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RESEARCH

at the Laurentian Forestry Centre of Natural Resources Canada

Exotic Forest Pests

Canada

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From top to bottom and from left to right

Page 1
M. Blais (NRCan) – *Melampsora larici-populina*

Page 3
C. Guertin (INRS-Institut Armand-Frappier) / L.D. Dwinell (USDA Forest Service)

Page 4
NRCan / NRCan / G. Kyei-Poku (NRCan) / NRCan

Page 5
K. Bolte (NRCan) / S. Sopow (NRCan) / R. Lavallée (NRCan)

Page 6
NRCan / NRCan / A. Kunca (National Forest Centre of the Slovak Republic)

Page 7
J. Thibault (NRCan) / NRCan / C. Moffet (NRCan) / NRCan

Page 8
S. Sela (CFIA) / S. Sela (CFIA) / D. Rioux (NRCan) and G. Bilodeau (CFIA) / D. Rioux (NRCan) / Nicolas Nadeau-Thibodeau (NRCan)

Page 9
NRCan / G. Pelletier (NRCan) / R. Gal (NRCan)

Page 10
C. Aerni (NRCan) / G. Villemure (NRCan)

To find out more

Exotic Forest Pests 101
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Butternut Canker
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Scleroderris Canker, European Strain
http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/25078.pdf

Sudden Oak Death
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Annosus Root and Butt Rot
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“Conducting research is an attitude, a method. Often, the answers lead you to a whole new set of questions. Forest research must be based on a long-term vision since the findings are linked to the rhythm of tree growth.”

Robert Lavallée,
Research Scientist

By definition, exotic forest pests are diseases or insects that are present outside of their natural range. They are described as “invasive” when they alter the ecosystems into which they are introduced. According to Canadian Forest Service (CFS) researchers, more than 80 exotic pests harmful to Canada’s forests have become established here since 1882. This brochure describes the main exotic pests that are currently being studied at the Canadian Forest Service’s Laurentian Forestry Centre (LFC).

Pathways of introduction

Exotic pests make their way into Canada the same way as any other traveller from abroad: by air, land or sea. These pests may be present in various plant materials (whole plants, seeds, tubers, nursery stock), in logs purchased from abroad and in wood packaging materials, such as dunnage, used to secure cargo. Increases in global trade are providing more opportunities for pests to enter the country.

Exotic Forest Pests 101

“Last stop, everybody out!”

Although a large number of pests reach Canada, very few of them become established here because Canada’s climate, vast land mass and topography generally serve as effective natural barriers to invaders. Furthermore, exotic species have specific requirements and can only establish themselves successfully under certain conditions, such as the absence (or near absence) of predators or competitors, the presence of a compatible host and climatic conditions favourable to their reproduction and survival.

Only a few of the species that become established after introduction can be characterized as invasive. For example, Dutch elm disease has fundamentally altered landscapes, including those of the St. Lawrence Plain and of a number of large Canadian cities. In Quebec alone, 600,000 elms died or had to be felled between 1945 and 1960 as a result of this disease.

An Essential Strategy

To prevent damage by exotic pests, the Canadian Council of Forest Ministers has adopted an Invasive Aliens Species Strategy that is based on the prevention, early detection, rapid response and eradication, containment and control of the invasive alien species that nonetheless succeed in entering the country. The Canadian Food Inspection Agency, the Canadian Forest Service of Natural Resources Canada and Environment Canada are involved in implementing this strategy in the forest and agriculture sectors.

Why should we be concerned about exotic forest pests?

From an ecological standpoint, exotic pests can cause significant damage to native trees and other plants as they lack natural defences against such invaders. In addition to reducing the vigour of trees, they can kill them outright. They can thus change the dynamics and sometimes the balance of ecosystems. Their activity can lead to habitat losses for certain animal species and, in extreme cases, extinctions. Exotic pests also cause a reduction in the aesthetic value of forests, taking a particularly heavy toll on the urban landscape.

The economic impacts of exotic pests are significant, and include the more obvious effects such as the reduction in tree growth and decrease in wood quality, as well as mortality. Other impacts result from the decline in forest sector activities, job losses and international trade restrictions resulting from the imposition of phytosanitary measures. For example, treatment to destroy pinewood nematode in pine intended for export cost a total of $72 million in 1993. Expenses are also incurred for regulations, for research and for monitoring of introduced species (detection, control and containment).

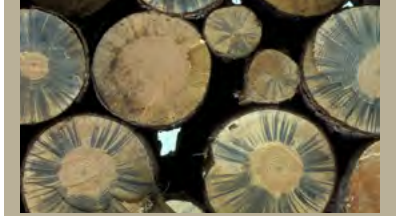
The risks associated with the introduction of exotic species and the associated damage could increase in Canada over the coming years, as a result of increased trade and the limited number of known early detection, control and eradication measures.

Exotic pests and forest certification

All forest certification standards require that managers of certified forest land be familiar with the applicable acts and regulations. With respect to exotic forest pests, certification stakeholders must be familiar with the International Plant Protection Convention, the International Standards for Phytosanitary Measures pertaining to forests and forest products, and the *Plant Protection Act*. Other important regulatory documents in Canada include the Plant Protection Regulations and the directives governing the importation and exportation of plant material and the domestic movement of such material, which establish regulated areas for specific pests. Certain provincial acts also apply to exotic pests.

Focus of research activities

Exotic forest pests have long been a focus of research at the LFC, where Dutch elm disease, beech bark disease, pine shoot beetle and gypsy moth, among others, have been studied. In addition to investigating the biology of these pests, the researchers assess the potential economic, social and ecological risks associated with their presence or introduction. This risk assessment allows them to identify pests that require more stringent monitoring or mitigation measures.



Collaborative Efforts

The Canadian Food Inspection Agency (CFIA) is responsible for developing forest policies and directives aimed at preventing the introduction and spread of regulated pests in Canada, as well as the development of export programs for Canadian forest products. The CFS provides important scientific information supporting the CFIA’s work.

Other research priorities relate to increasing our understanding of the pathways of introduction and the movement of exotic species, together with improving the evaluation of the spread and introduction of invasive pests. Work is also being done to develop models to predict the impacts of emerging invasive exotic species under current and future climatic conditions. These models will help to guide decision making with respect to the measures that need to be implemented.

This research is supported by collaborations with other CFS Centres as well as provincial government and university research institutes.

Alert! Support control measures for exotic forest pests by reporting observations of such pests to the CFIA at 1-800-442-2342

EMERALD ASH BORER
AGRILUS PLANIPENNIS FAIRMAIRE

Hosts: Ashes
Presence in Canada: Ontario and Quebec
Origin: Asia
Year introduced: 2002

This exotic pest poses a serious threat to the economy and the environment in urban and forested areas of the United States and Canada.

The adult beetle is metallic green and 7.5 to 15 mm long.

Since it was first detected in the United States and Ontario in 2002, and then in Quebec in 2008, the emerald ash borer has killed millions of ash trees. This insect attacks healthy ash trees, causing damage that leads to mortality within a few years. It probably arrived in wood packaging material or dunnage on merchant ships and then took refuge in forests and cities. Its subsequent spread was facilitated by the movement of infested firewood and nursery stock.

Female emerald ash borers lay their eggs on the bark surface or in bark crevices on the trunk or branches, from June to August. After about 10 days, the eggs hatch and the larvae bore through the bark and begin excavating meandering galleries, all the while feeding on the inner bark and the outer sapwood. The larvae overwinter under the bark from October to April, after which pupation begins. Adults emerge from June to August. The emerald ash borer may take 1 or 2 years to complete its life cycle.

The presence of woodpeckers in winter and woodpecker holes is often a sign of emerald ash borer attack, as is a thinning tree crown, deformed and cracked bark on the trunk, and vigorous (epicormic) shoots growing on the trunk or branches.

Although the adult insect can fly more than several kilometres, human activities are the main factor in the spread of this pest. It is one of the pests regulated by the CFIA.

Would it be possible to completely eliminate emerald ash borer populations? No, because there is no detection method that can be used to quickly identify trees that have recently come under attack. By the time affected trees are discovered, the first generation of adult beetles is long gone; in fact, they left a year earlier at which time there were few visible symptoms. Since it is very difficult to control the emerald ash borer once it becomes established, it is important to halt its spread and reduce its numbers.

To help keep emerald ash borer populations in check, CFS researchers developed TreeAzin™, a synthetic insecticide that is injected into the bark at the base of ash trees and moves upward with the flow of sap. The active ingredient in this insecticide comes from the neem tree, a species native to India. This product was registered in Canada in 2012.

Sinuous (S-shaped) galleries under the bark.

Research has shown that, in Canada and the United States, nature's own biological control agents play a role in regulating pest populations. It has been observed that, in addition to woodpeckers, some wasp and fungal species kill a portion of the emerald ash borer population.

Potential biological control agents include entomopathogenic fungi, which act like contact insecticides. The fungal spore adheres to and penetrates the insect's cuticle; the fungus produces toxins that kill the insect within a short time. CFS researchers are studying these fungi with a view to developing and making available new pest control products.

Emerald ash borer attacked by an entomopathogenic fungus.

What is a regulated area?

A regulated area is a zone consisting of all or part of a property, a municipality, a county or a province in which the CFIA has prohibited or placed restrictions on movements of plant material in order to prevent the spread of undesirable pests. No one may move regulated pests or any regulated article (logs, firewood, wood chips, seedlings, pruning residues, etc.) out of the regulated zone unless they have been authorized to do so in writing by a CFIA inspector under the conditions provided in a movement certificate. Vehicles used to transport regulated pests are subject to the same conditions. As of September 2012, regulated areas are in effect for the following pests: emerald ash borer, scleroderris canker (European race), pine shoot beetle, brown spruce longhorn beetle, Asian longhorned beetle, Dutch elm disease, hemlock woolly adelgid and gypsy moth.

BROWN SPRUCE LONGHORN BEETLE
***TETROPIUM FUSCUM* (FABRICIUS)**

Hosts: Spruces
Presence in Canada: Nova Scotia
Origin: Europe (from Scandinavia to Turkey), Japan and western Siberia
Probable year of introduction: Beginning of the 1990s
Year discovered in Canada: 1999

Adult beetle, 10 to 15 mm long, with a flattened body.

The larva is 1.5 to 2.5 cm long.

In its native range, the brown spruce longhorn beetle is considered a secondary pest because it attacks trees that have already been subject to other types of insect attack or environmental stresses. When its population increases, this pest may attack healthy trees. In Europe, Norway spruce stands more than 50 years old are particularly susceptible to attack, but firs, pines and larches may likewise come under attack.

In North America, the brown spruce longhorn beetle appears to attack only spruce trees. Although this pest was discovered in Halifax in 1999, researchers suspect that it arrived in Canada in the early 1990s in wood packaging aboard container ships. To date, brown spruce longhorn beetles have been found only in Nova Scotia, and although a single adult beetle was detected in New Brunswick, there was no indication that the pest had spread.

In the spring, female beetles lay eggs in the bark of standing or recently felled trees. About 2 weeks later, the larvae emerge and tunnel into the inner bark. They usually overwinter under the bark, in L-shaped galleries about 2 to 4 cm deep in the sapwood. These galleries, which tend to be concentrated in the lower part of the tree, reduce the quality of the wood.

Pupation occurs the following spring, and adults emerge about 2 weeks later by chewing a round or oval hole in the bark, which may be plugged with coarse sawdust. Adults live for only 2 weeks and are present from June to August.

Resin flows on the trunk, yellowing of foliage in the crown and fungi-induced blue discolouration of the wood are signs of brown spruce longhorn beetle activity.

The LFC and its collaborators, including the Institut national de la recherche scientifique–Institut Armand-Frappier, are currently exploring several avenues of research. For instance, with a view to reducing beetle numbers, they are studying a new biological control approach that involves having the insects themselves disseminate a fungus that can infect them.

More specifically, the researchers modified the base of a Lindgren trap by adding a special autoinoculation chamber. An adult insect is attracted to a specific odour inside the trap and enters this chamber where it becomes contaminated with thousands of spores from a pathogenic fungus. The researchers have demonstrated the effectiveness of this part of the strategy. It is hoped that, before dying, the contaminated insect will have a chance to mate and transmit the fungus to its partners. If this strategy works, the insect will act as a vector of the disease. This approach specifically targets the brown spruce longhorn beetle. Test results are promising but additional field tests are required. They will be carried out in 2013.

“With methods permitting early and rapid detection of pests, we can act more quickly to eradicate infections, determine where the pests come from and where they end up.”

Richard Hamelin, Research Scientist

Effective and Rapid Methods of Detection

Every exotic fungal species that enters Canada poses a serious threat to our forests. Exotic fungi that are harmless in their country of origin can quickly become pathogens of our trees, which have no defence mechanisms against these new pests. Once established, it is difficult, and sometimes impossible, to eradicate them.

LFC researchers are studying tree diseases with a view to checking their spread. To limit the impact of these diseases on forest resources as a whole, it is important to precisely diagnose a disease from the outset. One challenge that researchers face at present consists in correctly identifying species of fungi. Many of these fungi, including *Charala fraxinea*, which causes ash dieback disease, have few distinctive morphological features that can be used for identification.

These species can now be differentiated with the help of a new molecular biology tool: the DNA barcode. It is a short segment of DNA from one or a few genes that contain sufficient variation to permit the rapid and effective identification of individual species. All individuals have an internal genetic label that identifies the species to which they belong, somewhat like UPC barcodes on consumer products.

DNA barcoding is a fast, easy and inexpensive method for identifying genetic differences resulting from the evolution of species. It also helps to overcome the shortcomings of traditional methods of identification based on sometimes indistinguishable morphological features.

DNA barcodes for pathogenic forest fungi may prove to be a powerful identification tool, enabling experts to distinguish between phytopathogenic fungi that have only benign effects on forest trees and those that can cause severe damage to forests in Canada. Researchers have used this type of barcode to identify the fungal species found on poplars that cause poplar leaf rust.

An early warning system based on DNA analysis of asymptomatic plants that are imported into Canada has been put in place. The result of collaboration between the CFS and the CFIA, the system targets live plant material, such as cuttings, seeds, ornamental plants and bonsai. It can be used to detect exotic fungi previously unknown to science and to carry out a summary evaluation of the risk they pose to our forests.

Detection methods aim to prevent the accidental introduction into Canada of exotic fungi such as Chalara fraxinea, *which induces the formation of cankers on the trunk of ash trees.*

“Diseases that may ravage our forests in the future are currently slumbering within their hosts. If they are accidentally introduced into Canada, we must be able to correctly identify them to protect our forests more effectively. This is a significant challenge that research scientists need to tackle.”

Jean Bérubé, Research Scientist

BUTTERNUT CANKER

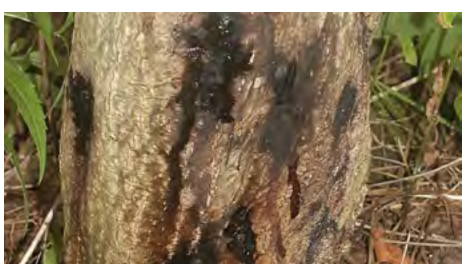
***SIROCOCCUS CLAVIGIGNENTI-JUGLANDACEARUM* (N.B. NAIR, KOSTICHKA & J.E. KUNTZE) BRODERS & BOLAND**

Host: Butternut
Presence in Canada: Quebec, Ontario and New Brunswick
Origin: Unknown
Year introduced: Unknown

Butternut canker first infects the lower crown of a tree and then spreads downwards. In spring, an inky-black fluid exudes from cracks in the canker. In summer, the cankers appear as sooty black patches, often with a whitish margin. Peeling the bark away reveals brown to black areas. Older cankers are found in bark crevices or loosely covered with shredded bark.

The continuing spread of butternut canker is the primary threat to the survival of butternut, which has been protected under the *Species at Risk Act* since 2003. Conditions favouring the growth and establishment of butternut trees are becoming increasingly rare, because butternut are found in mature forests with an increasingly closed canopy.

Controlling butternut canker is a challenging task. LFC researchers have proposed a variety of measures aimed primarily at protecting healthy trees by promoting vigorous growth and seed production. Opening up the canopy around butternuts increases their exposure to sunlight and allows them to occupy a dominant position favouring their growth. The effect of this opening of the canopy on the health of butternut is currently under study. To ensure adequate seed production, silviculturists recommend maintaining a density of about 10 butternut trees per hectare and creating stand openings of a size equal to twice the height of the surrounding trees to promote seed germination.



Practical measures recommended for forest stands are as follows.

- Remove infected trees as quickly as possible to limit the spread of the disease.

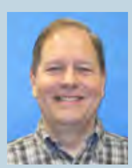
- Remove all the trees with more than 30% crown dieback and more than 20% of the circumference of the main stem cankered, as well as trees with more than 50% crown dieback, even if the stems are not cankered.

- Prune the affected branches on high-value trees.

It should be noted that on federal lands, a permit must be obtained before any intervention involving butternut can be carried out.

Harvesting of uninfected trees may accelerate the disappearance of this species and significantly reduce the existing genetic pool of resistant butternut. Important conservation efforts are therefore needed to locate and protect uninfected butternut trees. Efforts should be devoted to exploiting the genetic resistance to canker that is believed to exist in part of the butternut population. Research is currently under way at the LFC to find potentially resistant trees and to assess their resistance.

"Protecting butternut will require considerable attention; this noble deciduous species, which is prized for its wood and nuts, is an important part of forest biodiversity, and deserves the efforts devoted to its preservation."



Pierre DesRochers,
Coordinator, Forest Health

SCLERODERRIS CANKER, EUROPEAN STRAIN

***GREMMENIELLA ABIETINA* VAR. *EU* (LAGERBERG) MORELET**

Hosts: Pines
Presence in Canada: Eastern Canada
Origin: Asia and Europe
Year introduced: Unknown
Year identified: 1974

Scleroderris canker is a serious disease of natural forests, plantations and nurseries. There are two distinct races of the causal fungus in eastern North America: the American strain and the European strain. In both cases, infection begins with browning of the needles, which kills the buds on the affected shoot; the dead needles are loose and tend to drop off the branches and collect on the ground. The shoot subsequently turns greenish yellow under the bark and dies. Tiny black dots can be seen at the base of needles or dead twigs. The disease spreads down into the main stem, where a canker may form. The European race, which is more virulent than the North American race, can cause an infection that spreads throughout the crown. A canker forms when the disease reaches the trunk. Under favourable conditions, the European strain can kill affected trees over a few years.

The chief mode of infection is through the dispersal of fungal spores to pine needles under moist conditions, primarily in June and July.

Although infection may be initiated during the growing season, the disease cannot progress rapidly until winter, when the cool, moist conditions favour the establishment of the disease.

In the early 1980s, foresters expressed concern about the spread of scleroderris canker in red pine plantations in the Hautes-Laurentides and Outaouais regions. At that time, LFC researchers developed a treatment to halt the spread of the disease. The treatment consists in systematic pruning of branches in the lower half of the tree and, if necessary, the lower two thirds in infected plantations that are less than 20 years old. The pruned branches can be left on the ground, but dead trees in the plantation should be felled because standing dead trees help to maintain the reservoir of pathogens present on the site. This simple approach leads to the eradication of scleroderris canker on a given site after a few years, because the disease can only spread over short distances (less than 5–10 m).

SUDDEN
OAK DEATH
PHYTOPHTHORA RAMORUM **WERRES, DE COCK & MAN IN'T VELD**

Hosts: A number of tree species, including some oaks, ashes, maples and firs
Presence in Canada: Detected in some nurseries in British Columbia
Origin: Unknown

Dead oaks in California.

Bark lesion on a tanoak.

Bleeding canker on a tanoak.

Organ containing spores that spread the disease (small arrow) and thick-walled spore that can persist from year to year (large arrow).

Sudden oak death disease is well-established in the western United States, particularly in the state of California, where it has destroyed many stands of oak and tanoak. Although major phytosanitary measures have been implemented across North America, concerns persist about the ability of the disease to become established in eastern North America.

In natural forests, the disease occurs in two forms. Rarely lethal, the foliar form causes browning of the leaves and sometimes twig dieback. Affected plants, such as the California bay laurel, are a source of inoculum and play an important role in spreading the disease. The second form, which is usually lethal, is manifested by bleeding cankers that form on the trunk or branches, usually 1 to 2 m above the ground.

A reddish brown or nearly black liquid seeps from wounds in the bark. Cankers are generally found on oaks and other trees that are at least 10 cm in diameter; they produce few spores. These cankers girdle the stem, eventually killing the tree.

Since 2003, infected material from California, among other places, has been identified in a few nurseries in British Columbia. Destruction, quarantine and disinfection measures have prevented the disease from becoming established in natural forests.

Close collaboration between the CFIA and the CFS has made it possible to establish a clear picture of the extent of the problem and to consider adequate prevention and detection measures. An effective detection method using molecular tools has been developed at the CFS. Although the risk of introduction was determined to be high, the overall risk was deemed moderate for British Columbia and low for eastern Canada. The assessment of the overall risk takes into account climatic conditions, the risk of spread and potential economic and environmental impacts. For Canada, these impacts range from moderate (British Columbia) to low (eastern Canada).

LFC researchers have studied the susceptibility of the foliage of certain trees in eastern Canada to sudden oak death. The results show that under favourable temperature and moisture conditions, often present in eastern Canada, white ash, yellow birch, balsam fir and larch are the most susceptible species. These potential hosts could act as inoculum reservoirs and therefore present a risk of spreading the disease.

"Eradication from the natural environment is generally not feasible: the spores survive for months in the ground or in plant debris and can also be transported hundreds of metres by strong winds."

Danny Rioux, Research Scientist

ANNOSUS ROOT AND BUTT ROT
HETEROBASIDION IRREGULARE
(UNDERW.) GARBEL. & OTROSINA

Hosts: All pines, but red pines and ponderosa pine especially
Presence in Canada: Ontario and Quebec
Origin: Mexico and the United States **Year detected in Quebec:** 1989

The causal fungus of annosus root and butt rot enters a pine stand by colonizing freshly cut stumps. The disease spreads through contact between the roots of infected stumps and the roots of healthy trees. This radial spread, which occurs at a rate of about 1 metre per year, results in a roughly circular patch of dead trees after a few years. The French common name of the disease, "maladie du rond," comes from the circular areas of mortality. Annosus root and butt rot is spreading northward in Quebec at a rate of about 10 km/year. Fruiting bodies, or conks (visible part of fungus), which form at the base of infected trees or stumps; root rot; and windthrow caused by decay in the structural roots are signs of the pathogen's presence in a stand.

In Quebec, approximately 1 million red pines are planted annually. At present, a number of plantations are due to undergo thinning. Silvicultural operations of this type or damage caused to trees during these operations can exacerbate the problem of annosus root and butt rot. CFS researchers have estimated that the disease kills trees within 5 to 8 years after a thinning operation is carried out in a plantation. Since disease spread is greater in late summer and in fall, silvicultural operations should be carried out in the winter, when the stumps are covered with snow.

When silvicultural operations are carried out in plantations infected with annosus root and butt rot, the freshly cut stumps must be treated. If there are only a few infected stumps, they can be extracted and destroyed. Since the stumps are very difficult to burn, it is better to bury them in a location where the water table is high. One way to prevent the spread of annosus root and butt rot is to dig a trench 60 to 80 cm deep around the affected zone. Since these solutions are costly, they can only be envisaged on a small scale. Consideration should also be given to converting the site to hardwood species, because conifer seedlings succumb rapidly to the disease, which is ever-present on the site.

When inspecting a red pine plantation for annosus root and butt rot, the first thing to look for is crown dieback (red or short needles) or thin foliage in the crown. This monitoring effort should be carried out in September, October or November, when the most obvious signs of the disease—the fruiting bodies—are present. It is important to check for fruiting bodies at the base of dead or declining trees or nearby stumps; they may be concealed in the litter.

Once annosus root and butt rot becomes established in a stand, it is very difficult to eradicate it because the fungus can persist in the roots for decades. Furthermore, in the first 2 weeks after a tree is felled, *Heterobasidion irregulare* has free reign to colonize the stump because very few competing fungal species seek to do so. Treating stumps with a protective product immediately after cutting is recommended as a routine practice to prevent stump infection by the causal pathogen. This treatment should become a standard practice to slow the spread of the disease.

At present, there are no products registered specifically for the control of annosus root and butt rot in Canada. LFC researchers have developed a product consisting of *Phlebiopsis gigantea* (which does not harm trees) spores harvested in Canada that can be sprayed on stumps to protect them. An application for the registration of this product is currently being processed by the Pest Management Regulatory Agency; it can be sprayed manually or applied mechanically during forestry operations by means of a distributor attached to the tree feller. In several European countries, pines have been successfully protected by spraying an aqueous solution of *Phlebiopsis gigantea* spores onto stumps.

POPLAR LEAF RUST
***MELAMPSORA LARICI-POPULINA* KLEB.**

Hosts: Poplars
Presence in Canada: Invasive in eastern Canada
Presumed origin: Eurasia

Leaf rust is the most prevalent disease of poplars around the world. It causes poplar leaves to drop early and reduces growth in affected trees, leading to mortality in the most severe cases. Rust diseases are caused by members of the lower fungi that require an alternate host plant to complete their life cycle. In the case of poplar leaf rust, larch serves as the alternate host.

Researchers with the Laurentian Forestry Centre and the ministère des Ressources naturelles du Québec conducted a study on two poplar leaf rust species in plantations and nurseries throughout Quebec: an indigenous species (*Melampsora medusae* f. sp. *deltoidae*) and a species native to Europe (*Melampsora larici-populina*) which was recently discovered in Quebec. The European rust, found in Quebec for the first time in 2002, appears to have spread rapidly in nurseries and plantations in most regions of Quebec, except the Abitibi-Témiscamingue region. Some fast-growing poplar clones, propagated in nurseries and then outplanted, were found to be resistant to the indigenous rust but showed a high level of susceptibility to the European rust.

LFC researchers have developed a detection method. This approach, which uses genetic markers developed from the analysis of the DNA of the yellow-orange rust pustules, circumvents several problems that hampered the investigation of this disease in the past. To identify this rust disease by the conventional method, it is necessary to culture the causal fungi by infecting poplar leaves or young seedlings, a process that must be repeated for each sample, making the procedure very time-consuming.The new method using DNA markers makes it possible to process a large number of samples much faster.

"In natural forests, poplar leaf rust causes damage that is considered minor. However, in nurseries and plantations of fast-growing poplar, this fungal pathogen can cause significant damage."

Philippe Tanguay, Research Scientist

WHITE PINE BLISTER RUST

CAUSAL FUNGUS: *CRONARTIUM RIBICOLA* J.C. FISCH.

Host: White pine
Presence in Canada: Across Canada
Presumed origin: Asia
Year introduced: Beginning of the 20th century

White pine blister rust is particularly common in plantations. For example, in 2010, 68% of Quebec's eastern white pine plantations were found to be infected.

In the fall, the causal fungus, which is present on *Ribes* spp. (currants/gooseberries), infects pine needles, which become covered with yellow spots the following spring. The fungus spreads toward the branches and the trunk, eventually giving rise to a canker that may initially appear as a swelling. In mid summer, about two or three years after infection, orange pustules form on the canker and produce an exudate containing a first type of spores that attract insects. The fertilized spores induce the formation of white blisters the following spring. At maturity, these blisters burst and discharge orange spores that are dispersed by the wind over long distances, eventually infecting the leaves of *Ribes* species. In late summer or early fall, filamentous fruiting bodies develop on the underside of the leaves of this host. Unlike the spores produced on pine, the spores released from these fruiting bodies are transported only over short distances; these spores infect the needles of eastern white pine. The cankers that form on white pines are perennial and enlarge from year to year. The pathogen spreads radially, producing fruiting bodies on the margins of the canker, which eventually girdles and kills the infected part of the tree. Tree mortality occurs when a canker girdles the main stem.

Cool, moist conditions are required for the production of rust spores on *Ribes* species that can infect eastern white pine. In general, sites where *Ribes* species are abundant should be avoided. During site preparation work, harvest residues should not be windrowed because this technique promotes the growth of *Ribes*.

A manageable disease

It is important to monitor the plantation following reforestation with eastern white pine in order to control the disease. CFS researchers recommend inspecting the plantation for signs of blister rust when the trees reach their sixth year. The inspection should be carried out in May or June, which is when infected needles turn red. If the plantation is established in a high rust hazard zone, the inspection can be carried out earlier. The goal is to determine the rate of infection and, if necessary, to recommend a suitable pruning height. If the rate of infection rises above 8%, systematic pruning of lower branches is recommended to limit the spread of the disease. Pruned branches can be left on the ground because the fungus can only persist on living material and cannot spread from pine to pine. Trees with an infected bole should be felled.

Breeding research aimed at increasing white pine resistance to blister rust has been carried out for more than half a century in Ontario and Quebec. A number of hybridization experiments with five-needle pines (including crosses between *Pinus wallichiana* and eastern white pine) have made it possible to induce blister rust resistance in eastern white pine. Other characteristics, such as cold hardiness, have also been studied in the hybrids.

From left to right: healthy white pine, white pine recently killed by rust and white pine killed by rust a few months ago.

"To reduce the risk of rust infection, it is important to select a suitable planting site. This includes sites with well-drained soil, such as on upper slopes, especially those with a southern exposure. Flat, well-aerated sites that are exposed to air currents favouring rapid evaporation of morning dew are also suitable."

Gaston Laflamme, Research Scientist

Planting blister rust-free seedlings

Although using blister rust-free planting stock may seem like a straightforward way to prevent the spread of the disease, the solution is not that simple. White pine blister rust spreads slowly in host tissues: it takes at least two years for signs and symptoms to appear. Every year, some 2 million eastern white pine seedlings are produced for reforestation use in Quebec. Although nurseries implement preventive measures, an outbreak could occur and infected seedlings could be delivered and planted without anyone knowing since they would be asymptomatic at that time.

CFS researchers have developed a test that can be used to detect blister rust in pine tissues before the symptoms have a chance to appear. This test, which is based on the DNA fingerprint of the causal pathogen, was introduced in 2011 and it has been used ever since to support the issuance of phytosanitary certificates for white pine seedlings produced at six forest nurseries in Quebec.