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ABSTRACTS OF PAPERS, ALPHABETICAL BY FIRST AUTHOR

PLANTS FOR PLANTING INTERNATIONAL UPDATE

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Update of the international standard proposal for Plants for Planting.

This presentation introduces the current status of the International Plant Protection Convention (IPPC) standard for the international movement and trade for commodities known as Plants for Planting.

The IPPC expert working group has presented a proposal for an international standard intended to provide guidance to produce and export plants for planting with minimal plant pest introduction to importing countries. The standard will allow National Plant Protection Organizations (NPPO) to utilize phytosanitary requirements for a variety of processes to establish a "systems approach" that are integrated production measures to promote preventive pest risk management within defined parameters. A system approach requires the integration of different measures, at least two, which act independently and with a cumulative result. (ISPM14) The systems approach processes provide alternative or supplement options to single measures, particularly the port of entry import inspection. The production system approach can provide phytosanitary protection in situations where no single measure is either available or has been sufficient for phytosanitary protection to the importing country.

The standard will provide a foundation framework that will allow for the development of a process that is mutually accepted between countries with the purpose to minimize the export of regulated pests on plants for planting to an acceptable level by involving both import and export NPPOs, the plant producers and other entities at critical control points throughout the production and distribution process.

The proposed IPPC standard will be a guidance tool for plant producers to mitigate plant health risks in the country of origin and utilize uniform system approaches for plants for planting. The overall goal of this standard is to minimize the export of organisms on plants for planting. Often these plant associated organisms may not be viewed as plant pests in the country of origin, they may be organisms that are unknown to science or contaminating pests that are difficult to detect based on current import inspections. The net affect, substantially reduce the pest risk export of plants for planting with the least possible impact on trade within an international standard.

Exploring Patterns of Pest Interceptions on WPM

Using USDA's Pest ID Database

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“We cannot inspect our way out of the problem” is a current perception based on the recognition that over the past 8 years total imports (minus crude oil) increased 6.5 times faster than addition of inspectors at the 326 US Ports-of-Entry. Analysis of patterns in USDA's Pest Inspection Database (PestID) now provides APHIS and CBP managers with enhanced container surveillance and inspection algorithms.

Innovations include real-time email alerts, access to GIS maps and historical time-series of pest origin, points of interception, and final destination, automatic pest targeting, feedback on regulatory effectiveness, and improved detection surveys of escaped pests. APHIS is developing ways to predict the risk of outbreak for selected, especially high-threat species such as Medfly (worldwide), vineyard snail (Australia), and glassy-winged sharpshooter (California), among others. A global monitoring system is visualized that will track climate signals at four to five “epicenters” of frequent pests arriving on commodities from offshore.

In this “on-hands” workshop, we illustrate underlying concepts and demonstrate different toolkits under development that bring to decision makers at APHIS and CBP the kinds of information they most need in easily understandable, “finger-tip accessible” formats. We demonstrate how ISPM No. 15 has affected interception of the 8 target families at US ports-of-entry, and escapes beyond the ports. Since 2003, have WPM pests decreased as intended, or have they increased? Which groups have been the most responsive to the new regulation? What are the likely future trends? Where are the majority of the pests coming from, going to? What commodities are they associated with, and how do they change with the seasons?

OCCURRENCE OF THE EMERALD ASH BORER, *AGRILUS PLANIPENNIS* IN RUSSIA AND ITS POTENTIAL IMPACT ON EUROPEAN FORESTRY

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The emerald ash borer (EAB), *Agrilus planipennis*, is a beetle native to East Asia where it causes little concern, attacking preferably weakened or dying ash trees. It was first discovered in North America in 2002 and, since then, it has become one of the most serious insect invaders, killing millions of healthy ash trees in urban and forested settings. Similar damage is now observed in the region of Moscow, Russia, which causes serious concern for Europe. We provide new information on EAB occurrence and biology in the region of Moscow and eastern Russia. In view of the new occurrence of this pest in European Russia, the following recommendations for research and management strategies in Europe can be made.

(1) The susceptibility of the European ash species, *Fraxinus excelsior*, *F. angustifolia* and *F. ornus* to EAB should be urgently assessed, since other measures in Europe will largely depend on the potential impact that the beetle may have on native trees. (2) A climate envelope should be calculated for EAB based on current pest distribution, and projected to Europe. (3) More surveys should be carried out in the region of Moscow and elsewhere in Russia to assess the present distribution of the beetle in the country, since recent tree mortality may have been unnoticed. Surveys should focus at least partly on *F. pennsylvanica* because it is widely planted in Russian cities and it has been shown to be particularly sensible to EAB attacks. The development of trapping systems for EAB in North America should be carefully followed and traps should be used as soon as possible to support the monitoring programmes. (4) Should the native European ash species appear to be susceptible to EAB, Europe should be proactive and develop research programmes aiming at better understanding the ecology of the beetle and developing detection and management methods, if possible in collaboration with North America and Asia.

FORAGPROTECT: AN INVASIVE EXOTIC SPECIES ASSESSMENT AND MANAGEMENT SYSTEM FOR FORESTS AND AGRICULTURAL LANDSCAPES

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The primary goal of ForAgProtect is to produce an assessment and management tool for invasive exotic pest species that can be used by professionals in their forest and agricultural crop protection efforts. This tool uses GIS to integrate a broad range of geographic information with the important biological factors of individual exotic species. The main objective is to create an applied system complex enough to: assess risk of introduction, focus detection efforts, provide for rapid response and to help prioritize management actions and eventual restoration efforts.

Spatially-explicit data layers are being developed relative to potential pathways of introduction (ex: the location of nurseries, second homes, transportation routes, campgrounds, sawmills, scenic areas, etc.). Their physical (GPS) locations are being mapped and a data base is being created with specific contact information. To assess the potential for pest establishment and spread, specific host availability data layers (from aerial photos, FIA data, etc.) are being developed and will be integrated with layers reflecting the biological needs of the exotic pest (microclimate, elevation, aspect, soils, etc.). The assembly of these types of spatial data layers will be applicable to more than one pest and therefore will represent an institutional knowledge base that could be readily adapted to address the threat posed by a variety of different exotic pest species.

EARLY WARNING SYSTEM AGAINST INVASIVE ALIEN FUNGAL SPECIES ENTERING CANADA

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The ISPM 15 international phytosanitary measure was developed to control pests on woody packaging material. Unfortunately it does not target live plant material of any kind shipped between trading countries. Many forest invasive alien fungal species responsible for diseases such as chestnut blight, Scleroderris canker, white pine blister rust, butternut canker and sudden oak death came to North America on live plant material. Many more will certainly arrive in the future.

In order to target this pathway of introduction that is not subjected to the ISPM 15 measure, we developed a new early warning system based on cloned fungal ribosomal DNA extracted from live plant material (leaves, stems, twigs and seeds). Annually, 400 randomly selected samples from major Canadian ports of entry will have their DNA extracted, PCR amplified for the ribosomal ITS region, then cloned and sequenced. Homologies with reference sequences from GenBank will provide information about the potential of foreign fungi found inside the live plant material to be invasive forest pests. The data will provide a 'radar image' of new fungal threats presently coming from abroad.

FIREWOOD: ROLES, RESPONSIBILITIES, AND RISKS

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The USDA Emerald Ash Borer Program, in cooperation with state partners and other stakeholders, is diligently working to control and manage this non-native pest through survey, regulatory, and educational efforts. Through these efforts firewood has been identified as a pathway for the passive dispersal of emerald ash borer (*Agrilus planipennis*) Fairmaire. While focused on emerald ash borer control and management, the program has encountered other pest species that may also hitchhike on firewood.

Regulating firewood transport, sales, and use is a significant challenge for the program. Enterprises offering firewood for sale range from very small “Mom and Pop” operations to the large “big box” stores. The larger enterprises requiring regulation and education are readily identifiable. Even smaller regional businesses distributing firewood for sale are relatively easy to identify. The smallest firewood dealers, those of the home business type, are very difficult to identify since their business longevity may be fleeting or only identified by a small local newspaper ad or front yard sign.

Another firewood challenge is that of the vacationer. People have a long history of burning wood and this tradition continues as campers, vacation home owners/renters, hunters, etc. travel to their destination with firewood. Most unknowingly transport infested firewood to their journey’s endpoint and create a new point of infestation.

It is known through other pest studies that pests hitchhike on material transported great distances infesting new areas. With the expansion of global trade new arrivals of pests will require us to establish a new paradigm in our views of firewood.

ʻOHĪʻA – BACKBONE OF HAWAII'S TERRESTRIAL ECOSYSTEMS AND CULTURE

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Hawai'i's dominant native forest tree, ʻohiʻa, (*Metrosideros polymorpha*), provides the backbone of Hawaii's terrestrial ecosystems and the fabric that harbors the rich remains of the archipelago's native fauna and flora. In addition to supporting a preponderance of Hawai'i's unique natural heritage, the ʻohiʻa tree itself has great cultural significance to Native Hawaiians. Forests dominated by ʻohiʻa are home to at least 22 extant species of native forest birds, the Hawaiian hoary bat, and many of Hawai'i's remaining native plants and invertebrates. Endemic Hawaiian honeycreepers, including 16 on the endangered species list, are dependant on these forests for critical habitat, as they have adapted to feed and nest in ʻohiʻa trees. Due to Hawai'i's isolation, organisms evolving here are often naïve to predators and diseases, and vulnerable to competition from invasive species that have escaped from the natural enemies of their home ranges and into Hawai'i's favorable climate. A recent report listed 13 insect species, 25 fungal or bacterial diseases, as well as a genus of nematodes that are potential pests of *Metrosideros* and other members of the Myrtle family (Myrtaceae). The fungal pathogen, *Puccinia psidii*, known as "ʻohiʻa rust" in Hawai'i, established and spread throughout the main Hawaiian Islands within months in 2005. Damage to ʻohiʻa has been minor so far, but should another strain of *P. psidii* or another pest cause total defoliation, as *P. psidii* has done to other Myrtaceae in Hawai'i, the ecological consequences could be catastrophic. Repeated destruction of the new growth of ʻohiʻa trees would result in low reproduction, dieback of the crown, and eventual death of the tree, and overstory changes could alter the composition, structure, and function of the forest. The Hawai'i Department of Agriculture has restricted the importation of plants in the Myrtle family from areas infested by this rust to prevent other, potentially more harmful strains of the rust from being introduced. This may also minimize importation of other pests of Myrtaceae, but only from those restricted areas. Given accelerated trade, a pathways approach to regulating the importation of plants in this family from the mainland and foreign countries is essential to maintaining Hawaii's unique and fragile ecosystems. For more information see:

www.hear.org/species/puccinia_psidii/pdfs/ofr_2008_1008_loope_ohia_rust_assessment.pdf

ARCHAEOPHYTOPATHOLOGY IN WESTERN SWITZERLAND: GENETIC CHARACTERIZATION OF *PHYTOPHTHORA* COLLECTIONS

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The genus *Phytophthora* accounts for numerous notorious plant pathogens. This work aimed at the molecular identification of isolates from two collections of *Phytophthora* spp. (Agroscope Changins-Wädenswil ACW and Swiss Federal Research Institute Forest Snow and Landscape WSL) established during surveys carried out between 1976 and 2006 in Switzerland. Species were identified by direct sequencing of the internal transcribed spacer (ITS) rDNA and for some of them by sequencing of nuclear genes such as 18S, 28S, β -tub, Ef1- α and mitochondrial genes such as cox I, NADH 1 and cox II. Species mostly associated with diseased plants included *P. cactorum*, *P. cryptogea*, *P. citricola*, *P. megasperma*, *P. gonapodyides*, *P. cambivora*. Interestingly molecular identification pointed at the not yet recorded presence of *Phytophthora* taxon "Raspberry", *Phytophthora* taxon "Pgchlamydo", *Phytophthora* taxon "Salixsoil" and the recently described species, *P. hedraiaandra* and *P. inundata*, on the Swiss territory. Several additional isolates belonged to the genus *Pythium* and did not match known species. Numerous first reports and/or new host pathogen combinations are reported for the first time from several hosts. Results indicated that several *Phytophthora* species were more widespread in natural and managed ecosystems than previously thought. This consequently justifies the effort for conservation of phytopathological samples as a historical record of *Phytophthora* outbreaks.

CURBING INTRODUCTIONS OF FOREST INSECTS AND DISEASES ON PLANTS FOR PLANTING

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At least 18 devastating forest insects and diseases have been introduced to the United States since the early 1800s via the pathway of trade in living plants. Five of these introductions have been detected since 2000 – indicating rising rates of introduction.

Rates of introduction are rising due to increases in the number of plants in international trade and the geographic range of suppliers, coupled with more rapid transport which allows more pests to survive transit. At the same time, phytosanitary safeguards have been relaxed. Individual nations, regional bodies such the North American Plant Protection Organization, and the International Plant Protection Convention are studying new approaches to curtailing introductions via the plants for planting pathway.

To be effective, the proposed new approaches must overcome several problems, particularly the inability of pest risk analysis to identify and evaluate pests that are unknown to science. (At least six of the most damaging forest pathogens that entered the United States on imported plants were unknown to science when they were introduced.) In recognition of this dilemma, this Work Group of the International Union of Forest Research Organizations has called for adoption of an international standard (modeled after the international standard on wood packaging) that would allow clean stock programs to apply to the full range of pests, not just quarantine pests.

This proposal has great promise – but it is unlikely to be adopted and put into practice for several years. Protecting forests from invasions requires stringent measures to rein in movement of forest pests via this pathway *now*.

The Nature Conservancy has worked with stakeholders representing environmental, forestry, nursery, government and academic groups, to develop a set of consensus recommendations for curtailing such introductions in both the short and long term. We seek operation of a comprehensive program relying on a systems approach by 2015. In the short term, we advocate temporary measures focused on high-risk groups as determined by evaluating such factors as type (seed or tissue culture v. whole plants), geographic origin, or absence of either pest risk analysis or import history demonstrating a low risk. These high-risk plants would be subject to enhanced risk reduction efforts, which might include temporary prohibitions on importation; enhanced inspection at entry; enhanced post-entry quarantine; or mandatory disinfestation treatment.

GENETIC CHARACTERIZATION OF OOMYCOTA ISOLATES RECOVERED FROM DECLINING FOREST IN POLAND

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Oomycetes account for numerous highly destructive plant pathogens with the genera *Pythium*, *Phytophthora* and *Peronospora*. Despite the ecological and agronomic importance of this group few studies have been dedicated to monitor their occurrence and diversity in natural ecosystems. This work aims to investigate oomycete diversity in declining *Alnus* and *Quercus* forests in Poland. Species were identified by direct sequencing of internal transcribed spacer (ITS) rDNA. Only a few oomycete species dominate highly diverse mycofloras associated with the studied ecosystems. *P. taxon salixsoil* as well as other *P. gonapodyides*-*P. megasperma* ITS clade 6 spp. have been mainly isolated. Numerous pathogenic spp. such as *P. alni*, *P. cambivora* and *P. quercina* have been isolated. *P. inflata* and *P. hedraiandra* have been isolated for the first time from natural ecosystems in Europe and worldwide. *P. polonica*, previously reported as a new species, has been found in many occasions from these areas. The genera *Pythium* and *Saprolegnia* proved complex and numerous members are yet undescribed. However recently described *Pythium* species such as *P. sterilum* and *P. spiculum* were also found in these declining forest stands. This survey included riparian ecosystems where *P. taxon salixsoil* proved the only *Phytophthora* present in water with *Pythium* and *Saprolegnia* spp. Results indicated that several *Phytophthora* species were more widespread in natural ecosystems than previously thought, and that numerous species of *Pythium* and *Saprolegnia* have yet to be described.

USDA Biological Control Research Programs and Overseas Opportunities

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Emergency control measures for invasive species often rely on use of pesticides and other destructive practices. Public concern about pesticide contamination of the ground water and the environment has led to increased restrictions on the use of pesticides for control of many destructive invasive species. Biological control often provides a cost effective, environmentally friendly and sustainable solution. Both the United States Department of Agriculture's Agricultural Research Service (ARS) and Forest Service (FS) have very active biological control programs to identify and expand the number of available biological control agents for key pests and weeds.

The ARS biological control program addresses agricultural and other pests of regional and national importance including *Aphis glycines* (soybean aphid), *Anoplophora glabripennis* (Asian longhorned beetle), *Euphorbia esula-virgata* (leafy spurge), *Cirsium arvense* (Canada thistle) and *Centaurea solstitialis* (yellow starthistle). ARS has several Overseas Biological Control Research Laboratories (OBCLs), with cooperators located in many countries around the world. Scientists at these laboratories search for biological control agents in the host's native range, study the basic biology and ecology of candidate agents, evaluate host specificity and ship the most promising agents to the U.S. ARS and collaborating scientists in the United States further evaluate these agents prior to their release. The OBCLs also facilitate international cooperation and collaboration on mutually beneficial high priority biological control research. Research at the OBCLs and at ARS laboratories in the United States led to the release of the *Melaleuca* weevil (*Oxyops vitiosa*) which caused massive reductions in *Melaleuca quinquenervia* in Florida. Natural enemies also were successfully released for gypsy moth, *Tamarix ramosissima* (tamarisk), *Arundo* (giant reed), *Lygodium microphyllum* (old world climbing fern) and numerous other pests.

The Forest Service invasive species biological control research focuses on priority pest species in forest and rangelands such as *Agilus planipennis* (emerald ash borer), *Adelges tsugae* (hemlock woolly adelgid), *Chondrilla juncea* (rush skeletonweed), *Centaurea masculosa* (spotted knapweed) and *Bromus tectorum* (cheatgrass). The program includes overseas evaluation and exploration as well as further development of mass rearing protocols prior to the natural enemy's release. The success of the biological control program is based on the scientists' close partnership with international, federal, state, university, tribal, state, local and nongovernmental organizations. Partnerships with Chinese scientists, APHIS, and state organizations have led to the field release of three parasites of the emerald ash borer and several hemlock woolly adelgid predators. Partnerships between Forest Service scientists and the OBCLs have led to the release of the release of many biological controls of invasive plants in the west.

ASSESSING THE HAZARD OF *PHYTOPHTHORA ALNI* IN THE UNITED STATES

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Phytophthora alni subspecies *alni* (PAA), currently present throughout Europe, is a hybridized soil- and waterborne pathogen, which causes root and collar rot of species of the genus *Alnus* (alder). Once introduced, the pathogen quickly spreads naturally with streams, floods, and other drainage water. PAA can also be passively transported with the bare-root nursery stock, as it is able to adhere to fine roots of visually symptomless infected plants of alder and other tree species exposed to the pathogen.

Susceptibility Hazard products were developed for the Conterminous United States (CUS) in 1 square kilometer (km²) units by the U.S. Forest Service, Forest Health Technology Enterprise Team's (FHTET) Invasive Species Steering Committee. The product's intended use is to develop a detection strategy for PAA. Supporting information was taken from Exotic Forest Pest website URL: <http://spfnic.fs.fed.us/exfor/> and guidance from Dr. Thomas Jung (Phytophthora Research and Consultancy, Bavaria). The Susceptibility Potential Surface was produced by combining the Introduction and Establishment Potential Surfaces in a final equal-weighted overlay. It is estimated that 119,313,300 hectares of forest are susceptible to attack from PAA in the Conterminous US (CUS). An important assumption in modeling the PAA hazard in the US is that it is likely that the hazard will come from nurseries receiving infested plants and the delivery of infested plants to the general population, not from direct planting of alder in natural forests as is what commonly occurs in Europe.

The Introduction Potential Surface was developed using three primary variables in the analysis: 1) wholesale nurseries, 2) production nurseries, and 3) metropolitan areas. Each of the variables was used to depict potential locations where PAA could be released into the CUS. The Establishment Potential Surface was also developed using three variables for analysis: 1) alder host, 2) flood-prone areas, and 3) slopes less than 11 percent. These data were combined to depict the potential of PAA becoming established.

INCREASING GLOBAL TRADE AND CLIMATE CHANGE: CO-FACTORS INCREASING THE INTERNATIONAL MOVEMENT AND ESTABLISHMENT OF FOREST PESTS

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Global trade, both in variety and quantities of goods moved, is increasing year by year. For example, WTO statistics indicate that between 2000 and 2005, global sea and air freight rose by around 20% with volumes now exceeding 7 billion tons per year. Trends in eco-climatic variables under different climate change scenarios also show marked differences in key drivers such as temperature, rainfall, soil moisture, etc. This juxtaposition of dramatically increased trade-driven international pest movement and more gradual shifts in climatic suitability in previously unsuitable regions of the world is providing new opportunities for plant pests to enter and establish in new locations.

Within the dramatically increased trade statistics, it is possible to determine which commodities are the high risk pathways for international movement of pests of phytosanitary concern. While wood, wood products and wood packaging have been recognised as key pathways and are subject to stringent phytosanitary controls, it is now becoming increasingly apparent that it is the 'plants for planting' pathway that poses the greatest current and future risk. Trade in live plants, often complete with root balls and associated soil, is increasing rapidly and globally. Full circumnavigation of the globe is now normality for live plants and, while there are phytosanitary rules in place, they tend only to reflect known pests. Those pests not on the lists of recognised organisms will consequently tend to be missed.

Transport along a pathway does not, of course, always result in successful establishment of pests in new locations. Previously, many organisms could not establish because of climatic unsuitability, reflecting the ecological and climatic barriers that determine distributions of pests in their natural ranges. The fact that distributions of pests in their native ranges is now changing and has been linked to climate change, indicates that climatic suitability for pests moving along trade pathways is also changing. Prediction of which pest will become damaging in new locations is not easy but lessons can be learnt from the ways in which pest organisms are adapting to climate shifts in their current locations. Overwinter temperatures, synchronicity of insect emergence with bud burst of hosts in the spring, reduced tree defences arising from climatic stress and warmer summers accelerating development are all aspects that provide insights into future pest adaptations to climate change. There is no doubt that the complex interactions between climate, pest and host tree will require detailed study to increase our understanding and allow development of pest management strategies for the future. However, it does seem inevitable that the increased opportunities for pests to encounter new and suitable eco-climatic zones for establishment will result in many new infestations and challenges in pest management.

MODELING THE RISK OF ASIAN GYPSY MOTH, *LYMANTRIA DISPAR* (LINNAEUS), MOVEMENT ON SHIPS FROM ASIA TO THE UNITED STATES

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The Asian strain of gypsy moth, *Lymantria dispar* (Linnaeus) (AGM), is considered a more threatening biotype than the European gypsy moth (EGM) that is in the United States. This is because AGM females are capable of flight and it has a larger host range than EGM. AGM has been intercepted and introduced at U.S. ports. These introductions have costs millions of dollars to eradicate.

We generated pest risk assessments, each comprised of three analyses, which characterized the risks to the United States associated with AGM on ships arriving at U.S. ports from Asia. We first geospatially characterized the risk of infestation at Asian maritime ports based on suitable habitat and U.S. bound ship volumes during the flight period. We then conducted a quantitative pathway analysis that estimated the approach rate of infested ships at U.S. ports coming from Asia. In the third analysis, we generated a pest risk assessment that characterized the risk to the United States if AGM were introduced from infested ships.

Our pest risk assessments can be used to inform regulatory policy and trade practices between Asia and the United States and help mitigate the likelihood of AGM introduction via the maritime ship pathway.

DETECTION OF PINE STANDS DAMAGED BY PINE WILT DISEASE USING IKONOS DATA

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Pine wilt disease, which damages pine stands and is caused by the pine wood nematode (*Bursaphelenchus xylophilus*), has spread throughout most of Japan. Finding disease damage at an early stage is important to stop the spread of the disease to other trees and prevent its expansion to other pine forests. However, current surveys of forest damage are conducted only by foresters. Such field surveys to find damaged stands and evaluate damage are time and labor intensive, and it is difficult to detect damaged stands located far from roads in mountainous areas. In this study, we used high-resolution satellite imagery to detect damage to pine stands caused by pine wilt disease.

The study was conducted in Japanese red pine (*Pinus densiflora*) stands on Mt. Tsukuba in Ibaraki Prefecture, Japan. A total of 66 plots (10 ×10 m each) were established in the study area, taking the damage ratio into consideration; all trees were tallied and examined for damage. The ratios of damaged pine trees, healthy pine trees, and hardwood trees were then calculated in terms of basal area. For satellite imagery, IKONOS “Geo” multi-spectral and panchromatic images taken in December 2000 were used. Pan-sharpened color imagery and multi-spectral imagery were analyzed, and normalized difference vegetation index (NDVI) values were calculated from the images. The relationship between the mean NDVI for pixels in each plot and the field-observed conditions in each plot was then examined.

The damage ratio and the ratio of hardwood trees tended to decrease and the ratio of healthy pine trees tended to increase as the NDVI increased for both imagery types. Moreover, to validate a prediction method, regression equations were derived from half of the plots and applied to the other half of the plots. The root mean square errors (RMSEs) for predicting the damage ratio and ratio of healthy pine trees from the NDVI were approximately 0.15 and 0.12, respectively, for the pan-sharpened imagery; the RMSEs for the same two ratios were approximately 0.17 for the multi-spectral imagery. The pan-sharpened color imagery effectively predicted the damage ratio in pine stands on a 10 ×10 m square basis. However, a mixture of deciduous hardwood trees in the study area increased the prediction error because the NDVI calculated from imagery in winter could not separate hardwood trees and damaged pine trees.

