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Laurentian Forestry Centre
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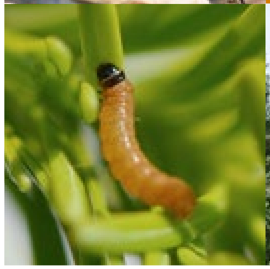
# Spruce budworm



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## Spruce budworm

Regular spruce budworm (SBW) outbreaks are responsible for the most significant damage caused to Canadian forests. For over 50 years, researchers at the Canadian Forest Service (CFS) have been interested in this insect. This pamphlet aims to gather current knowledge on SBW, its cyclical outbreaks and control methods, and to illustrate how this issue can drive innovation. This overview focuses on the work carried out by researchers at the Canadian Forest Service's Laurentian Forestry Centre (CFS-LFC). This research is made possible through our partnerships with researchers from other CFS centres, provincial governments, universities and organizations dedicated to forest protection, particularly Quebec's Société de protection des forêts contre les insectes et maladies (SOPFIM).

For further information on the
Canadian Forest Service and our research:
http://www.nrcan.gc.ca/forests
http://scf.rncan.gc.ca/projects

"Research is not an easy ride; it is a rocky road."
*Wladimir A. Smirnoff*

# The insect

**Origin:** Indigenous

**English name:** Spruce budworm, SBW

**Latin name:** *Choristoneura fumiferana* (Clemens)

**French name:** Tordeuse des bourgeons de l'épinette, TBE

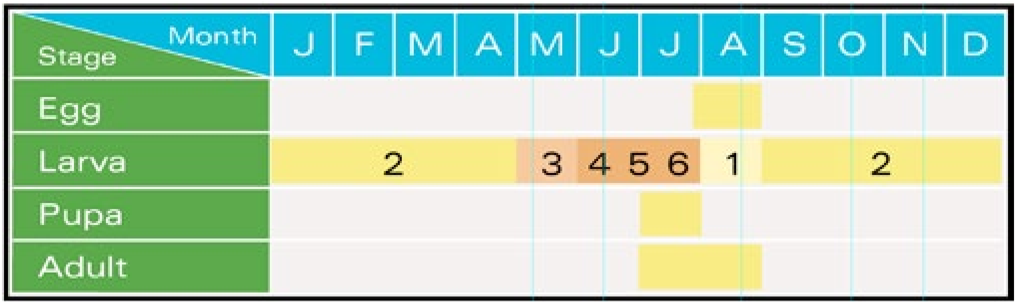
**Distribution:** Throughout Canada; its distribution area coincides with that of balsam fir, white spruce and, increasingly, with that of black spruce. SBW is considered the most significant pest in North American fir and spruce forests.

**Potential hosts:** Balsam fir, white spruce, red spruce, black spruce, Norway spruce, American larch, jack pine and Eastern hemlock.

**Diet:** Generally lives and feeds on annual shoots and needles (heteroconophagous), plant leaf tissue (phyllophagous) and pollen (pollinivorous); also occasionally attacks seeds and cones.

**Behaviour:** Bores into and feeds on the woody and non-woody parts of plants; spins a silk shelter in which to hide or feed.

## Biological cycle




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. They do not feed at this time.

The SBW goes through six instars; it overwinters in the second. Its fifth and sixth instars are the most damaging. The pupa forms itself at the feeding site or further inward along the branch. This instar lasts between 7 and 10 days. The adult is a small grey-brown moth that lives for approximately one week. Males emerge 1 to 2 days before females. Mating occurs the day the female is born, and egg-laying often begins the next day. Moths can move over great distances by taking advantage of the movement of air masses. SBW defoliation during an outbreak can last 8 to 10 years in a given stand.

To read the complete fact sheet on SBW: https://tidcf.nrcan.gc.ca/en/insects/factsheet/12018








## SBW ecology

Researchers at the CFS-LFC study the interactions between SBW populations and the biotic and abiotic factors of infested forest stands. Integrating the results of this research will help to develop and refine a mathematical model of the behaviour of this insect's populations. Gaining a better understanding of the effects of forest stand management will help prevent and limit the consequences of SBW outbreaks.

## The ecological role of SBW

The boreal forest landscape is shaped by periodic large-scale natural disturbances such as fires and insect outbreaks. The latter are part of natural forest dynamics and play a role in the regeneration of the forest stands they affect. Researchers found that the spatial distribution of stems in stands is more complex following a severe outbreak. This heterogeneous stand structure leads to variations in the intensity of light on the ground, which creates favourable conditions for the germination and survival of fir seedlings. At the landscape scale, the arrangement of stands is also more diversified after a severe outbreak.

Furthermore, SBW outbreaks have an impact on biodiversity. The increase in plant diversity after an outbreak could be a factor in preserving certain species for a longer period between major disturbances (fires or outbreaks). As they are more vulnerable to SBW outbreaks and windthrows, fir-dominated stands generate larger quantities of dead wood than stands where black spruce is dominant, and the presence of many organisms is related to that of dead wood.

## The impact of outbreaks on the carbon budget

An SBW outbreak abruptly reduces the volume of harvestable wood, but its impact on carbon is more complex. Insect attacks reduce growth and, in the worst cases, kill trees, thus transferring their carbon content from the living biomass pool to the dead wood pool. However, measures taken in stands of shore pines killed by the mountain pine beetle show that the rapid plant regrowth and the slow decomposition of tree stubs decrease the rate of carbon loss to the atmosphere. Dead stands are also more likely to burn in the first few years, but analyses only show a moderate interaction between these two types of disturbances. At the landscape scale, an SBW outbreak leads to forest renewal and reduced living biomass, thus limiting its carbon content. Regardless of the method used, all interventions aiming to reduce outbreak severity have an impact on the carbon budget since they help conserve carbon within forests. They also help to maintain the production of forest products that stock carbon.

## A changing distribution area?

The northern part of the current SBW distribution area is generally defined by the area comprising the insect's main hosts (balsam fir and white spruce). There are zones in eastern Canada where this area is limited by unfavourable weather, but cold winter weather is not the primary mortality factor for SBW. In fact, whenever host trees are available, cool summers limit the northern and altitudinal distribution, since the eggs hatch later and larvae do not have enough time to find an appropriate overwintering shelter. If the warm season is extended, young larvae do not have sufficient energy supplies to survive the winter while awaiting budburst in spring. This factor limits the insect's southern distribution.

Models precisely describe the current distribution of the insect in eastern Canada. Climate change is currently affecting this distribution area, which should slowly shift towards northern latitudes and higher altitudes, where it will eventually be limited by the availability of adequate hosts. In fact, the current outbreak began at abnormally high latitudes on the north shore of the St. Lawrence River, in Quebec. More severe and extended outbreaks can therefore be expected in areas that were spared in the past due to their unfavourable climate.

## When detection and innovation go hand in hand

In the 1980s, CFS-LFC researcher Luc Jobin and his team developed Multi-Pher pheromone traps. Multi-Pher (for multiple pheromones) traps are still being used today to attract males of SBW, those of gypsy moths and even those of agricultural insects, making it possible for researchers to monitor populations. In 1988, Luc Jobin was awarded the Joseph-Armand-Bombardier prize for the invention of the Multi-Pher trap, a distinction aiming to highlight research projects having led to technological innovations.

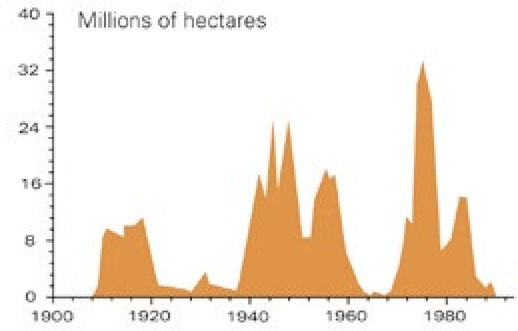
## Studying climate change in the field

At the Valcartier forest research station, CFS-LFC researchers are currently experimenting with T FACE (Temperature-Free Air Controlled Enhancement), a device used to simulate climate change effects. With this equipment, they are studying how rising temperatures affect bud break phenology and all other bud development phases in balsam fir and black spruce seedlings. To do so, they raise the temperature by 2°C from May to October. SBW larvae are also introduced into the device to study their phenology and to see how rising temperatures caused by climate change could eventually affect the phenological synchronization linking hosts to defoliators. This device can also be used to study the effect of rising temperatures on parasitoids that attack SBW.

# Cyclical outbreaks

## Going back in time

By analyzing annual tree growth rings, researchers can determine when SBW outbreaks occurred in the past. That is how we know that cyclical outbreaks have been occurring since the 18th century. The SBW population cycle varies between 30 and 40 years, which is exceptionally long for an insect. Outbreak length also varies from one region to the next. For example, the outbreak that occurred in the mid-20th century lasted 30 years in western Canada and over 40 years in central Canada. Since the early 20th century, eastern North America has faced three SBW outbreaks, the severity of which has increased from one cycle to the next. In Canada, the last outbreak reached its peak in the 1970s, when 50 million hectares of forest were affected.




*Areas affected by SBW outbreaks*

## The current outbreak

SBW population levels remained endemic between 1992 and 2006. In 2011, in Quebec, over 1.6 million hectares were affected by defoliation ranging from light to severe. The outbreak spread over an area of more than 7.1 million hectares in 2017. The rate of spread mainly increased on the north shore of the St. Lawrence River (Côte-Nord), north of Lac St-Jean, and in the Bas-St-Laurent and Gaspésie regions. In 2015, the Canadian province that had been the most affected by the SBW in terms of area was Quebec (94%), followed by the Northwest Territories (2.5%) and Ontario (2.2%).

For more information about the areas infested in Canada's territories and provinces, visit the National Forestry Database (http://nfdp.ccfm.org/) and Quebec's Ministère des Forêts, de la Faune et des Parcs (MFFP) website (http://mffp.gouv.qc.ca/forets/fimaq/insectes/fimaq-insectes-portrait-releves.jsp).

## Factors that influence outbreaks

The factor that is most favourable to the emergence of large-scale outbreaks is the availability of large forests of host trees. These environments are favourable to the survival of young larvae and to the migration of adults. Infestation periods generally coincide with the natural cycles of SBW enemies, namely predators (mostly birds), parasitoids and pathogens. Other factors, such as weather conditions, play a lesser-known role during outbreaks.

The lower density of SBW populations at the end of an outbreak cycle is closely related to the survival of the insect's last instars. This drop in the survival rate is mainly attributable to natural enemies and a lack of food.

## What role could mites be playing?

Since the beginning of the current outbreak, CFS-LFC researchers have further focused their work on SBW populations in the Côte-Nord and Bas-St-Laurent regions. They have observed the presence of red mites and are hoping to study their potential as markers of SBW migration. During the larval stage, red mites use SBW as a vehicle for dispersal. SBW moths collected in the traps set to monitor populations are being used to detect the presence or absence of red mites. This will provide a clearer understanding of the spatial and temporal evolution of SBW outbreaks in Canada.

## Damage caused

The damage caused by SBW is mostly visible in regions where large stands of mature balsam fir and white spruce trees are found. In June, the damage becomes visible: damaged buds, abnormally spread out small branches, defoliated current-year shoots, and numerous larvae suspended on silk threads.

In late June, severely affected stands take on a rusty orange colour due to dried out needles being held into place by the silk threads woven by the larvae. In the fall, the wind sweeps away most of these needles and the stand takes on a greyish colour.

Trees do not suffer many consequences from a single year of defoliation, other than decreased growth and increased vulnerability to attacks by other insects. However, repeated defoliations lead to a sharp decline in growth and an increase in mortality. In balsam fir, death usually occurs after four or more consecutive years of severe defoliation.

SBW is found throughout the country, but it has been most economically damaging in eastern Canada, where it has also significantly damaged the landscape. The impact of insect outbreaks is different from that of forest fires, another significant disturbance in boreal forests. Outbreaks are more selective, occur at a larger scale, and their frequency is often more predictable, albeit widely varying. Fires and certain management practices have contributed to the homogeneity of boreal forests, where only a few species are found over large areas, which influences the extent of the damage caused by insect outbreaks.

For further information on SBW outbreaks and the damage caused:

https://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13383



## From the biological chain to the wood products value chain

Even though SBW has been studied extensively, its impact on wood fibre quality has not been well documented. Previous research has shown that trees having undergone repeated defoliations by SBW were also attacked by a number of secondary insects, including borer beetles, longhorned beetles, and horntail wasps. These wood-feeding insects are often linked to decay fungi, thereby accelerating the deterioration of tree and fibre quality. SBW impact varies according to the product manufactured by the industry (pulp, lumber). Researchers at the CFS-LFC and at the Canadian Wood Fibre Centre, in collaboration with other organizations (SOPFIM, Université Laval, MFFP, Université du Québec à Montréal and FPInnovations), are studying SBW impact on wood value and fibre quality. Studies on the biological chain aim to determine the initial defoliation rate at which trees are colonized by insects and fungi, and the rate of decay following tree mortality. For their part, studies focusing on the value chain of wood products aim to determine the impact of these colonizations on wood processing. The ultimate goal is to gain a better understanding of how the biological chain, which is responsible for the degradation of wood and fibre quality, affects the value of wood products so as to better plan management measures in space and time.

# Human intervention

If humans never intervened, SBW outbreaks would end naturally, either due to a lack of food or to being overtaken by their natural enemies. For economic reasons, human intervention is often recommended, and different control methods are used. The goal? To protect the forest and reduce losses. Subject to very strict provincial and federal regulations, the control methods used have evolved over time, as the relevant knowledge became available.

The different methods presented here are currently used in forests. SBW larvae can be knocked out of ornamental trees simply by shaking the trees or by spraying them with water. For smaller trees, larvae can be picked off by hand.

## Biological control using B.t.: a classic approach

*Bacillus thuringiensis* (*B.t.*) is a spore-forming bacillus. When the spore is mature and ready, a toxic crystal (chitinase) develops and becomes a source of infection in lepidoptera only. This toxin is capable of dissolving the chitin contained in the insect's intestinal walls. The insect ingests the *B.t.*, and the cells lining its intestine swell and burst. The SBW then stops feeding and dies. After having attacked the SBW, the bacteria disappears as it can no longer reproduce.

### A brief history of *B.t.*

First isolated in Japan in 1901, *Bacillus thuringiensis* – also known as *B.t.*– was scientifically described in 1911 by a German researcher from the region of Thuringe, hence its Latin name *thuringiensis*. It was not until the late 1950s that the first commercial preparation of *B.t.* appeared.

In the early 1970s, CFS scientists carried out intensive research in order to operationalize the large-scale application of *B.t.* in forestry. At that time, the application of *B.t.* was 20 times more costly than that of chemical insecticides. They also had to address a number of questions related to the application of *B.t.*: How can it stick to the foliage? What dose should be applied? Their research was successful since by the mid-1980s, *Bacillus thuringiensis* var. *kurstaki* (*B.t.k.*) had replaced chemical insecticides in aerial sprayings.

For further information on *B.t.k.*,
refer to Health Canada's fact sheet:
http://hc-sc.gc.ca/cps-spc/pubs/pest/_fact-fiche/btk/index-eng.php

For further information on the *B.t.* spraying program in
Quebec: http://www.sopfim.qc.ca/en/index.php

The current control strategy favours the use of *B.t.* solely to protect dense balsam fir stands with a high commercial value. An early intervention strategy is based on the idea that SBW outbreaks are similar in nature to forest fires: they begin in one stand and spread to neighbouring stands. An obvious solution would be to eliminate the epicentres by spraying them with insecticides, which would slow the progression and reduce the severity of the outbreak, much like water quells fire. Research on early intervention focuses on the detection, containment and treatment of small areas infected by small but growing SBW populations, before they reach the outbreak level. This strategy has been under study in New Brunswick since 2014.

## A passionate researcher

1957: Russian researcher Wladimir A. Smirnoff accepts a position in insect pathology research at the CFS-LFC. For 28 years, he greatly contributed to the development and recognition of this field of study. His outstanding contribution to the concept of biological control strategies against harmful forest insects stems from his persuasive promotion of the microbial insecticide *Bacillus thuringiensis* as a means of biologically controlling SBW outbreaks.

"At night, while we sleep, bacillus chains entangle themselves in inextricable imbroglios; larvae emerge in the shape of dinosaurs or brontosaurs, and fields of crystals as chaotic as the lunar surface string by."

*Wladimir A. Smirnoff*

A fellowship was created in his name in 2002. It aims at encouraging and promoting research in this great scientist's preferred fields.

For further information
on the Smirnoff fellowship:
http://sopfim.qc.ca/en/smirnoff-fellowship.html



## Biological control at a smaller scale: using parasitoids

In Quebec, several parasitoids play an important role in maintaining SBW populations at endemic levels between outbreaks.

The small wasp *Tranosema rostrale* lays a single egg directly under the skin of caterpillars. After hatching, the wasp larva feeds on the caterpillar from the inside, thereby killing it. Researchers observed a significant increase in *T. rostrale* egg mortality when SBW caterpillars were exposed to temperatures above 20°C. However, *T. rostrale* larvae do not operate alone. A virus found on the surface of the wasp's eggs contributes to the destruction by causing significant immune system issues and hormonal imbalance. Genomics research projects aim to determine how the virus's characteristics could be used to our advantage in the fight against SBW outbreaks, by identifying the viral genes responsible for the caterpillar's health issues.

The female wasp of the *Elachertus cacoeciae* species uses another strategy: it paralyzes the SBW caterpillar before laying its eggs on the tree's needles. When the wasp larvae hatch, they make their way to the paralyzed caterpillar and begin feeding on its abdomen. As for the fly *Actia interrupta*, it does not lay eggs. Rather, it directly produces larvae, which set out in search of SBW caterpillars into which they can bore and feed.

Aerial release tests with *Trichogramma minutum*, a parasitoid wasp, have been carried out since 2017 with the use of drones. This wasp lays its eggs inside SBW larvae. This biological control method could be efficient for treating small areas, such as private forests, or specific areas in public forests (e.g., parks, urban forests). Using drones could increase the release speed and make the task easier for users. This method is simple and could be useful at the beginning of an outbreak or in an isolated infected area.

## New possibilities stemming from genomics

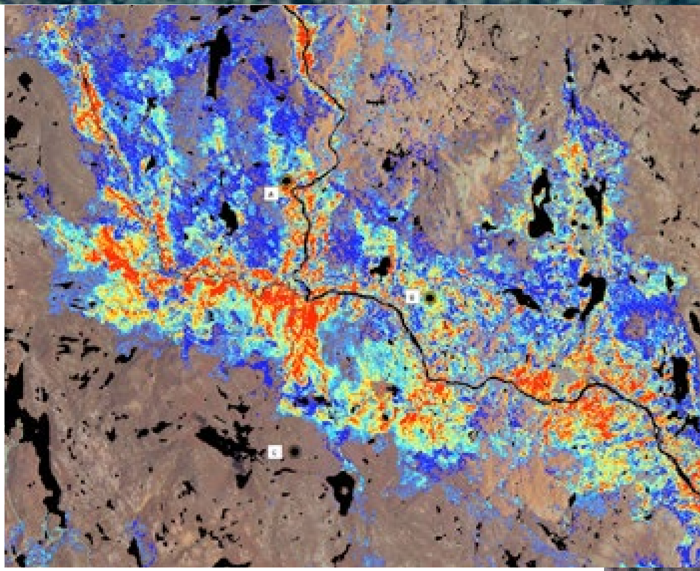
Although SBW biology has been studied extensively, this insect still holds many secrets. A new field of research, ecogenomics, could potentially unravel the remaining mysteries regarding this pest. Researchers in ecogenomics begin by characterizing an insect's genome, i.e. decoding all of its genetic material. They can then use this information to develop tools (e.g., genetic markers) to study ecological processes (e.g., butterfly migration) that would otherwise be difficult to quantify, and to assess their impact on the evolution of outbreaks. The results of these analyses will help improve decision-support systems used in the management of SBW populations. Genomic analyses are also paving the way to the development of new antiparasitic products and to the improvement of existing ones.

Knowing that access to tools for controlling pests such as the SBW is limited, genomics leads the way in developing innovative pest control strategies. Teams from the CFS, Université Laval and the University of Alberta have joined forces to decode the SBW's genome. The annotated sequence of the genome will be an inexhaustible source of information on the insect's biology that will make it possible to identify genes that could be targeted in the development of new control tools, such as the genes involved in winter survival, for example.

For further information on the research project on the genomics of defoliators:
http://cfs.nrcan.gc.ca/projects/91

## Silvicultural strategies

Foresters can adapt harvesting protocols to the vulnerability of balsam fir. They can also select new management techniques, such as converting stands at an early stage, early harvesting, or salvaging areas that are currently infected or that are likely to be in the future. CFS-LFC scientists are developing defoliation and mortality estimation methods using satellite imaging, mainly in stands that are severely affected by SBW. Maps and methods will be developed and used to increase the predictability of wood supplies for the forest industry, and to estimate the quantity of bioenergy available.



# A source of innovation

## How does climate change affect population dynamics?

Climate change can influence the behaviour of insect populations in their current distribution area by altering the ecological interactions that govern them. However, these effects are hard to predict, even for species that have been studied more extensively, such as the SBW in North America.

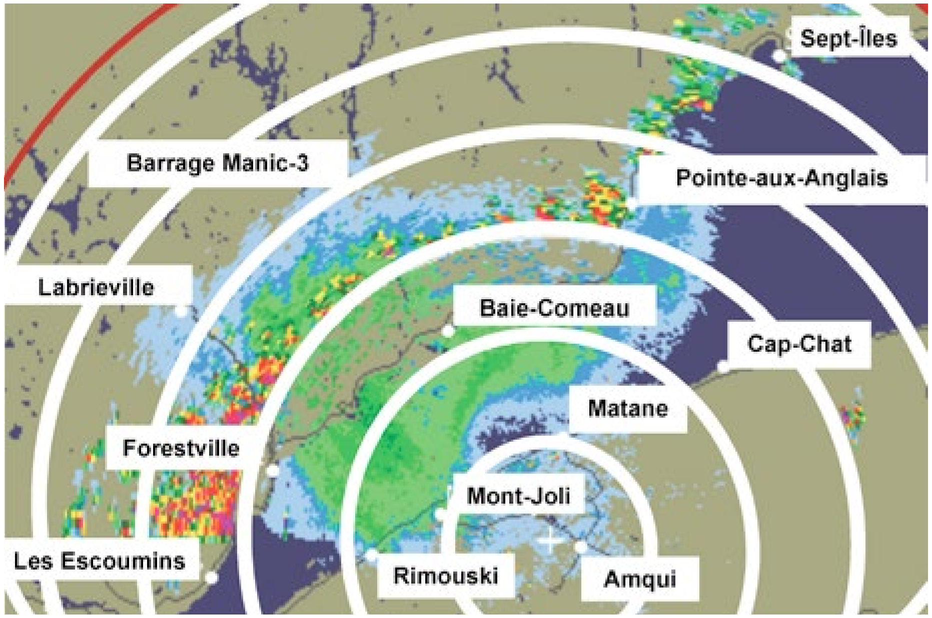
Researchers at the CFS-LFC developed a software called BioSIM, designed to link weather data to a given pest's reaction to temperature. Generic modelling tools such as BioSIM use the knowledge available on the reactions of certain species to the main climatic factors to predict their geographic distribution and their future behaviour. These models mainly take into consideration the factors that determine insect seasonality and those that influence insect survival in the winter. Once the seasonality model is available for a given insect species, its distribution can be predicted by overlaying a climate map with that of the distribution of vital resources for the species in question.

Used throughout the world, BioSIM has been used in Quebec to optimize the planning of control methods, such as spraying against SBW, and to predict the impact of climate change on mountain pine beetle infestations in western Canada.

For further information on BioSIM:
http://cfs.nrcan.gc.ca/projects/133

## Detecting mass flights using a radar

Researchers at the CFS-LFC are now using weather radars to track the mass flight movements of SBW moths, which regularly fly at an altitude between 400 m and 800 m to maximize their dispersal distance. These mass flights can be detected using a radar, just like the various forms of precipitation (snow, rain, freezing rain). This tool is used to monitor population dispersal by tracing their origin, their density, and the speed and direction of their flight. This technique can be useful in an early intervention strategy context. Other research is being carried out, namely to determine atmospheric conditions that limit mass flights, to develop real-time mass flight detection tools, and to link weather radar images to traditional detection methods.






## All for science!

In the wake of citizen science, which involves a network of volunteers collecting samples for scientific programs, CFS researchers have implemented a project called "Budworm trackers." Using traps, citizens collect SBW in Newfoundland, Nova Scotia, New Brunswick, Prince Edward Island, Quebec, Ontario, and in the state of Maine. This way, a larger territory is sampled, and the sampling frequency is much greater. Researchers aim to better understand the movements of moths and how they spread during an outbreak. With the help of citizens, science can evolve at a faster pace.

For further information on this project or to take part in it:
http://budwormtracker.ca