2025 NCF-Envirothon Alberta

Current Issue Part A Study Resources

Key Topic #2: Forest Health in a Changing Climate

5. Explain how globalization has enabled the spread of invasive insect species and impacted the world's forests.
6. Describe how wildfire impacts the hydrology, wildlife, and soils of forest communities.
7. Describe the conditions of drought as it relates to forest ecosystems, and identify how increasing drought severity and frequency impacts global forests.
8. Explain the biology and impacts of typical forest insect pests such as Mountain pine beetle, Spruce beetle, Spruce budworm, Forest tent caterpillar, Emerald ash borer, and Asian longhorn beetle.
9. Describe biology and impacts of typical forest diseases such as Western gall rust, Armillaria root rot, needle casts and needle rusts.
10. Describe how the prevalence and spread of forest pests and diseases are expected to shift with climate change.

Study Resources

Resource Title	Source	Located on
Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts	*Ramsfield et al. - Forestry: An International Journal of Forest Research, 2016*	Pages 32 - 33
How Does Wildfire Impact Wildlife and Forests	*Meghan Snow – US Fish and Wildlife Service, 2022*	Page 34
Forest Pest Management	*Natural Resources Canada, 2015*	Pages 35-42
Biotic Pathogens	*Natural Resources Canada, 2015*	Pages 43-46
Forest Pests and Climate Change	*Climate Atlas of Canada, 2024*	Pages 47-48
Shape-shifting forests: A tale of climate, wildfires, and surprising outcomes	*Natural Resources Canada, 2024*	Pages 49-50
Drought	*Natural Resources Canada, 2024*	Pages 51-53

Study Resources begin on the next page! ➡

Forestry An International Journal of Forest Research

Institute of Chartered Foresters
INTERNATIONAL UNION OF FOREST RESEARCH ORGANIZATIONS

Forestry 2016; **89**, 245–252, doi:10.1093/forestry/cpw018
Advance Access publication 22 March 2016

Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts

T.D. Ramsfield[1]*, B.J. Bentz[2], M. Faccoli[3], H. Jactel[4] and E.G. Brockerhoff[5,6]

[1]Canadian Forest Service, Northern Forestry Centre, 5320-122 Street NW, Edmonton, AB T6H 3S5, Canada
[2]USDA Forest Service, Rocky Mountain Research Station, 860 N. 1200 East, Logan, UT 84321, USA
[3]Department of Agronomy, Food, Natural Resources, Animals and Environment, University of Padua, Viale dell'Università, 16-35020 Legnaro (PD), Italy
[4]INRA, BIOGECO, UMR1202, Cestas, France
[5]Scion (New Zealand Forest Research Institute), PO Box 29237, Christchurch 8540, New Zealand
[6]Better Border Biosecurity Collaboration, New Zealand

*Corresponding author. E-mail: tod.ramsfield@canada.ca

Received 19 February 2016

Forests and trees throughout the world are increasingly affected by factors related to global change. Expanding international trade has facilitated invasions of numerous insects and pathogens into new regions. Many of these invasions have caused substantial forest damage, economic impacts and losses of ecosystem goods and services provided by trees. Climate change is already affecting the geographic distribution of host trees and their associated insects and pathogens, with anticipated increases in pest impacts by both native and invasive pests. Although climate change will benefit many forest insects, changes in thermal conditions may disrupt evolved life history traits and cause phenological mismatches. Individually, the threats posed to forest ecosystems by invasive pests and climate change are serious. Although interactions between these two drivers and their outcomes are poorly understood and hence difficult to predict, it is clear that the cumulative impacts on forest ecosystems will be exacerbated.

Introduction

There is growing recognition among the scientific community and policy makers that sustainable forest management is affected by multiple factors associated with global change. Exponential population growth has resulted in the addition of 1 billion people between 1999 and 2012, leading to a global population of over 7 billion people that must be sustained by Earth's resources. Forests are of vital importance to humanity as they provide a wide range of essential ecosystem services (e.g. fuelwood, fibre, carbon sequestration etc., see Thompson et al., 2011) but the ongoing loss of forest cover means the increasing demand must be met from an ever shrinking resource (Brockerhoff et al., 2013). Concomitant with population growth has been the expansion of global trade networks and an increase in the volume of traded goods (e.g. Hulme, 2009). This has led to a considerable increase in the establishment of populations of non-native species in virtually all parts of the world (e.g. Roques et al., 2009; Aukema et al., 2010; Wingfield et al., 2015). While many of these species appear to be relatively benign, some have major deleterious impacts on trees in natural and managed ecosystems, as well as urban environments. For example, the invasive emerald ash borer has been devastating ash trees in North America (Poland and McCullough, 2006) and *Phytophthora ramorumis* causing dieback and mortality of a wide range of tree species in Europe and North America (Gru¨ nwald et al., 2012). Climate change can exacerbate invasions of forest pests as well as impacts of native pests. For example, climate change can facilitate the range expansion of both native and exotic pests (insects and pathogens), or affect tree resistance to pests (Jactel et al., 2012a), and there is increasing evidence that this is a widespread phenomenon (Battisti et al., 2005; Marini et al., 2012; Anderegg et al., 2015). Using the planetary boundaries approach of Steffen et al. (2015), Trumbore et al. (2015) identified that the main stressors of the world's forests today are invasive species and diseases as well as climate change, along with deforestation and the increasing demand for forest resources. An additional contributor to forest health problems is the ongoing intensification and mechanization of forest management which has increased the vulnerability of forests to disturbance from biological invasions, climate change and other stressors (Seidl et al., 2011). However, there is increasing recognition that forest management can be adapted to increase the resistance and resilience of forests to disturbance (Jactel et al., 2012b; DeRose and Long, 2014; Bahamondez and Thompson, 2016, this issue).

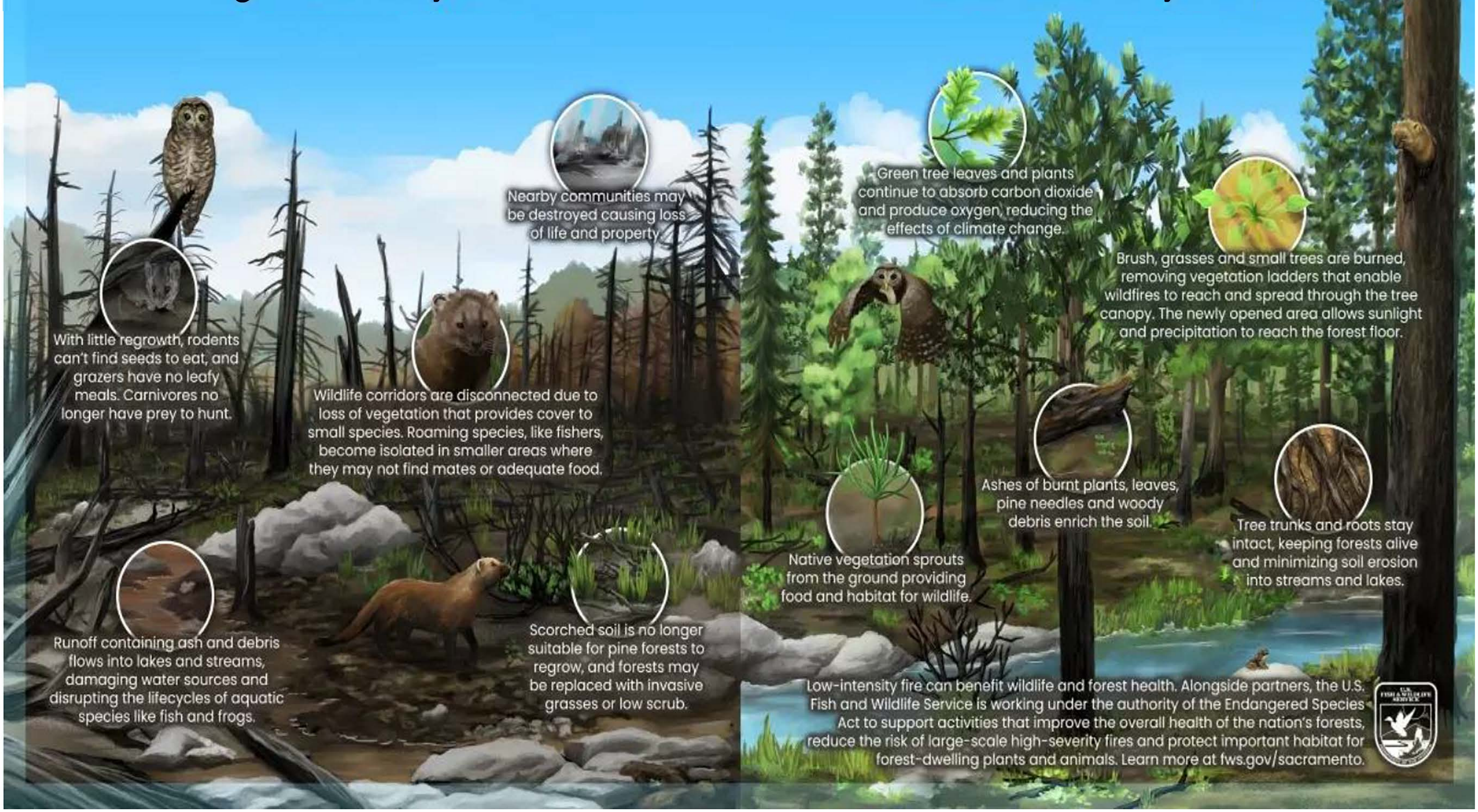
How does fire impact forests and wildlife?

Wildfires are inevitable, but not all fire is harmful to forests. Low-intensity fires can naturally "clean" and thin the forest by removing flammable and thick vegetation on the forest floor. The result is improved habitat for wildlife, healthier soil and new growth of native plants.

It also helps reduce the risk of large-scale high-severity fires that burn through the forest—from the floor to the canopy—with intense heat. High-severity fires across large landscapes can be devastating for wildlife, habitat and surrounding communities.

High-Severity Fire

Low-Intensity Fire



Government of Canada / Gouvernement du Canada

Forest pest management

Native insects and diseases play an essential ecological role in Canada's forests.

By consuming trees and other plant material, forest insects and micro-organisms contribute to healthy change and regeneration in forest ecosystems. They help renew forests by removing old or otherwise susceptible trees, recycling nutrients and providing new habitat and food for wildlife.

However, it's not for their ecological benefits that forest insects and diseases sometimes make national news. When infestations are so severe they destroy or damage large areas of commercially valuable forest, or infest Canadian forest products bound for export, then insects and diseases—whether native or alien—become "pests."

Mountain pine beetle, spruce budworm, and Dutch elm disease are all examples of well-known forest pests that have led to significant losses in value of Canadian forests.

What's what: native, alien, invasive

Forest insects and diseases in Canada are typically classified into three broad categories:

- Native: Indigenous species that have existed in Canada for thousands of years. Outbreaks occur periodically. Examples are spruce budworms and mountain pine beetle.
- Alien: Species introduced into Canada's forests within recent history. They are also referred to as "exotic," "non-native" and "foreign." Examples include emerald ash borer, brown spruce longhorn beetle and Dutch elm disease.
- Invasive: Insects and diseases that spread beyond their known usual range.

Both terms, "alien" and "invasive," refer to shifts from one ecosystem to another, not to shifts across national borders. So, even organisms that move into new ecosystems within the same country can be considered alien and invasive if they extend beyond their usual geographic range. The spread of mountain pine beetle from British Columbia's lodgepole pine forests to Alberta's jack pine forests is an example of a native forest insect behaving invasively.

From friend to foe

Native forest insects and diseases are generally of little concern when they exist at non-damaging population levels.

It is when populations of these native species increase beyond an acceptable threshold, or when alien or native species behave invasively that concerns arise. If ecological or economic damage results in measurable impacts—such as a decline in ecosystem health or large reduction in the available wood fibre—then the insect or disease outbreak is seen as being a disturbance and active management intervention may be considered.

The challenge for forest resource managers is therefore two-fold. First is to assess the risks posed by potential and actual outbreaks and spread. Second is to apply risk-based decision-making to manage forest ecosystems in a way that minimizes the negative impacts of outbreaks and maximizes the positive impacts.

Mountain pine beetle

Dendroctonus ponderosae

Distribution

Saskatchewan, Alberta, British Columbia.

Present in most lodgepole pine forests of British Columbia, adjacent, central and northern Alberta, and in isolated locations in southwestern Saskatchewan. The geographic range has been expanding northward and eastward for the past decade.

Micro-habitat(s)

Trunk, Bark

Biology

The mountain pine beetle has a life cycle that normally lasts one year. In late summer, the adults emerge from the trees in which they feed and develop and fly off in search of new hosts, into which the females bore waiting for males to come to them. The females bore vertical galleries just under the bark, in which they lay their eggs. The larvae that emerge from the eggs spend the winter feeding under the bark. Adult emergence takes place between July and September.

A key stage in the life cycle occurs when the beetle transmits a blue stain fungus to the tree. Attacking beetles carry the spores of the fungus, which gain entry to the tree and eventually overcome its defense system and its ability to withstand beetle attack.

The mountain pine beetle and associated blue stain fungi (*Ascomycetes*) act together to kill trees. Adults transport spores of the blue stain fungi to new trees within a specialized sac (mycangium) on the maxillary cardine. These fungi are believed to stop water transport in the stem and thus kill infected trees.

Although the mountain pine beetle has many natural enemies including insect predators, parasitoids, and woodpeckers, these do not have sufficient impact on incipient and outbreak populations to exert effective control.

Damage

Infested trees can be detected through crown and external symptoms. The first signs are boring dust and resin on the bark associated with the attacking adults, but the mountain pine beetle can only be positively identified (and the success of an attack can only be positively determined) by looking under the bark.

At low (endemic) populations the mountain pine beetle survives in weakened or stressed trees. As populations increase or more trees become stressed because of drought or other causes, the population may quickly increase and spread. Healthy trees are then attacked and huge areas of mature pine stands may be threatened or killed. Warm summers and mild winters play a role in both insect survival and the continuation and intensification of an outbreak. Adverse weather conditions (winter low of -40°C or high winds during dispersal period) can reduce the beetle populations and slow the spread, but insect populations may recover (not the individual insects) and resume their attack on otherwise healthy forests.

Aerial detection of successfully attacked trees is possible as early as late spring (more typically mid-summer) in the year following attack. Detection of small groups of red-topped trees should be followed with ground inspection to verify cause.

The current outbreak in BC is starting to wane. MPB populations are likely to continue to spread eastward through jack pine and are unlikely to be stopped by an occasional cold winter. Over the last decade the insect's range in northern Alberta has expanded annually, despite several cold winters.

Symptoms

Accumulations of pitch or sawdust are conspicuous around entrance holes bored into the bark of trees by adult beetles from mid-July to early September. Sawdust is quickly blown or washed away, but abundant pitch tubes may remain for more than a year after attack. Pitch tubes may be much less evident on trees under severe drought stress prior to attack.

During the fall and winter after attack, woodpeckers feed on bark- and wood-boring insects on infested trees. Trunks of trees foraged on by woodpeckers are easily visible as much bark is stripped off and bark fragments accumulate in piles on the ground at the base of trees. Removal of bark from infested trees reveals adult egg galleries, larval feeding galleries, and one or more life stages (eggs, larvae, pupae, adults), depending on the time since attack. Egg galleries are 10–41 cm (average, 28 cm) long, oriented vertically on the stem, and have a short curved or diagonal section at the bottom.

Grayish blue staining of sapwood, caused by colonization of ray parenchyma cells by blue stain fungi transmitted by adult beetles, provides a conspicuous symptom shortly after successful attack. Various fungal fruiting structures (such as synnemata and perithecia) and mycelia of blue stain fungi and other fungi are often evident in beetle galleries and pupal chambers.

Tree foliage begins to dry out as soon as the conduction of water up the tree is interrupted. As a result, the colour of the foliage on infested trees gradually changes from bright to dull green. This early symptom in the lower crown will often become visible 2-3 months after attack. However, more distinct colour changes occur during the onset of the growing season the spring following attack when tree foliage turns brick red. The needles of infested trees first turn a faint yellow and then a reddish brown by late summer, which allows easy detection; however, by the time trees prominently display these symptoms, they are typically vacated by the mountain pine beetle, which has moved on to attack other trees. With time, retained foliage colour becomes more dull, and most of the foliage drops in 2-3 years; this will vary from species to species and with weather conditions. These rapid and distinct colour changes are used to schedule aerial mapping of recently attacked trees.

Diet and feeding behavior
Phloeophagous: Feeds on phloem.

Brown spruce longhorn beetle

Tetropium fuscum (Fabricius)

Distribution

Nova Scotia

Micro-habitat(s)

Bark

Biology & Damage

The adult has a flattened body, 1 to 1.5 cm long. The head and neck area are dark brown to black. The elytra (wing covers) can be tan, brown or reddish brown and have 2 to 3 longitudinal stripes. The antennae are red-brown and about half of the body length. The legs are dark brown. The egg measures one mm long, is oblong and white with a tinge of green. The larvae is yellow-white, about 14 to 28 mm long, and slightly flattened. The larva's head is reddish and about half of the body. The head is reddish brown and about 3 mm wide. The pupa is white and measures 10 to 17 mm long and 3.8 mm wide.

In the spring, female beetles lay eggs in the bark of standing or recently felled trees. Eggs are usually laid singly, but sometimes in clusters of up to ten eggs. Larvae hatch 10 to 14 days later, and bore into the phloem to feed, producing a network of irregular tunnels packed with sawdust-like frass (excrement).

Most *T. fuscum* overwinter as prepupal larvae either under the bark or in characteristic L-shaped pupal cells about 2-4 cm deep in the sapwood. Pupation occurs in spring and adults emerge about 14 days later, chewing a round or oval exit hole in the bark about 4-6 mm in diameter. The adults live approximately two weeks and can be found from June to August. Both males and females are strong flyers.

Over most of the range of spruce in Canada, the BSLB would likely have one generation per year.

In its native range BSLB is recognized mainly as a secondary forest insect, attacking trees that have already been subjected to other types of insect attack or environmental stresses. During a population outbreak, beetles can attack living, healthy trees. Outbreak levels have the potential to persist for a decade and continually cause damage over extensive tracts of vulnerable conifer forest. In Europe, *T. fuscum* often attacks stands of Norway spruce over 50 years of age. Tunnels in the wood as a result of larval feeding reduce timber quality.

Symptoms

- streams of resin scattered along the trunk
- holes in the bark about 4 mm across
- networks of feeding tunnels just under the bark, up to 6 mm across;
- tunnels in the wood about 4 cm deep and 6 mm wide. These tunnels appear L-shaped when the wood is cut longitudinally.
- Coarse sawdust may be found in and around tunnels or plugging the exit hole.

Other information

This insect is native to Europe, where it can be found from Scandinavia to Turkey. It is also known from Japan and western Siberia. The find in Nova Scotia is believed to be the first discovery in North America.

In March, 1999, the brown spruce longhorn beetle (BSLB), *Tetropium fuscum* was found in dying red spruce trees in Point Pleasant Park, Halifax, Nova Scotia. The following summer, the Canadian Forest Service (CFS) reared over 40 *T. fuscum* adults from red spruce bolts collected in the park. Subsequent investigations by the CFS concluded that *T. fuscum* was also attacking apparently healthy trees. Specimens collected in the park in 1990, originally identified as a related native species (*Tetropium cinnamopterum*) have also now been confirmed as *Tetropium fuscum*. Some fungi such as *O. tetropii* or *Pesotum fragrans*, have been isolated from brown spruce longhorn beetles or from boles infested by this insect. These fungi are not considered as being pathogenic.

Diet and feeding behaviour

Phloeophagous: Feeds on phloem.

Borer: Bores into and feeds on the woody and non-woody portions of plants.

Spruce budworm
Choristoneura fumiferana (Clemens)

Distribution
Canada

Micro-habitat(s)
Needle, Bud, Male flower, Cone

Damage, symptoms and biology
Spruce budworm damage appears in May. Evidence of a spruce budworm infestation includes the destruction of buds, abnormal spreading of new twigs, defoliation of current-year shoots and, if an affected branch is disturbed, the presence of large numbers of larvae suspended from strands of silk.

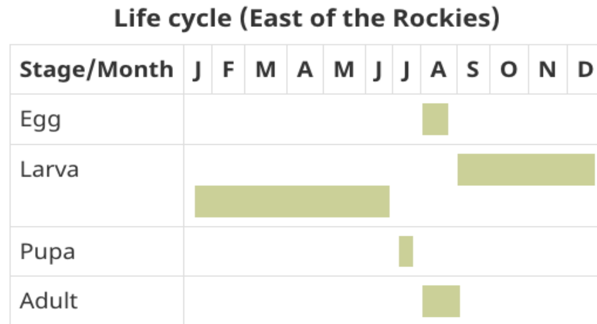
Defoliation begins at the top of the tree and quickly progresses to the periphery of the crown from the top downwards. Current-year needles are partially or completely consumed and, if large numbers of larvae are present, previous-year needles may also be affected. Spruce budworm larvae also feed on staminate (male) flowers and cones. During epidemics, the larvae may destroy all of the cones.

Severely affected stands turn a rust colour due to the presence of dried out needles held by strands of silk spun by the larvae. In the fall, most dead needles are dispersed by the wind and defoliated stands take on a greyish appearance.

A single year of defoliation generally has little impact on the tree. However, it does cause weakening of the tree, making it more susceptible to attacks by other insects. Defoliation over a few consecutive years causes tree growth loss. However, if defoliation of current- and previous-year shoots continues uninterrupted over several years, some trees will die, while others will continue to gradually decline for several years, even after the end of the infestation. This is the case with fir, the species most vulnerable to spruce budworm attacks, which dies after four consecutive years of severe defoliation.

In July and August, the female deposits her eggs in clusters of 10 to 30 under the needles of shoots, preferring those exposed to sunlight. The newly hatched larvae move towards the interior of the crown in search of a suitable overwintering site and construct a silken shelter, called a hibernaculum.

Life cycle (East of the Rockies)



Other information
A native species, the spruce budworm is considered the most serious pest of fir and spruce forests in North America. Its range coincides with that of fir, white spruce, and more and more with the range of the black spruce.

Radial growth analyses of trees have shown that cyclical invasions likely occurred between the 18th and 20th centuries. Spruce budworm populations are believed to have fluctuated during this period at intervals of 30 to 40 years. Since the beginning of the 20th century, three invasions have occurred in eastern North America.

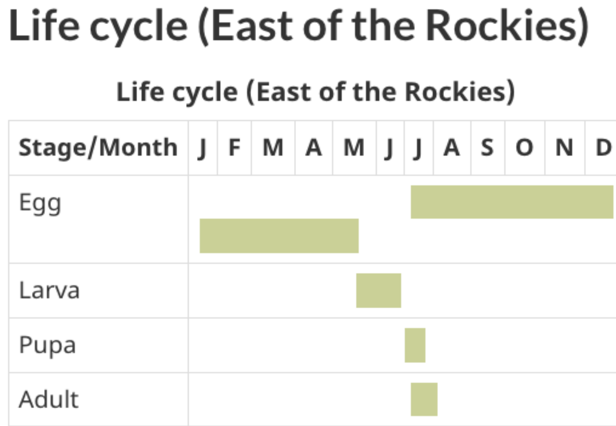
The spruce budworm is generally found in large fir stands. Much research has been conducted on this insect by the Canadian Forest Service and it is being monitored by the provincial forest departments. Most control methods mentioned in the recent literature involve the use of biological insecticides, primarily *Bacillus thuringiensis var. kurstaki* (B.t.k.).

Through a combination of annual surveys, prediction models, targeted control strategies and proper forestry practices, it is now possible to reduce economic losses caused by spruce budworm outbreaks.

On isolated or ornamental trees, vigorously shaking the tree or spraying with a powerful water jet will cause the larvae to drop to the ground. On small trees, the larvae can be removed by hand.

Diet and feeding behaviour
Heteroconophagous: Feeds occasionally on seeds and cones, but usually lives and feeds on stems and needles.
Phyllophagous: Feeds on the leaves of plants.
Webworm: Spins a silk shelter in which to hide or feed.
Pollinivorous: Feeds on pollen.

Forest tent caterpillar
Malacosoma disstria Hubner



Distribution
Canada

Micro-habitat(s)
Leaf

Damage, symptoms and biology
Defoliation is caused by the caterpillar, which begin to feed on the new leaves as soon as they appear in May. Given this insect’s voracious appetite and gregarious behaviour throughout most of its development, its presence can be quickly detected. Older larvae devour entire leaves and, when the tree is completely defoliated, migrate in search of other sources of food. Larvae can also be observed in colonies on tree trunks sheltered from the sun’s rays.

During massive invasions, trees can be completely defoliated over large areas. Even when severely defoliated, trees withstand infestations relatively well. Infestations generally last no more than three consecutive years. However, on trembling aspen, radial growth loss and twig dieback occur. Denuded trees will produce another crop of leaves during the season.

In the fall, the presence of egg bands, which resemble spongy, brownish masses, can be easily detected on small branches and twigs. In late June, the female deposits between 150 and 350 eggs in masses that encircle the twigs. The embryo develops over the course of the season and overwintering takes place as a fully developed embryo within the eggshell.

Other information
A species native to North America, the forest tent caterpillar is the most widespread defoliator of deciduous trees. Its range extends from coast to coast.

The insect has been known for many years and the first outbreak was recorded in 1791. Since then, the forest tent caterpillar has been reported at regular intervals in Canada.

Infestations are generally short and parasitoids are very important in the natural control of populations. The most important parasitoid is the large flesh fly, Sarcophaga aldrichi Parker, which acts quickly after the start of an infestation, and can destroy up to 80% of the pupal population.

In recreational parks or on ornamental trees, it is recommended that egg bands be removed in the fall. At that time of year, they are more visible because the leaves have dropped. In the spring, colonies of young larvae at rest can be removed by hand. On small trees, a water jet can be used to dislodge larvae from the foliage.

Diet and feeding behaviour
Phyllophagous : Feeds on the leaves of plants.
Free-living defoliator: Feeds on and moves about freely on foliage.

Emerald ash borer

Agrilus planipennis

Distribution
Quebec, Ontario

Micro-habitat(s)
Leaf, Branch, Trunk

Damage, symptoms and biology
Tree decline, including:

- yellowing of the foliage
- thinning crown
- evidence of adult beetle feeding on leaves
- long shoots growing from the trunk or roots
- vertical cracks in the trunk
- deformed bark (3-4 mm)
- small D-shaped emergence holes
- S-shaped larval tunnels under the bark filled with fine sawdust
- presence of woodpeckers in winter and woodpecker holes

The EAB has killed millions of ash trees in Southwestern Ontario, Michigan and surrounding states, and poses a major economic and environmental threat to urban and forested areas in both countries. The EAB attacks and kills all species of ash (except Mountain ash which is not a true ash).

The emerald ash borer has only one generation per year in the south of its distribution area in Michigan. Adult emergence starts with the month of June and ends with the end of July. A few days after mating, female lay eggs, one at the time, in bark crevices. One female lays between 60 and 90 eggs during its lifespan. Larvae dig S shaped galleries in the phloem in order to feed themselves. They hibernate in the bark and pupate in April or May. The lifecycle of the emerald ash borer, north of its distribution area, is not known for the moment, but it could last two years.

Other information
Native to eastern Asia, this pest was first discovered in Canada and the U.S. in 2002.

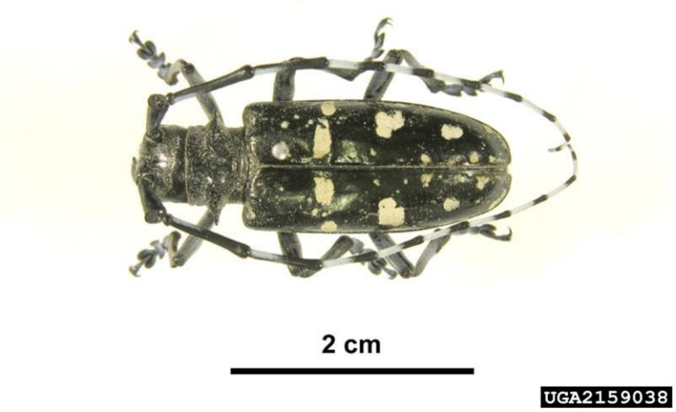
While the EAB can fly up to several kilometres, another significant factor contributing to its spread is the movement of firewood, nursery stock, trees, logs, lumber, wood with bark attached and wood or bark chips.

Regulated materials can be freely moved within a regulated area, but cannot be moved outside of a regulated area without prior written permission from the CFIA. Anyone violating this requirement may be subject to a fine and/or be liable for prosecution.

Regulated materials for EAB include nursery stock, trees, logs, wood, rough lumber including pallets and other wood packaging materials, bark, wood chips or bark chips from ash (Fraxinus species), and firewood of all tree species.

Diet and feeding behaviour
Phyllophagous : Feeds on the leaves of plants.
Xylophagous : Feeds on woody tissues (wood).

Asian longhorned beetle
Anoplophora glabripennis



Distribution
Ontario, United States

Micro-habitat(s)
Twig, Bark

Damage, symptoms and biology
In China, this species may have a one or two year life cycle, depending on the geographical region. The egg, larva, or pupa can overwinter. Young adults emerge from infested trees in May and may fly several hundred meters to search for a host. However, they tend to attack the same tree from which they emerged. Adults are active from early-summer to mid-fall. They feed on the bark of twigs periodically throughout the mating and egg-laying period. On sunny days the adult beetles are most active from mid-morning to early-afternoon. They usually rest in the canopy on cloudy days.

In preparation for egg-laying, females chew oval grooves in the bark in which they lay one egg about 5-7 mm in length. On average, each female will live 40 days and during that period will lay about 25-40 eggs. The wounds may occur anywhere on the tree, including branches, trunk, and exposed roots. Eggs hatch in one to two weeks. Young larvae begin feeding in the phloem tissue and as they mature they migrate into the wood, creating tunnels as they feed. These galleries cause tree dieback and death. Larvae become pupae, then adults, in the tunnels in summer. The new adults exit the tree through large round holes about 10-15 mm in diameter created by the newly emerging adults. Dripping sap is often seen to be flowing from the egg-laying wounds.

Piles of coarse sawdust around the base of the tree and in branch axils can be seen as well. The adults are large bluish-black beetles (2.5 to 3.5 cm in length) with white spots and very long antennae. The larvae and pupae are normally inside the tree within the larval tunnels. Full grown larvae can reach 50 mm in length.

Other information
In China, *Anoplophora glabripennis* is known as the "starry sky beetle" and is considered a major pest of hardwood trees in many parts of the country. Based on the Chinese distribution and the current infestations in the United States and Canada, it has been shown that the beetle can survive well in the hardwood forests of southern Canada.

The first report of this beetle being established outside of its native range was from the cities of Brooklyn and Amityville, New York in 1996. Many trees were found to be heavily attacked, particularly maples. Quarantine and eradication procedures were quickly implemented to prevent further spread and to eliminate the population. In July-August, 1998, three separate infestations were discovered around Chicago, Illinois. In October 2002 an infestation was discovered in Jersey City, New Jersey. In September 2003 an infestation was discovered in an industrial park located on the boundary line between the Cities of Vaughan and Toronto in the province of Ontario. All of these infestations are under strict quarantine control and are undergoing eradication.

Diet and feeding behaviour
Phloeophagous : Feeds on phloem.
Borer: Bores into and feeds on the woody and non-woody portions of plants.

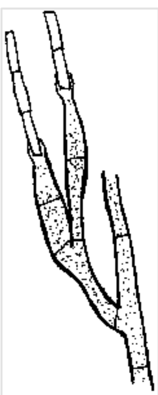
Biotic Pathogens

Bacteria are single-celled organisms that lack a true cell nucleus and have a single chromosome instead. There are only a few pathogenic bacteria that attack trees.

The majority of **forest pathogens are fungi,** which generally belong to one of the following divisions: *Basidiomycotina*, *Ascomycotina* or *Deuteromycotina*.

Deuteromycotina reproduce asexually by producing conidia on conidiophores (**Figure 1**) or within special structures, such as pycnidia. *Ascomycotina* reproduce sexually by producing 4, 8, 16 or 32 ascospores inside sacs, or asci (**Figure 2**), within structures called ascomata. These ascomata may be cup-shaped (apothecia), bottle-shaped (perithecia), or balloon-shaped (cleistothecia).

Basidiomycotina reproduce sexually by forming basidia, which produce four basidiospores (**Figure 3**) on a structure called ascoma. The basidia develop in gills, pores, teeth or other structures. Rusts (Uredinales) are *Basidiomycotina* that function as obligate parasites and have a complex life cycle that generally requires an alternate host.



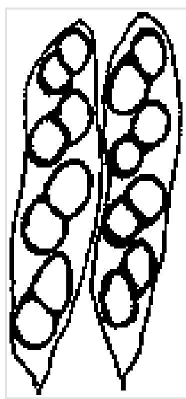
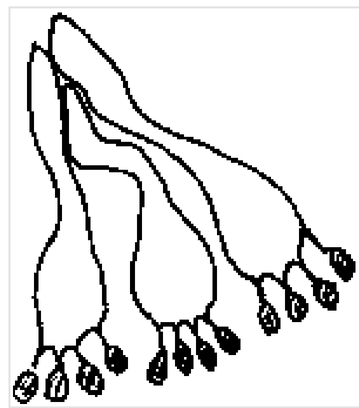


Figure 1 *Conidiophores and conidia*

Figure 2 *Asci and ascospores*

Figure 3 *Basidia and basidiospores*



Western gall rust

Endocronartium harknessii (J.P. Moore) Y. Hiratsuka

Micro-habitat(s)
Twig, Branch

Distribution
Canada

Damage, symptoms and biology
The fungus causes a gall that encircles the stem or bole of infected trees. White blisters develop at the site of the gall, just beneath the bark. In spring, the blisters burst and orange spores are released which end up infecting other pines. Rupturing of the blisters results in desiccation of the underlying living bark, killing the bark area around the gall. Following the death of the water-conducting tissues, some needles will die in the lower part of the branch, near the distal portion of the gall.

Damage is not significant on mature trees where most infections occur on branches. Branch galls do not result in serious growth losses. However, infections on young trees more often result in main stem galls that can cause stem malformations and predispose the tree to breakage in high winds or under heavy snow loads (Figs e, f).

A large number of galls reduces the aesthetic appearance and value of ornamentals and Christmas trees.

Other information
Unlike the other important stem rusts, *E. harknessii* does not require an alternate host to complete its life cycle. Infection occurs directly from pine-to-pine. This allows rapid intensification of the disease when conditions optimal for infection occur. However, such conditions only occur every several years, resulting in "wave years" of infection and gall formation.
Pruning the infected branches prior to spore production is a good means of control. Rodents feed on the galls in winter, and this may result in a high level of mortality some years.

Needle cast

Isthmiella faullii

Micro-habitat(s)
Needle

Distribution
Eastern Canada

Damage, symptoms and biology
This disease is the most common and most destructive needle cast in fir. It severely defoliates seedlings and young trees, reduces their growth, and may sometimes kill them. In larger trees, however, the damage does not cause any serious problems. The current year's needles are infected first, but they do not show any damage. The following spring, brown spots appear and spread, eventually covering the entire surface of the needles by mid-summer. The first fruiting bodies form on the upper surface of the needles and discharge spores in late summer or early fall. It is unclear just what role these spores play, but they may give rise to the second type of spores. Ascospores form in mid-summer on the needles infected two years earlier. Hysterothecia, the fruiting bodies bearing these spores, create a black line on the underside of the needles. This line is actually the ascus, which will release ascospores able to infect new shoots the following spring.

Other information
No measures are implemented to control this disease in the forest. With high-value trees, however, pruning of affected branches represents a good means of suppression. The disease causes considerable damage in Christmas tree plantations. Fungicide spraying may also be effective, but it must be done at the right time, that is, when the spores are released.

Armillaria root rot

Armillaria mellea

Micro-habitat(s)

Base of tree

Distribution

Eastern Canada

Damage, symptoms and biology

This is the most destructive and widespread disease involving pathogens that attack the roots and base of trees. In forest stands the disease will often kill trees either singly or in patches known as disease centers. These disease centers will continue to grow in size as the disease spreads outward over time.

Trees with armillaria root disease might or might not show external symptoms. The first symptoms of the disease are a decline in tree vigour, foliage yellowing followed by gradual browning, and a considerable flow of resin in conifers. Needles on dying pine trees first turn yellow-green and then red before falling off. Spruce needles often become a dull green (but not red) before they fall off. The infection begins when the fungus, living in the ground, sends out filaments that invade healthy roots. It then moves to the root collar, and spreads to the tree trunk. The spread of infection induces sapwood decay in the affected parts, and eventually kills the tree. Trees with root decay die as a result of sap flow being cut off or following wind throw. The infected areas have cream-coloured plates along with black mycelial cords resembling shoe strings. The rotting wood beneath the bark has a water-soaked appearance and is pale brown. Over time, the wood yellows, then whitens and becomes soft, spongy and stringy. In the fall, golden yellow fruiting bodies can be seen near infected trees or at their base. The fruiting bodies have darkish scales on the cap and fairly close yellowish white gills. The long, fibrous stem is encircled by a thin membranous ring. The fruiting bodies produce spores that are dispersed by the wind and end up creating new pockets of infection.

Other information

Armillaria root disease is caused by several closely related species of Armillaria. *Armillaria ostoyae* is the most prevalent and destructive of the Armillaria spp..

The causal fungus of Armillaria root rot can remain alive for many years in rotting wood on the ground. Some root disease centers have been estimated to be more than 400 years in age. Although the fungus usually lives on dead organic matter, it can attack healthy trees and cause major damage. The fruiting body is edible but opinion is divided regarding its flavour. It is best to consume only young specimens. Be sure to carefully identify them first. Trees whose foliage appears healthy but have rotten roots can be hazardous in campgrounds, or around buildings because they are susceptible to wind-throw.

Needle rust of pine

Coleosporium asterum (Diet.) Syd.

Distribution

Common throughout the range of host trees in Canada.

Damage, symptoms and biology

The pine-aster rust causes minor needle cast and discoloration of needles of pine and, in cases of severe infection, some reduction in terminal growth, but only rarely does it kill trees. Generally, only relatively small trees, less than 8 to 10 feet in height, are affected, and only heavily infected older needles are cast prematurely, resulting in lowered food production, consequent growth reduction, and reduced value for Christmas trees. However, death of seedlings could result from a combination of rust attack and insect attack fatal to the new shoots.

Coleosporium asterum is a macrocylic rust, producing five spore stages. In the early spring the pycnial stage appears as orange droplets on lesions on pine needles that were infected the previous fall. A white, columnar blister, the aecial stage, then forms on the needles in late spring or early summer, ruptures and releases orange-coloured aeciospores that are dispersed by the wind and infect the alternate hosts, aster, *Aster sp.*, and goldenrod, Solidago sp. Throughout the summer, on the underside of the leaves of the alternate host, the uredial stage develops and produces orange, cushion-like masses, which produce uredialspores that re-infect and spread the disease to other aster and goldenrod plants. Several generations of this stage may be produced during the summer months. In late summer, the telial stage develops on the underside of the alternate host leaves, germinates and produces the basidial stage, which releases basidiospores that are dispersed by the wind and re-infect the needles of the primary pine host, where the fungus then overwinters.

The current year’s foliage that is infected late in the fall usually dies and falls from the tree the following summer. In some cases the infected needles will persist on the tree for 3 to 5 years. Infections that result in whole tree mortality are rare because the current year’s needles are not affected until late in the fall, after the growing season is completed. Consecutive years of infection, accompanied by an additional stress, such as drought, could result in loss of vigour, growth loss, and whole tree mortality. Less vigorous trees are more susceptible to attack by other insects and diseases, such as bark beetles, Ips sp., and Armillaria root rot, Armillaria ostoyae (Romagn.) Herink.

The result of several consecutive years of defoliation can reduce the merchantability of trees in the Christmas tree and ornamental tree industry. In these cases, an application of a fungicide registered for control of this pine needle rust is recommended. The removal of any alternate host plants, aster, *Aster sp.,* and goldenrod, *Solidago sp*., from within 300 m of pine plantings should also provide some level of control.

Forest Pests and Climate Change

Many of Canada's most notorious forest pests and diseases have become household names in recent years:

- The mountain pine beetle killed off a large portion of British Columbia's Lodgepole Pine trees from the late 1990s through the 2010s and has also spread east, threatening forests in Alberta;
- The emerald ash borer has aggressively attacked eastern Canada's Green Ash trees, killing 99% of Toronto's 850,000+ Ash trees, and is now spreading west to the prairies; and
- Dutch elm disease is slowly but surely stripping cities and towns across eastern and central Canada of their majestic American Elms.

Under normal conditions, forest pests and tree diseases can be natural agents of disturbance that promote forest health and diversity. Unfortunately, our warming climate is tipping the ecological balance and turning them into a worsening threat.

Terry Teegee knows the forests of the west coast intimately, and has seen the astonishing results of insect damage first hand. He is Regional Chief of the British Columbia Assembly of First Nations, Tribal Chief of the Carrier Sekani Tribal Council, and a registered professional forester. Teegee and his community have witnessed sporadic pine beetle outbreaks going back many generations: "our elders talked about it: we'd hear stories about the forest being blood red." Recently however, pine beetle infestations have become massive in scale and in consequences.

The numbers are astounding. During the early 1990s, the beetle destroyed an average of about 45,400 hectares of forest per year; between 2004-2014 the beetle was a hundred times more destructive, killing over 6.4 million hectares per year. Teegee watched this devastation unfold. "We've seen a vast area being infested faster and faster," he says. "The reason for that is climate change."

> "We've seen a vast area being infested faster and faster. The reason for that is climate change."

Teegee says that climate change is leading to warmer winters and summers, and that both of these seasonal changes are contributing to the beetle's massive impact. In the past, he says, "we'd get an early freeze of the land and of the trees in October, and that kept the mountain pine beetle in check. That hasn't occurred often enough since the 80s." Teegee also observes that "with climate change we've seen a lot longer summers, meaning that there are two flights of mountain pine beetle. And that's unprecedented, but has happened more and more in the past twenty years."

The latest pine beetle infestations in BC have largely run their course, primarily because they've killed off most of their preferred tree species. But that doesn't mean the threat is over. Teegee says that "2008 was basically where mountain pine beetle exhausted its use of the pine tree because there were none left, and now it's carrying on into the boreal forest." The beetles have begun to attack jack pine, and forestry researchers have identified climate change as a major risk factor in the likelihood of this destructive species spreading to the vast pine forests of eastern Canada.

Teegee's experience of warming winters and summers leading to a sudden explosion of insect damage is a pattern that has also been seen with other pests across the country. In Toronto, for example, hotter summers allowed ash borer populations to undergo two reproductive cycles rather than just one, doubling their normal rate of infestation. Research has also shown that deep winter cold spells are needed to limit outbreaks of many pests, including ash borers and tent caterpillars. The warming climate thus weakens natural controls on insect pest populations at the same time as it accelerates their rates of growth and reproduction. This combination allows pests to spread much farther and faster than before.

> Deep winter cold spells are needed to limit outbreaks of many pests, including ash borers and tent caterpillars.

Pests attacking new species and making their way into new ecosystems are especially concerning consequences of climate change. Insects can now be found in unexpected places, such as near the tops of mountains or far north, near the tree line. These shifts in habitat and species can happen rapidly and can have devastating consequences when infestations reach forests that haven't evolved to resist these invasive threats.

Trees, of course, have natural defenses that allow them to repel and recover from many kinds of pests and diseases. Unfortunately the same changes in climate that promote the aggressive spread of insects also impact trees' capacities to defend against them. During warmer and drier conditions associated with periods of drought, trees are less resilient to the effect of insects and disease. And when faced with multiple sources of stress – such as an onslaught of insects during a drought – trees are much more likely to die.

Mitigation and Adaptation

Urban and wild forest management strategies can play an important role in reducing the impact of forest pests in the face of climate change.

The city of Winnipeg and the province of Manitoba, for instance, have implemented strategies to reduce the spread of Dutch elm disease, including practices around firewood storage, tree pruning, early detection, and the rapid removal of infected trees. Alberta and Saskatchewan have implemented a variety of strategies targeting the mountain pine beetle, in the hopes of slowing its spread, though they understand it may be difficult to stop it altogether.

Climate projections such as those presented in the Climate Atlas are essential to inform management strategies in both urban and wild settings. Projections show shifts in temperature, which could have implications about where pests might be found in the future, as well as what conditions trees will face as climate change alters the seasonal distribution of warmth, cold, and precipitation.

A key message arising from forestry research is that climate change will likely bring on sudden and unpredictable disturbances. Forest managers will have to cultivate diverse and resilient tree populations and management practices, because climate change means having to be ready for the unexpected.

Ultimately, the most direct way to preserve our forests in the face of these threats is to take prompt and effective action to prevent climate change from accelerating. The less warming that comes to pass, the less stress will be placed on the natural world, and the less our practices will have to adapt to more serious risks.

Teegee says "I think we're in dire straits with the reality of climate change," but notes that "the good thing about human beings is that we're resilient. We'll make a change." For Teegee, responding to climate change means recognizing that "we've lost that real connection with the land" and that fundamentally "we've really got to think about what's important in our lives" in order to live in balance with nature.

Government of Canada | Gouvernement du Canada

Shape-shifting forests: a tale of climate, wildfires and surprising outcomes

The story of North American forests is one of resilience, adaptation, renewal and hope. **January 2024**

If you hike or stroll through one of Canada's northern forests, you might experience a world of towering trees, cool shade filled with the scent of pines and spruces — home to many different plants and animals of all shapes and sizes. But Ellen Whitman, a wildfire research scientist at the Canadian Forest Service, sees things through a different lens. What she notices is a landscape quietly and gradually transforming.

A very different place

Ellen sheds some light on this phenomenon. "Globally, we're noticing a change in forest biomes as they shift away from mature forests toward shrub and herb-dominated ecosystems," she notes. "Head up to the Northwest Territories and you'll find parts of forests that have been utterly transformed. The towering jack pines have surrendered their reign to grasses and stunted aspens, armed with light seeds that can be carried on the wind," she says. The small, forested area that caught her eye back then is "a very different place now."

She first became interested in Wood Buffalo National Park and the southern Northwest Territories in 2014, after a major wildfire season. She worked with two other NRCan scientists, Marc-André Parisien and Dan Thompson, along with wildfire expert Mike Flannigan of Thompson Rivers University. The goal? To compare several paired forested areas with similar climate, pre-fire vegetation and soil conditions. One of each pair had experienced two fires in a short time, also known as short interval reburns. The other had a longer period of regrowth between fires. The differences were significant. The scientists published their findings in the international science journal *Nature*, noting that, in places with short interval reburns, open stands of aspens dominated in place of dense conifer forests, and the understorey vegetation beneath the trees consisted of sparse shrubs and grasses.

More recently, Ellen and a team of researchers studied wildfire and climate trends in northwestern boreal forests. Looking mainly at Alberta, using historical data from 1970 to 2019 their research findings were notable: the annual number of large wildfires and the number of extreme short interval reburns both increased as the climate grew warmer and drier. This research supports the growing body of evidence that increasing fire activity affects not just the local environment, but the overall ability of the forest to regenerate.

This transformation is most evident in western and northern parts of Canada and in the southwestern United States. In some reburned areas, you can still spot trees, but they're less dominant than in neighboring forests, creating a more open, almost savanna-like appearance. Savannas, which are common in Africa and Australia, have a drier climate characterized by rolling grasslands scattered with shrubs, trees and occasional patches of forest.

Key players: wildfires and climate

So, what exactly is happening? Ellen breaks it down: "Climate change and increasingly severe wildfires are key players in this transformation. While they might not be the sole driver, they're certainly capable of leading to this shift."

Climate stresses come in the form of droughts, floods and warmer than usual weather patterns. When it's drier than usual, wildfires tend to happen more often and become more severe.

What's more, areas recently burned by fires lack nearby sources of seeds for trees to regrow. Sometimes it's because the burned patch is so vast that the seeds would have a long way to travel. In other cases, it's because the seed bank, which refers to the dormant seeds that normally exist in the soil, was destroyed in the fire. And even if a tree seedling manages to take root, it might struggle with unusually hot and dry weather. Simply put, they may not survive in today's climate, which is different than it was when forests first took root decades and centuries ago.

Long term shifts

“There are ongoing long-term shifts away from old-growth tree species like spruce, toward shorter-lived ones like pine or aspen,” Ellen points out.

However, none of this is new, exactly. The balance of tree species in North American boreal forests have shifted many times since the last major ice age 11,700 years ago, as temperatures and wildfire patterns change. Wildfires are a natural phenomenon and can help forests thrive. “Fires can spark overdue regeneration, particularly where they’ve been artificially suppressed,” she points out. “Forests aren’t inherently superior to other ecosystems, and sometimes a bit of rebalancing is needed where they have invaded, such as in some former grasslands.”

Resilience: a race to keep up?

Forests and wildlife can be resilient. Trees have long been adapted to wildfires and changing conditions, while animals can find safer havens. Mature trees have great inertia, which means even if the climate changes fast, they will most likely persist. But Ellen notices a crucial shift. The speed of change is picking up and ecosystems have less time to recover between wildfires. She explains: “there’s some evidence they’re starting to lose the ‘safe operating space’ they need to be resilient to disturbances.”

The story gets more complex when the wider ecological impact is considered. Wildfires create a ripple effect. “In North America, the loss of large, old-growth trees could have consequences for creatures uniquely developed to thrive in mature forests,” notes Ellen. These include specialist species like martens and fishers, members of the weasel family that make their dens inside tree hollows, for example. Beyond that, wildfires impact human social and economic values by reducing carbon storage, altering water dynamics and even affecting how much sunlight the planet can absorb.

Hope, renewal, adaptation

The story of forests is not just a tale of loss, but one of renewal and adaptation. “We can expect most of our burned area to recover fine,” says Ellen. The reality is forests evolve. They may not always resemble the forests we’re used to seeing or respond how we expected. But different combinations of native and non-native plants are sure to fill the voids.

Ellen’s research serves as a reminder that our own actions have far-reaching impacts on the ecosystems we share. There are ways to adapt and mitigate these changes. Land managers can use strategies like fuel treatments and prescribed burning to lessen the severity and spread of wildfires. On a personal level, we can contribute by reducing energy use and cutting down on greenhouse gas emissions. The key is to find a balance that lets nature thrive, while providing the essential ecosystem services we rely on. There is still much work to do be done as Ellen and other wildfire scientists continue their quest to understand the drivers and consequences of changes unfolding in our forests.

Government of Canada Gouvernement du Canada

Drought

Drought is expected to become more frequent and severe in parts of Canada.

Drought is defined as a shortage of precipitation over an extended period, usually a season or more, resulting in insufficient water availability that adversely impacts vegetation, animals and people.

Areas of western Canada are already experiencing frequent and severe droughts. Scientists expect new areas across the country to be affected and drought to become even more frequent and severe. The consequences could have far-reaching impacts on Canada's forests.

Why knowing about drought is important

Drought threatens Canada's forests by limiting the available water that trees need to survive. When water is limited, trees become weakened. Weakened trees cannot grow at a normal rate, may not be able to regenerate, or could die. It is also difficult for trees to defend themselves against insects and diseases as they become stressed. Similarly, during wildland fires, weakened trees are at higher risk. For the Canadian forest industry, these issues directly affect the available wood supply.

Canadian Forest Service researchers have developed a measure of drought called the Climate Moisture Index (CMI). CMI is calculated as the difference between the annual amount of precipitation and the expected amount of water that evaporates each year and can be used to indicate the amount of moisture available in a given year.

Tracking drought helps forest managers anticipate and manage for a changing climate. For example, the SeedWhere program can be used to predict where similar climates will be located under a range of future climate scenarios and timeframes. Forest managers can use this tool to select the planting stock (e.g., species and provenance) that is best adapted to predicted drought conditions.

What has changed

Several regions of Canada experienced substantial droughts between 1951 and 2010, but with significant variability between decades. However, during the first decade of the 21st century (2001–2010), exceptional droughts were observed across the country – for example, the 2001–2002 drought in the Prairies (Figures 1 and 2), caused abnormally high aspen mortality (see Tree mortality).

Similar trends have been reported in forests around the world. With droughts expected to become more frequent and severe in most of Canada's forests, there are growing concerns about the impact of drought on forest distribution, tree health and regeneration success.

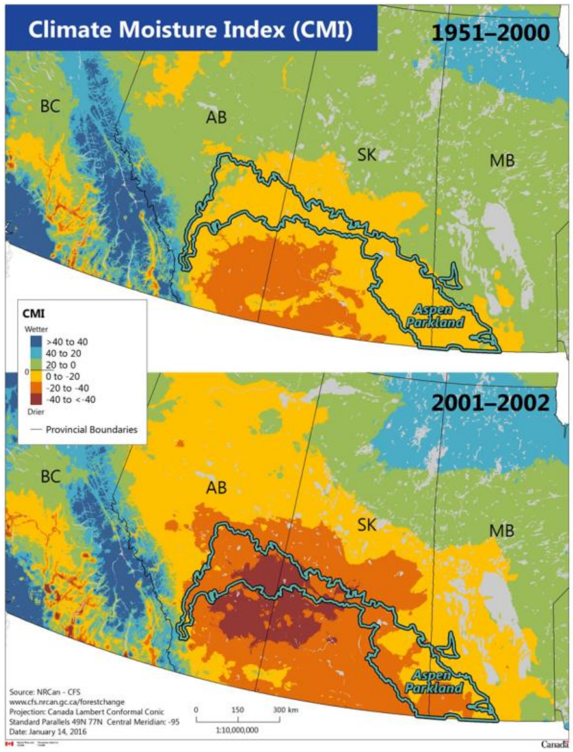


Figure 1 *– Mean Climate Moisture Index (CMI) for 1951–2000 and the 2001–2002 drought in the aspen parkland*

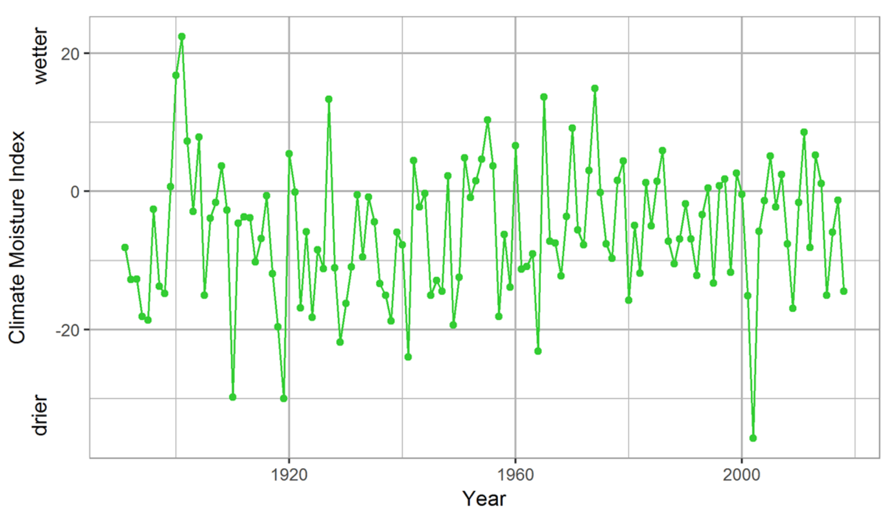


Figure 2 *– Long-term changes in the Climate Moisture Index (CMI) in the aspen parkland*

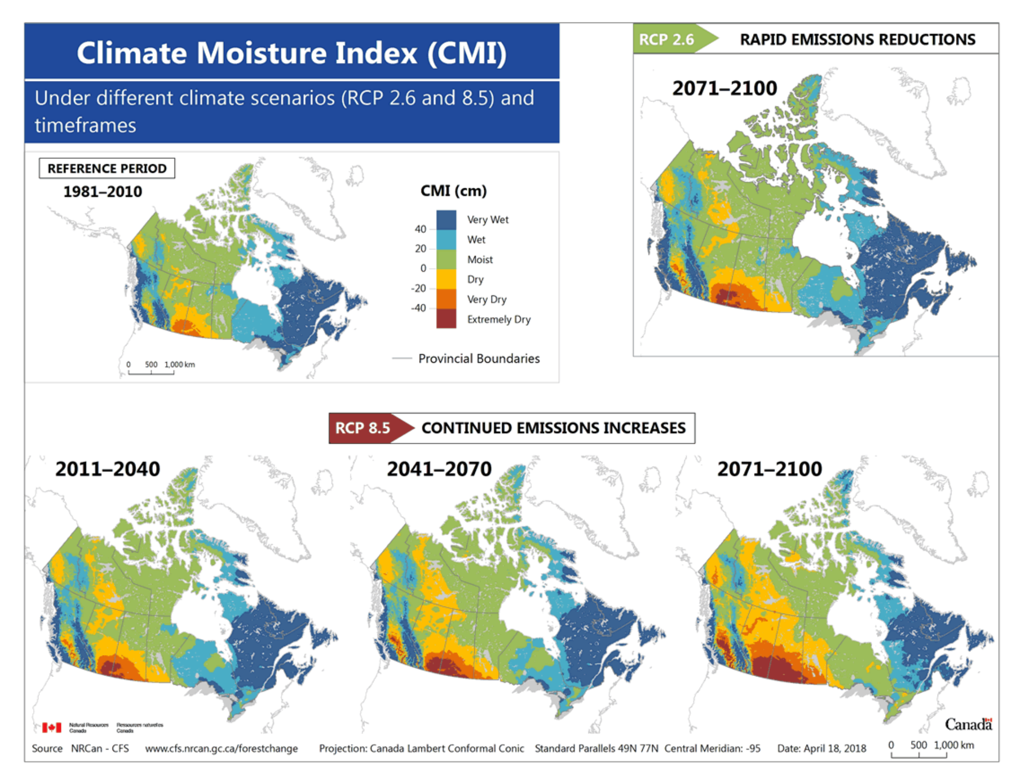


Figure 3 *– Reference period (1981–2010) and projected mean annual Climate Moisture Index (CMI) for the short- (2011–2040), medium- (2041–2070), and long-term (2071–2100) under the Representative Concentration Pathway (RCP)*

The outlook

Increases in drought could have far-reaching impacts on Canada's forests, both directly, through impacts on tree growth and survival, and indirectly, through drought-related increases in the frequency of disturbances such as fire and insect outbreaks.

Drought is expected to become more frequent in several areas that are already relatively dry, such as the southern interior of British Columbia and the Prairie provinces (Figure 3).

Some areas that have not previously experienced frequent drought are also expected to become drier in the future. The current prairie conditions are expected to spread northwards into areas of the southern boreal forest. Such a shift would lead to significant changes in forest ecosystems.

Moist regions, such as the Pacific and Atlantic coastal areas, are expected to be less affected, with limited changes in annual climate moisture index (CMI) values over the next 100 years. However, these moist areas could become more prone to the impacts of seasonal droughts even if the annual CMI indices remain positive.