In 1979, clumps (0.2-1.5ha) of massive mortality of *Quercus mongolica* were found in the Russian Far East. By 2002, these clumps had grown in size to the point where they coalesced into one large clump 100 ha in area. New small clumps of tree mortality have also started. This symptom is similar to that of Sudden Oak Death in North America, which was caused by *Phytophthora ramorum* (Shin-ichiro Ito personal communication). However, the causal agent of this massive oak mortality in the Russian Far East has not been identified.

3. Massive mortalities of *Quercus mongolica* in South Korea

Massive mortalities of *Q. mongolica* were first found in northern parts of South Korea in the summer of 2004. The symptoms were similar to those of JOW. The causal agent of this massive mortality was an unidentified species of ascomycetous fungus belonging to the genus *Raffaelea* similar to *Raffaelea quercivora* (*Raffaelea* sp. 1 in this paper) (Kyung-Hee Kim personal communication). *Platypus koryoensis* is the vector of this disease. The process of tree mortality is similar to JOW as follows: After *P. koryoensis* attacks, necrosis spreads in the sapwood, probably caused by *Raffaelea* sp. 1 infection. The necrosis stops water conductance, and the tree dies by wilting when necrosis completely blocks a cross section of the tree. The mortality tended to be high in trees with a large DBH as a result of *P. koryoensis* preferring these trees. However, mortalities were also observed in trees with smaller DBH than those killed by JOW, which probably depends on host preference of vector insects. It is interesting that sudden epidemics of similar disease syndromes are found both in Japan and Korea in the same time period despite the fact that host plants, vector insects, and probably pathogens differ between the two countries.

Platypus koryoensis is distributed in the Korean Peninsula, Taiwan, and the Russian Far East (Beaver 1989, Murayama 1934, Nobuchi 1967, 1980) so that *P. koryoensis* is probably native in South Korea. Therefore it is not essential for JOW epidemics that *P. quercivorus* is an invasive species although it does not mean that *P. quercivorus* is NOT an invasive species.

Scientists supporting the native hypothesis think that overmaturing of oak stands caused by the under-use of fuelwood forests after the energy revolution in early 1960s caused recent epidemics of JOW because reproduction of *P. quericovorus* tends to be more successful in trees with greater DBH. In Korea, forest vegetation was badly damaged during the Korean War in the early 1950s. Forest rehabilitation proceeded in South Korea by pine plantations and natural recovery of oak stands. In Korea, as in Japan, the use of fuelwood decreased greatly after the energy revolution. Overmature forests or trees with large DBH are also a likely cause of epidemics of massive oak mortality in Korea.

Kamata (2005) criticized the "overmature forest hypothesis" since JOW was not epidemic by the Meji era despite the fact that human population density was low enough for oak forests to be mature then. Kobayashi (2004) speculated and contradicted that *Q. crispula* forests were not as abundant as they are today when human disturbance was not so strong as it is today because *Q. crispula* is a species that occurs before climax species such as *Fagus crenata*. In Korea, however, *Q. serrata*, *Q. valiabilis*, and *Q. mongolica* can be major components of climax forests. Just looking at 60 years after the Korean War, it seems plausible that massive oak mortality in Korea is the byproduct of over maturation of oak forests. It does not seem possible that massive oak mortality was epidemic in Korea, in which trees belonging to the genus *Quercus* can be major components of potential natural vegetation.

4. The Situation in Northeast China and Taiwan

To test the "overmature forest hypothesis", we adopted a deductive approach. Situations in Northeastern China and Taiwan were investigated.

Quercus dentata and *Q. liaotungensis* are distributed in Liaoning Province as well as *Q. mongolica*. Silkworm farming using saturniid species is booming in Liaoning. Branches of *Quercus* trees, which sprouted from stocks that were cut at < 50 cm high, are cut and used for insect rearing. Thus abundance of *Quercus* trees large enough for *Platypus* spp. reproduction was low in Liaoning Province except for areas close to the border between Liaoning and Jilin Provinces. Similar results were shown in Yamanaka et al. (2002). *Q. mongolica* trees of large DBH were abundant in east of Jilin Province (Mt. Chanbaishan-Antu- Dunhua-Jilin). Trees in most of these areas were larger in DBH than those in forests with massive oak mortality in Korea. However, no massive oak mortality or symptoms similar to JOW were found in China. In Northeastern China, there are no records of *P. koryoensis* or *P. quercivorus*. *P. koryoensis* was recorded from both Korea and the Russian Far East. *Q. monglica* is distributed from Korea to the Russian Far East through Northeast China. Therefore it is likely that *P. koryoensis* is distributed in Northern China although there are no records. There were few dead or fallen trees and fallen branches on the ground probably because these are still useful for fuel.

In Taiwan, *P. taiheizanensis* was found to reproduce in fallen trees of the genus *Castanopsis*. In the sapwood of these trees, discoloration similar to necrosis caused by *R. quercivora* was found in all cases. However, the development of the necrosis was not wide enough to cover cross sections. Fungal fauna on the gallery surface of *P. taiheizanensis* were collected. It is likely that a fungus similar to *R. quercivora* is closely related to *P. taiheizanensis*. However, this fungus does not cause as rapid development of necrosis for its host tree as *R. quercivora* does for *Q. crispula*. There was also records of *P. koryoensis* and *P. quercivorus* in Taiwan but no records of massive tree mortality. Relationships among host plants.- associated fungi *–Platypus spp. Iin Taiwan* are evolutionarily stable compared to evolutionarily unstable relationships among *Q. crispula-R. quercivora-P. quercivorus* in Japan and among *Q. mongolica-* unidentified fungus of the genus *Raffaelea –P. koryoensis* in Korea as Kamata et al. (2002) pointed out.

5. Implications for JOW from experience in Korea in 2004 and 2005

The initial response of the South Korean government to massive oak mortality was quick because scientists in KFRI had obtained information on JOW from Japanese scientists. In South Korea in 2004, 680 *Quercus* trees were killed in the first year of incidence. In 2005 the number of dead trees was 1220. All dead trees and most of living trees were treated with a great amount of insecticide in the same way as we do for pine wilt disease caused by pinewood nematode (PWDPWN). In Japan, the same treatment is the most common tactic for controlling JOW. However, it has been impossible to treat all dead trees because dead trees have been so numerous. One exception occurred in Toyama Prefecture in 2002. That was the first year in which JOW was first found in that prefecture, and all dead trees were treated there that year. The incidence of JOW increased in Toyama 2003, similar to the situation in South Korea in 2005. It is much better than nothing, of course, but the situation in Korea indicates that it is difficult to stop JOW only by treatment of dead trees. Other tactics should be involved in a control strategy to depress JOW.

Treatment of dead pine trees is thought to be effective to control PWDPWN because *Monochamus alternatus*, a vector insect of this disease, cannot reproduce on healthy trees. However, new adults of *Platypus quercivorus* emerge from living host trees. It seems reasonable that dead trees are treated first because the reproductive rate of P. *quercivorus* is higher in dead trees than in living trees. However, this does not mean that treatment of living host trees with many insects is unnecessary.

6. Discussion

Hypotheses for the present status of JOW epidemics are summarized as follows:

1. Invasive species hypothesis.
   - 1-1. Vector insect.
   - 1-2. Pathogen.
2. Climate change hypothesis
   - 2-1. Host plants growing in the warmest parts of their distribution are stressed.
   - 2-2. Spread of vector insects.
3. Mature forest hypothesis

Situations in East Asian countries shown in this paper suggest to that the list be narrowed down to two hypotheses, the invasive pathogen hypothesis (1-2) and the climate change hypothesis through plant stress (2-1).

In Taiwan, the associated fungus does not cause a rapid development of necrosis in sapwood of host plants. The similar phenomenon was observed in *Q. serrata*, *Q. acuta* and *Castanopsis cuspidate* when they were infected by *R. quercivora* . It is speculated that evolutionarily stable relationships developed between host trees and fungi in a long coevolutionary process. The hypothesis proposed that fungus was introduced to Japan and Korea. At present the pathogen in South Korea is thought to be a different species than *R. quercivora*. Identification of the Korean pathogen and the fungus associated with *Platypus* spp. in regions without massive mortality of host trees would be useful. Also, DNA analysis of both vector insects and associated fungi seems useful to understand the origin of this disease.

A climate change hypothesis thorough distribution of *P. quercivorus* depends on the fact that JOW is common in areas of the northernmost or highest border of the insect distribution. However, it is not the case for Korea. On the contrary, the climate change hypothesis through plant stress seems more plausible there because massive mortality in Korea also occurs in areas near the southernmost borders of *Q. mongolica* distribution.

Careful comparison of massive oak mortality between Japan and Korea will provide us useful information for finding the cause of these epidemics and for developing control strategies in both countries. Further cooperative research is needed.

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