Gypsy moth in Canada: Behavior and control

Paul Benoit and Denis Lachance
Quebec Region • Information Report DPC-X-32

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Paul Benoit and Denis Lachance

Forestry Canada
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Cover: (*Top left*) red oak stand defoliated by gypsy moth. (P. Therrien)
(*Center*) mature caterpillar of a gypsy moth. (T. Arcand)
(*Bottom right*) moderate defoliation of a red oak by gypsy moth. (L. Jobin)

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Abstract

How, where, and when the gypsy moth, *Lymantria dispar* (Linnaeus), was introduced into Canada and its actual distribution are described. The insect, its life cycle, and the environmental factors that influence its behavior are described and illustrated in detail. The report is concluded with a chapter on insect control.

Introduction

The gypsy moth is often considered to be the worst defoliation threat to deciduous trees in the northeastern United States. In Canada, its effects are limited but the insect's potential for destruction is significant and it is known for cyclic population explosions followed by sudden collapses. A single instance of complete defoliation can kill coniferous species, and three consecutive total defoliations can be fatal to deciduous trees. Gypsy moth larvae (caterpillars) are a nuisance in urban and recreational centers where, in addition to disrupting human activities, they affect tree health and hinder its fiber growth.

History and Distribution

The two sexes of *Lymantria dispar* (Linnaeus) differ markedly in appearance: female moths are a much lighter color and have larger bodies than males. The insect is widespread in Europe and northern Asia, where it is represented by numerous geographic subspecies (especially in Asia). The gypsy moth was introduced to North America from France in 1868 or 1869 by artist, naturalist, mathematician, and astronomer Léopold Trouvelot, who was raising silkworms and crossbreeding them with other insects to obtain hardy varieties. He was conducting his work in the Glenwood district of Medford, north of Boston, Massachusetts, when a cage containing gypsy moth caterpillars was blown over by the wind. Trouvelot searched unsuccessfully for the escaped insects and notified the authorities of the accident. However, there was little reaction and the incident was soon forgotten, until 1889 when the gypsy moth population underwent an unprecedented explosion. In spite of numerous control efforts, the insect invaded all the New England states. On several occasions, it has been accidentally carried to distant states such as Michigan, Florida, and California. Efforts to kill it after introduction have been partially successful in all of these states except Michigan where it is spreading rapidly (Fig. 1).

The first record of a gypsy moth introduction into Canada was at the port of Vancouver in 1911, when inspectors from the Plant Quarantine Division of Agriculture Canada found and destroyed eight egg masses on a small cedar from Japan. In the East, the insect was first discovered near Henrysburg and Stanstead, Quebec, in 1924, adjacent to the already infested Lake Champlain valley in New York State. At Henrysburg, all the egg masses found were creosoted, everything that would burn and could harbor eggs was burned, and stone fences were cleaned. The efforts were so successful that the last traces of the insect had vanished by 1926. The single egg mass found at Stanstead turned out to be sterile. The gypsy moth was found again in Canada in 1936 around St. Stephen, New Brunswick. This time, it took 4 years of intensive effort to eradicate the invading population. Later, despite monitoring programs in the forested areas of Quebec adjacent to the northern United States, and in spite of annual control attempts covering at times 800 ha from 1959 to 1965, the gypsy moth spread into southern Quebec. As early as 1966, 9700 ha were infested near Huntingdon and Châteauguay. The following year, the triangle formed by St-Chrysostome, Rockburn, and Hemmingford — more than 14 000 ha — was largely infested. In addition, there were local infestations over 800 ha near Ormstown and in the area bordering the northern shores of Lake Champlain.

In 1969, the gypsy moth appeared in Ontario, on Wolfe Island near Kingston. Since then, it has spread to some neighboring islands and to the north of Kingston, and has been observed in Ottawa and in the Cornwall area as far east as the Quebec border (Fig. 2). The insect was identified in Toronto in 1980 and spread rapidly around Lake Ontario up to Niagara Falls. During the next few years, the infestation increased in size until 1985 when defoliation occurred over some 246 000 ha in the eastern region and the adjacent part of the central region of Ontario. Infestations decreased dramatically in 1986 and 1987, to about 12 000 ha at moderate to severe defoliation.

In 1978, it was accidentally reintroduced to British Columbia (in the Kitsilano section of Vancouver) when a former resident of Île-Cadieux, a small island municipality west of Montreal, Quebec, inadvertently brought with him about 40 egg masses stuck to outdoor recreational equipment. The gypsy moth's presence was revealed by the moths captured in pheromone traps. Extensive control measures were undertaken in 1979. The insect did not reoccur in the area, but introductions were subsequently noted

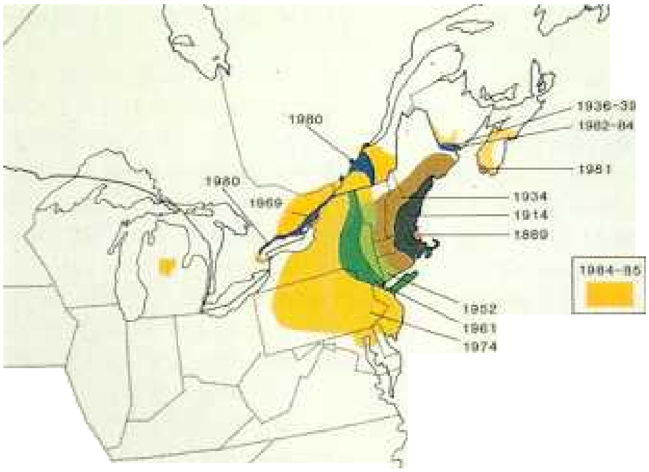

Figure 1. Dispersal of gypsy moth in northeastern North America since its introduction in 1869. (M. Bolduc and C. Moffet)

Figure 2. Oak and maple stand with oak trees defoliated by gypsy moth at La Trappe, Quebec. (L. Jobin)

elsewhere. Eradication operations were again carried out.

In New Brunswick, a new infestation was discovered in 1981 at Mohannes, Charlotte County, in an oak stand along the St. Croix River, and another caterpillar was found in the Oak Hill cemetery, 20 km away. A few egg masses were found elsewhere each year in this same county, but no defoliation was noted. In 1987, defoliation occurred over 5 ha near Moose Mills, and eradication operations were carried out. This situation correlates well with that existing in adjacent Maine, USA.

Finally, in western Nova Scotia, egg masses and cocoon remains were found in 1981 and since then, the gypsy moth has been found in isolated locations throughout the western half of the province mainly from Halifax to Kemptville.

The most recent surveys in Quebec indicate that the gypsy moth is common throughout the southern region between the American border and the St. Lawrence River. The insect is gradually advancing toward the East and has reached the Quebec City area where egg masses have been found since 1982. They are destroyed as soon as found.

In the United States, where the battle to control the gypsy moth has continued for more than 100 years, major infestations last 3–4 years in one locality, and the insect then lies dormant for 7 or 8 years. The infestations in Quebec seem to follow the same pattern. At present, the gypsy moth is not overrunning large expanses of forest like the spruce budworm or the forest tent caterpillar. The infestations are local and usually brief, occurring as a series of separate buildups and declines throughout the distribution area.

Host Plants

Of all insects with varied diets, the gypsy moth undoubtedly can adapt to the largest number of plants. This is especially true of older caterpillars, which can feed on grasses, swamp plants, shrubs, bushes, and hardwood and conifer trees. From laboratory tests and field studies, researchers have listed nearly 500 potential host species. In Quebec, to date, observers have noted more than 30 tree and shrub species that provide food for the gypsy moth.

During a major buildup nearly all plants are vulnerable to attack, although in low populations the caterpillars, especially young ones, stay on the species most favorable to their development.

From our own data and lists of known hosts in Europe and the United States, we can identify the species most susceptible to defoliation by the gypsy moth in Eastern Canada and particularly in Quebec. (We thank Dr. M.J. Lechowicz, Department of Biology, McGill University, for the final revision of the host plant list.)

Hosts favored by all larval stages: alder, apple, basswood, beaked hazel, birch (except yellow and cherry birches), hawthorn, larch, oak, poplar (except silver poplar and eastern cottonwood), rose, serviceberry, and willow.

Hosts favored only by older larvae: balsam fir, beech, hemlock, pine, and spruce.

Hosts least favored by older larvae: cherry, cherry birch, elm, eastern cottonwood, hickory, hornbeam (blue-beech), maple (except mountain, red, and striped maples), pear, silver poplar, staghorn sumac, and yellow birch.

The susceptibility of hosts also depends on the availability of other food sources in the area where they are growing. Thus, in an area where gypsy moths are very active, a single ornamental sugar maple would be very susceptible to defoliation but the same tree species scattered through a red oak stand could remain unharmed.

The following plants are left undamaged by the gypsy moth unless the larvae are starving: ash, dogwood, eastern white cedar, honey-locust, huckleberry, juniper, black locust, mountain maple, mulberry, nannyberry, raspberry, red cedar, red current, red maple, sassafras, striped maple, sycamore, tuliptree, and walnut.

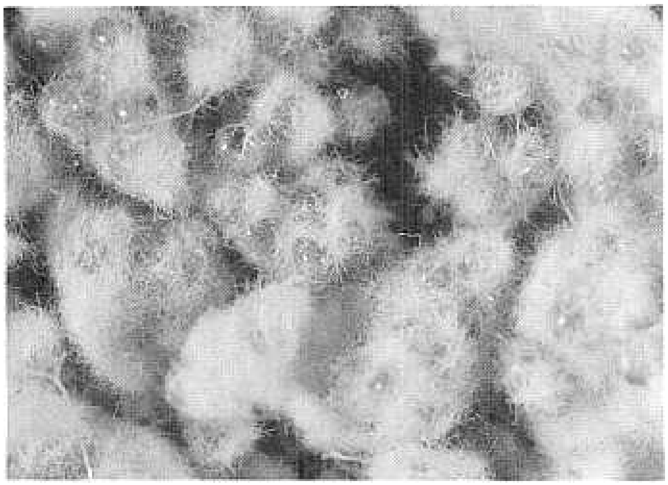

Figure 3. Individual eggs seen without their protective cover of hairs. (T. Arcand)

Description

Egg

Eggs are laid in oval or often elongated pear-shaped clusters containing less than 100 to nearly 1000 eggs; the largest recorded number is 1400 but the average is 400–600. During a light infestation the average is higher than during a major infestation or at the end of an epidemic.

Egg masses are 15–40 mm long, 10–25 mm wide, and about 5 mm thick. During laying, the female covers the eggs with beige or buff-colored abdominal hairs giving the egg mass the appearance of a small sponge, hence the French name "spongieuse."

The individual eggs within the clusters are roughly spherical, slightly flattened on the bottom, and generally flattened or indented on top. They are about 1.5 mm in diameter. They are pale yellow to salmon pink when freshly laid and turn brown or dark brown as the embryos develop, a process that takes about 3 weeks. The surface of the egg appears smooth to the naked eye, but is marked with small irregular hexagons except at the indentation on the top, which contains a micropyle (small opening) surrounded by a rosette.

When spring conditions become favorable for hatching, 2–4 warm days are needed for all the viable larvae in a cluster to emerge. In a particular locality, the hatching period can last from 10 to 30 days or even longer (Figs 3–5).

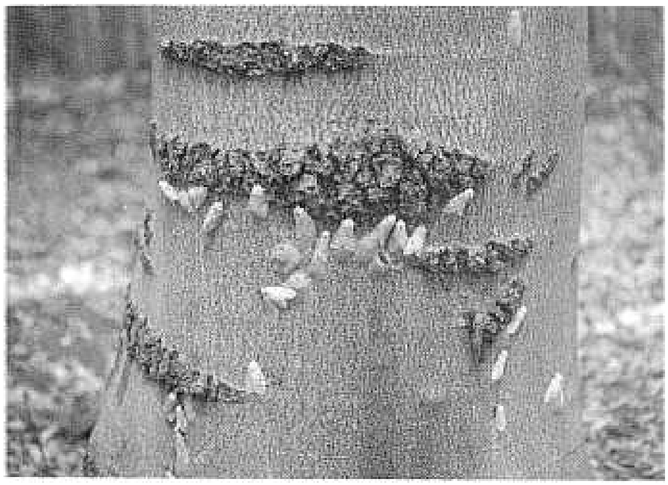

Figure 4. Female moths laying egg masses on beech. (L. Jobin)

Caterpillar

Larvae, or caterpillars, go through several instars (stages of development). Larvae that will become male moths go through five instars; females, six. Larvae molt between one instar and the next, that is, they cast off one exoskeleton (outer skin) for a larger one.

Instar I — When the larva emerges from the egg, it is 4.6 mm long. Its head is shiny black and dotted with yellowish hairs. In several hours, the predominant body color changes from brownish yellow to dark brown. The body has numerous dorsal, subdorsal, and lateral tubercles (spots). The dorsal and subdorsal tubercles produce long, thin, silky hairs, or shorter

Figure 5. Gypsy moth egg masses laid under a tar-paper trap. (L. Jobin)

hairs that thicken at the basal end, or both types together. The lateral tubercles put out thread-like hairs that are sometimes longer than the insect's body and are bearded with tiny barbs. Near the end of the first instar, the larva becomes reddish brown and the tubercles turn black.

Instars II to IV — The insect can reach 20 mm long before the fourth molt. The head changes from shiny black to marbled brownish white. The body turns dark brown finely marbled with yellow, and gray and orange splotches appear on its upper surface.

Instars V and VI — Length varies from 23 to 60 mm at maturity. The predominant color of the head is creamy to yellowish white. The top and sides are splotched with brown or black and a stripe of the same color runs along the outer edges of the clypeus (upper lip). The proportion of white to black varies greatly

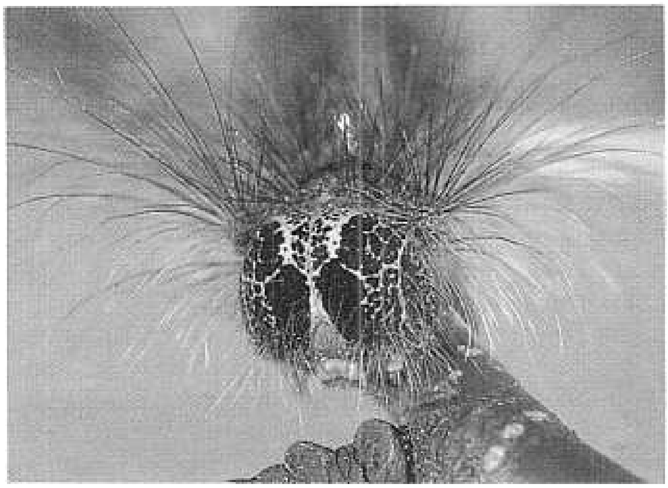

Figure 6. Head of a mature caterpillar showing tufts of hairs characteristic of the gypsy moth. (T. Arcand)

from larva to larva, but the head is always dotted with numerous yellow hairs. The dorsum (back) is creamy white and marked with small irregular black spots which make it appear dark gray, but with a paler central stripe. The most notable features during these later instars are the subdorsal tubercles, which are blue on the second to sixth segments and red on the seventh to twelfth segments. Moreover, the long tufts of hairs protruding from the lateral tubercles near the caterpillar's head, which are very prominent when the insect is viewed head-on, are rarely seen in other species of caterpillars (Fig. 6).

Pupa

The pupa (*Pupa obtecta*) resembles a mummy. The wings and appendages are glued down against the body. The pupa is smooth and cylindrical, and the fourth, fifth, and sixth abdominal segments are free. Ranging from 15 to 20 mm long for the male and 15 to 35 mm long for the female, it is initially soft and pale but later becomes fairly hard and turns chocolate brown to dark brownish red. Tufts of short, ocher yellow hairs cover the eyes, head, feelers, neck, and thorax and are arranged in eight equidistant rows on the abdomen. A small tubercle on the undersurface of the last visible segment of the abdomen distinguishes the male from the female. At the tip of the abdomen is the cremaster, a small hook with which the pupa attaches itself to any close object. This stage lasts an average of 10 days for females and 13 days for males (Figs 7 and 8).

Figure 7. Pupae on a tree trunk. (R. Gagnon)

Figure 9. Male moth (approx. 2.5 cm life size). (T. Arcand)

Figure 8. Pupa showing the characteristic yellow hairs of the gypsy moth. (T. Arcand)

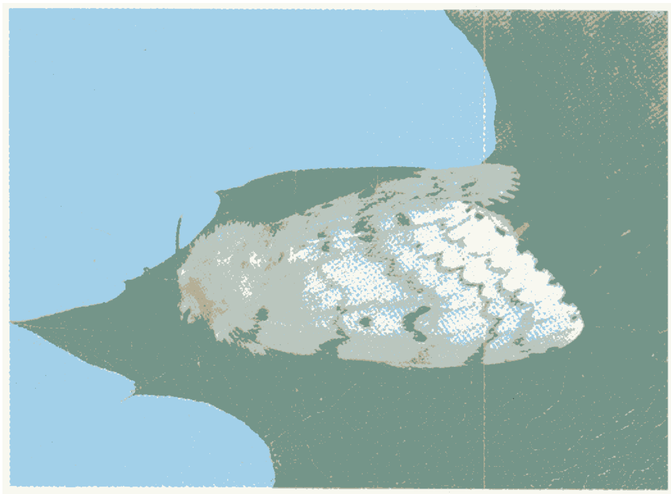

Figure 10. Female moth (approx. 3 cm life size). (T. Arcand)

Moth

Male moths have a wingspan of 37–50 mm. The predominant color is yellowish brown on the upper surfaces and slightly paler underneath. The body and legs are even paler than the undersides of the wings, while the head, thorax, and antennae are grayish brown. The forewings show several dark brown lines, marks, and splotches. The most distinguishing feature of the male gypsy moth is the conspicuous feathery antennae that separate it from many other species with a similar description.

The females have a wingspan of 37–62 mm. The body and wings (upper and lower surfaces) are white to yellowish white, except for the underside and the upper surface toward the end of the abdomen, which are pale yellow. The markings on the forewings vary from brown to black and are sometimes very faint. The antennae and legs are dark brown. The abdomen is much bigger than that of the male (Figs 9 and 10).

Life Cycle

The life cycle of the gypsy moth consists of four stages: egg, larva, pupa, and moth. Only one generation of moths is produced each year (univoltine).

Laying and Hatching

The eggs are laid between early July and late August according to the region. The embryo starts developing as soon as the eggs are laid but the larva stays in the egg until the following spring. Egg clusters are deposited nearly anywhere: on the trunks and branches of trees, on or under rocks, in hollow stumps, under debris on the ground, on building walls and fences, and on or under any equipment resting on the ground. Hatching begins the following May and can extend to June; eggs that receive the most sunlight hatch first.

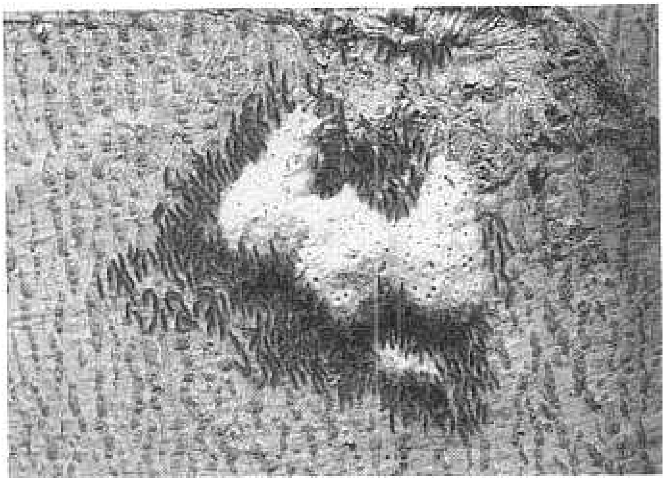

Figure 11. Newly hatched caterpillars. (P. Benoit)

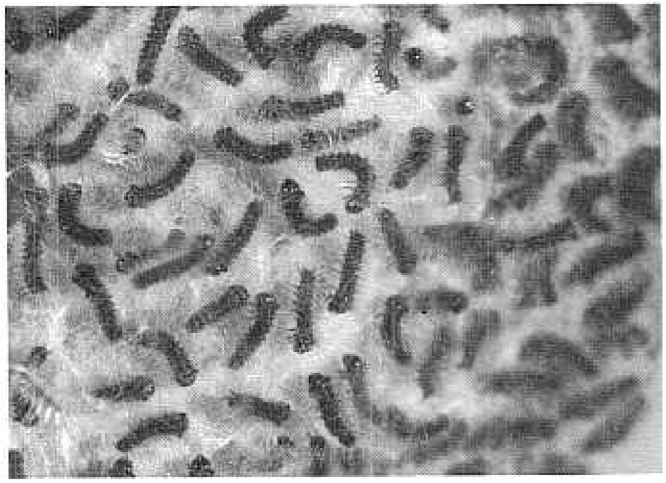

Figure 12. Enlargement of newly hatched caterpillars showing their numerous hairs. (T. Arcand)

Period of Caterpillar Development

Following emergence, the young larvae stay on the surface of the egg cluster for several hours to more than a day before setting out. They climb to the tops of trees or bushes and start feeding. If foliage is not yet developed or if the caterpillars feel overcrowded, they arch their bodies at a touch of wind and are blown away on a long silk thread. This is the most effective natural method of dispersal used by the gypsy moth. The insects may be carried by the wind to better feeding grounds, or to unsuitable locations. Young larvae can live for up to a week without feeding, but high mortality sometimes occurs during the dispersal period. Larval activity lasts 2–3 months and extends through May and June, and sometimes into July. The length of the first instar is 5–10 days, the next three or four instars take about a week each, and the fifth (males) and sixth (females) last between 10 and 15 days. The actual duration of each instar depends on the weather and the environment. In the first instar, the caterpillars move very slowly and are inactive at temperatures below 10° C. They do not reach their normal level of activity until the temperature rises above 20° C. Larvae in stages 1–3 stay on the leaves day and night. Once they reach the fourth instar, however, they move off the foliage to the crotches or underside of the branches or on the dark areas of the bark or they come down from the trees for shelter during the day and feed only during the evening and part of the night. If there are many larvae and there is strong competition for food, their behavior changes and older larvae also feed during the day. Several factors — including the quantity and quality of food, population density, and low temperatures — often cause additional molts, especially during the first two instars. Also, in any egg cluster, some larvae always go through additional molts regardless of environmental conditions.

During the larval stages, a gypsy moth devours an average of 1 m^2 of foliage, the male slightly less and the female slightly more. The last larval instar causes the most damage. During this period, usually in July, the caterpillar devours 60–70% of the foliage it will eat in its lifetime. This is why the damage caused by the insect appears so suddenly (Figs 11 and 12).

Caterpillar to Moth

The pupal stage appears to be a time of rest because the insect is immobilized; however, during a 9- to 17-day period in July, the caterpillar completely changes its anatomy and morphology to become a moth, whose behavior and purpose are totally different.

When the caterpillar reaches full maturity, it finds a sheltered spot anywhere, stays inactive for about 24 hours, and then empties its alimentary canal. About 1 hour later, it starts to weave a loose cocoon of silk produced by a mouth gland, adding bits of leaves or other debris. After weaving its cocoon, a process of 5 or 6 hours, the larva rests suspended head down, occasionally jerking or twisting rapidly. Pupation (the change to a pupa) is complete about 3 hours later.

Emergence of the Adult Moth, Mating, and Egg Laying

After 9–17 days and depending on the resistance of the cocoon and the hardiness of the insect, the moth takes from 5 minutes to several hours to emerge. It then dries off fairly quickly, and its wings take from 20 minutes to 2 hours to unfold and stiffen. After emerging, the female crawls a short distance from the cocoon and begins to give off a pheromone, a specific scented gas that attracts male moths for mating. Secretion of the pheromone begins about 9 hours after emergence and continues for about 20 hours. Attractancy increases with the age of the virgin female, but is greatly reduced after mating has occurred. The male flies in a zigzag pattern toward the source of the pheromone. Once he locates the female, he communicates by dancing over and around her while rapidly beating his wings. The time spent mating can vary from 30 minutes to 3 hours, but the average is 1 hour and the first 5–7 minutes are the most critical for successful insemination. Male moths can successfully inseminate several females. A single female can sometimes be fertilized by more than one male. When two or more males approach the same female simultaneously, they compete for her by veering toward each other and touching wings. This appears to be an important mechanism for dispersing males to the more sparsely populated areas on the edges of the infestation.

The female with her eggs is very heavy and will fly only on rare occasions. Individuals that do fly are usually much smaller than average. The female begins laying by sticking a bit of hair from her abdomen to some bark, rock, fence, or another support and laying several eggs side by side on the hair. She then continues laying eggs in a cluster on top and in front of the first ones, usually creating a mass in the form of an elongated pear. As laying proceeds, the eggs are cemented together and covered with hairs from the female's abdomen, which are dislodged by continuous brushing movements. The female's abdomen shrinks progressively during the process. A single female generally lays only one cluster of eggs and does not usually manage to lay all the eggs she has produced. Laying takes 2–3 days but most of the eggs are laid within the first 24 hours. The embryos develop partially during the 3 weeks following laying and complete their development the next spring.

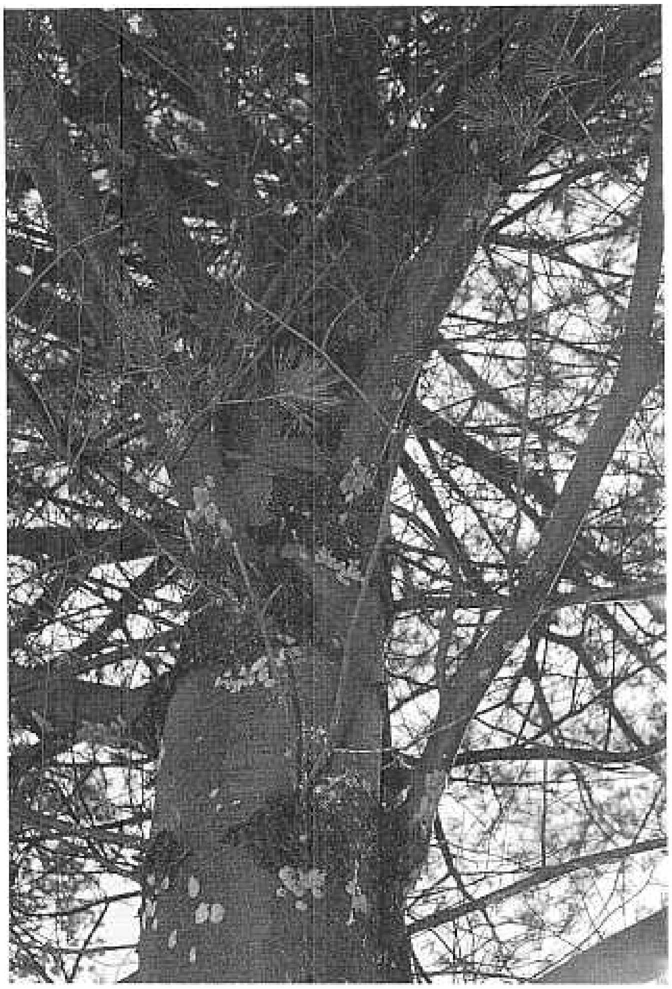

Figure 13. Numerous egg masses laid high on a white pine trunk. (P. Therrien)

The distribution of eggs laid close to the ground as opposed to high in the trees depends on the availability of debris, rocks, fences, and stumps. In urban parks or in forests where the ground is mostly bare, most of the eggs will be laid high in the trees (Fig. 13).

Environmental Influences Nonliving

Temperature

Gypsy moth embryos must go into diapause (arrested development) under the cold temperatures of winter before they can hatch in the spring. The temperature sometimes drops too low, however, for the insects to survive. A temperature of -25° C can kill 20% of embryos if it lasts for 1 day and up to 95% if it lasts for 5 days. In Canada, embryos can withstand longer exposure to cold than embryos in Massachusetts, but the lethal temperature is the same for both. However, 5 cm of snow can protect 50% of embryos against a temperature of -38° C.

Warm weather too early in the spring can reduce the population by causing eggs to hatch prematurely before the leaves are on the trees. In early spring, warm weather is often followed by cold periods that kill a large percentage of the newly hatched caterpillars.

Light plays a major role in caterpillar behavior. The larva hatches with an instinct to move toward the light, which is blocked when its front legs lose contact with a solid object, as happens when it reaches the end of a branch, so that it can turn around. Light also controls the larva's feeding pattern. At the fourth instar, larvae switch feeding from day to night. The caterpillars remain in their resting sites during daylight, but as the light decreases at dusk, they return to the foliage to feed particularly during the evening, with a smaller peak before dawn.

Moisture

During rainy periods, newly hatched caterpillars hide under leaves and are not dispersed by the wind. Individuals that are not yet attached to the foliage may be dislodged by raindrops. High relative humidity, when not accompanied by rain, shortens the prehatching and hatching periods and lengthens the lifespan of the adult moths.

Although human means of transportation are responsible for long-range dispersal, the wind is the major natural springtime dispersal agent and can carry newly hatched caterpillars for distances greater than 50 km. The silk thread from which the insect dangles from the trees, as well as its numerous long tapered hairs and shorter bulbous hairs, gives it a very high soaring coefficient. The soaring coefficient is a measure of a body's ability to be carried by an air current and is obtained by dividing the caterpillar's surface area in square centimetres by its mass in grams. The soaring coefficient of a newly hatched larva is 514.3, a figure that compares favorably with those for highly efficient airborne seeds such as dandelion and milkweed. The soaring coefficient drops sharply when the caterpillar reaches the second instar.

Wind-borne young caterpillars may be observed for nearly a month during a normal spring (20 days during a late spring). Maximum dispersal occurs between the 10th and 15th day after the start of hatching when warm weather (minimum 10° C) is accompanied by winds of at least 4 km/hour. Dispersal is optimum with temperatures between 20 and 30° C and winds of 8 km/hour or greater. There is probably no limit to the height to which the young insects can be carried: they have been captured at heights up to 600 m; tests at higher altitudes have not been conducted.

Although wind dispersal seems to encourage the establishment of secondary centers far from the main infestation, the danger is less serious than it appears because the farther the individuals travel the more they are isolated and the less they are able to establish new infestations; natural mortality rates are also higher. From the Lake Champlain area, the site of the original gypsy moth infestation in Quebec, the infested area expanded by only about 5 km/year in all directions north of the United States border. The infestation could spread faster, however, if larvae, cocoons, or especially egg masses on materials were transported beyond the main area by commercial or private vehicles.

Another dispersal factor is the migration of older caterpillars from their food-depleted area to new food sources in adjacent areas. They travel only short distances, but this type of dispersal is very common where the caterpillar population is high.

Environmental Influences — Living

Food

Generally, caterpillars that feed on their preferred hosts have a lower death rate and develop more rapidly than caterpillars that feed on less favored species. Among male and female populations, a relatively stable proportion of individuals go through additional molts. This proportion varies, particularly during the first instar, depending on food quality and especially on food availability. For reasons still unknown, there is also a low percentage of caterpillars that develop through fewer instars than the norm.

Population Density

In very high populations, completion of the first instar takes longer, more individuals go through extra instars, the weight of pupae drops, and the female moths lay fewer eggs.

Predators

A wide variety of insects and other arthropods, birds, and small mammals eat substantial numbers of gypsy moth eggs, caterpillars, pupae, and adults. Chickadees and black carpenter ants are the two currently recognized predators of eggs in Eastern Canada. However, if insects behave here as in the northeastern United States, feeding on eggs by soldier beetles, dermestid beetles, trogositid beetles, green lacewings, true bugs, and mites should be fairly common.

Among the arthropod predators of larvae, the ground beetles and tiger beetles, the carabids — especially those of the genera *Calosoma, Carabus, Harpalus*, and *Agonum* — appear to be the most effective. The adults hunt during the day and the larvae hunt at night. Tiger beetles, stinkbugs, ants, the yellowjacket *Vespula consobrina* (Sauss.), the baldfaced hornet, the pigeon tremex, and some flies and spiders are other arthropods that are helpful in controlling low residual gypsy moth populations (Figs 14–16). Under such conditions, amphibians (toads and frogs) and reptiles (snakes and lizards) also contribute to controlling larvae and moths. Among mammals whose diets consist largely of insects, the raccoon and skunk are the most important gypsy moth predators and feed on its various forms. As both mammals are nocturnal, it is assumed that they eat pupae in forest litter and female moths resting at the foot of trees. The caterpillars, which feed mostly at night, are less accessible.

Among small mammals, chipmunks and squirrels provide some control, but shrews, moles, and mice are by far the most effective predators. Important species include the white-footed mouse, woodland jumping mouse, meadow jumping mouse, northern redback vole, short-tailed shrew, masked shrew, smoly shrew, and star-nosed mole.

Finally, birds are also important predators (especially in low residual gypsy moth populations).

Figure 14. A carabid beetle, *Calosoma calidum*. (J.-P. Laplante)

More than 40 predatory species have been listed in Canada. The best known are the blue jay, American robin, black-capped chickadee, gray catbird, northern oriole, scarlet tanager, rufous-sided towhee, and red-eyed vireo. In addition to the numerous bird species that feed on gypsy moths during the spring migrations, there are others that take advantage of the additional food source created when gypsy moth populations reach epidemic proportions. These include the redwinged blackbird, American crow, European starling, common grackle, brown-headed cowbird, black-billed cuckoo, and chipping sparrow. In spite of the enormous quantities of gypsy moths that predators consume during infestations, they have a much more beneficial effect in controlling low residual populations.

Parasites

There are more than 100 known insect parasites of the gypsy moth in the egg, larval, and pupal stages. In northeastern North America, the most active of these parasites include members of about 5 families of Diptera and 16 families of Hymenoptera. In the latter

Figure 15. Stinkbug (*Picromerus* sp.). (T. Arcand)

Figure 16. Stinkbug (*Picromerus* sp.) piercing a gypsy moth caterpillar and drawing its hemolymph (blood). (T. Arcand)

group, the most important parasites belong to the following families: Braconidae (especially *Apanteles* spp. and *Meteorus* spp.), Chalcididae (*Brachymeria* spp. and *Chalcis* spp.), Encyrtidae (*Ooencyrtus* spp.), Eupelmidae (*Anastatus* spp.), and Tachinidae (*Zenillia* sp., *Compsilura* sp.). Several of these insects were imported from Europe and Asia and released among gypsy moth populations. Several have become established and kill considerable quantities of gypsy moths each year.

Pathogens

The gypsy moth is affected by natural diseases of two types: infectious diseases (caused by bacteria, fungi, and viruses), which are transmitted by contact from one larva to another; and noninfectious diseases, which are not contagious and result from internal changes that occur in the insect's body under unfavorable climatic or feeding conditions, or are simply hereditary.

Diseases do not prevent the gypsy moth population from sometimes reaching epidemic proportions, but they are generally the major cause of the collapse of extremely high populations.

Infectious diseases — The most effective natural pathogen is *Borrelinavirus reprimens*, a nucleopolyhedrosis virus that affects larva and pupa. The virus dissolves in the intestine and releases rods that cross the gut wall and infect the blood cells. The virus spreads to the fatty tissues and finally to the outer skin. Diseased caterpillars are generally found hanging from the foliage or bark by their abdominal appendages, forming an inverted U shape. The bodies of the dead larvae rupture easily, releasing abundant quantities of virus to infect other larvae on contact. In dense populations, up to 75% of larval mortality can often be attributed to this virus.

Several bacteria, *Streptococcus faecalis* and *Serratia marcescens*, and also *Serratia liquefaciens*, *Pseudomonas aeruginosa*, and *Bacillus cereus*, are common pathogens but, taken together, generally do not account for more than 15% of larval mortality. These bacteria are carried by the wind or in the droppings of birds and small mammals. They are sometimes consumed with the foliage by the larvae. Once eaten, they produce toxins and consume much of the insect's internal nutrients, causing fairly rapid mortality. These bacteria are poorly suited to artificial or specific control efforts, because they are rapidly killed by sunlight and are sometimes dangerous to man and other organisms.

On the other hand, one bacterium found naturally in the soil can be very effective in combating gypsy moth. This bacterium is *Bacillus thuringiensis*, often called *B.t.* At a certain stage in its life cycle *B.t.* produces spores and crystals that are both toxic to gypsy moth. The crystal, which is more toxic than the spore, dissolves inside the caterpillar, freeing units of protein. These units are broken down by enzymes in the gut into toxic polypeptides which paralyze the intestine; feeding stops, internal tissues break down, and the caterpillar dies. Commercial *B.t.* spray formulas have existed for more than 20 years, but have only recently become popular.

The gypsy moth is also vulnerable to several fungi, including *Beauveria bassiana*, *Paecilomyces farinosus*, and *Aspergillus flavus*. These control agents are generally insignificant, because they are effective only under special conditions of humidity rarely found in nature.

Noninfectious diseases — Although few studies have been conducted in this area, noninfectious diseases appear to be related to climate, food, and heredity. For example, when the insect encounters unfavorable feeding conditions, physiological disorders often appear at the time of egg laying or in the newly hatched larvae of the next generation.

Susceptibility of the Forest

Several factors influence forest susceptibility. The most important is forest composition, but site quality (drainage, soil, and exposure) and degree of disturbance also play a major role. Open stands on dry sites are more favorable to gypsy moth than dense stands on sites of average to high humidity. In Quebec, stands with a high percentage of trembling aspen or grey birch are ideal sites for gypsy moth infestations. This is not only because these species are favored by the insect but also because they grow in disturbed sites: intensively harvested areas, burns, abandoned agricultural lands, and similar areas. These low-productivity stands contain numerous stem-broken, injured, and rotting trees where the gypsy moth can find shelter, pupate, and lay its eggs. High levels of defoliation are often found in favorable habitats that allow caterpillars to stay up in the trees instead of coming down to the ground, where shelter is less available and predation is more frequent (Figs 17–19).

In contrast, forests highly resistant to gypsy moth grow in rich soil where trees are hardy and numerous enough to form a dense canopy, and ground cover is well developed. The characteristic species are sugar and silver maple, white ash, basswood, white elm, water birch, tulip-tree (southern Ontario), and occasionally eastern hemlock. Mixed hardwood, hardwood–hemlock, and maple–beech associations are resistant to the gypsy moth. Small mammals are more plentiful in these habitats and they are more successful in restraining buildups in the gypsy moth population. However, these species of trees are not immune to periodical or occasional defoliations and sometimes tree mortality, especially if they are surrounded by susceptible stands.

Effects of Defoliation

Negative Effects

Health — Heavy defoliation clearly has a pronounced negative effect on tree health. Defoliation makes the trees susceptible to secondary diseases and insects and, when followed by a period of prolonged drought, can cause the mortality of some individuals. Light defoliation has little effect on tree health.

Growth — Losses of growth in height and especially diameter can reach 50% in the 1st year after defoliation greater than 80%. Early defoliation reduces growth mainly in the upper portion of the tree, whereas late defoliation affects mainly the lower part and hinders hardening of the branches, which are therefore less able to withstand winter conditions (Gerardi and Grimm 1979, p. 102). If severe defoliation occurs in succeeding years, losses can be 75% in the 2nd year and 90% in the 3rd year. During infestations, even less favored stands can be defoliated if they are surrounded by vulnerable stands. Moreover, when an infestation threatens a

Figure 17. Degraded and opened stand susceptible and vulnerable to large populations of the gypsy moth. (L. Jobin)

Figure 19. Birch stand very susceptible and vulnerable to the gypsy moth because it is used as a campground — trailers or tent-trailers are good locations for egg laying and could be moved from an infested area to a clean one. (L. Jobin)

Figure 18. Type of birch stand very susceptible to the gypsy moth. (L. Jobin)

commercial forestry operation, the loss in diameter growth is often more important than the loss due to tree mortality. When mortality occurs, it is apparently higher during the first years of a heavy infestation than during the later years. After a gypsy moth infestation, the trees need 2 or 3 years to recuperate before they regain their normal levels of productivity. Often, partial thinning resulting from tree mortality favors rapid growth of the remaining trees if young enough to respond favorably. A few years after the collapse of an outbreak, the total volume of wood in the stand then equals or nearly equals the output that would have been normal for the type and age of stand.

Mortality — In a stand containing less than 20% highly susceptible hosts, repeated defoliation causes little mortality. The risk increases in proportion to the percentage of susceptible hosts. Nevertheless, twigs can die in the 1st year of heavy defoliation and are even more likely to be killed if further defoliation occurs in succeeding years.

Soil water — When heavy defoliation affects large areas of forest, the site can no longer use the same volume of water that normally is lost through foliage evaporation. Any water it cannot use is rapidly lost to water courses and reservoirs, whose levels may fluctuate and cause local floodings.

Refoliation — After total or near-total defoliation, the tree usually grows new leaves in August, but they are often malformed or smaller than normal.

Temperature — In a defoliated forest, sunlight falls directly on the vegetative cover, raising the temperature of the soil and the litter and driving away predators such as snakes, lizards, and frogs. In some cases, prolonged higher soil temperature may cause some root damage which in turn affects tree health.

Insolation (sunburn) — In a severely or completely defoliated crown, the thin bark of young branches or stems may overheat in places. The cambium can be partly destroyed and, under some circumstances, the bark can crack or dry out.

Metabolism — To a greater or lesser extent, serious defoliation affects all of the following functions: timing of leaf growth, production of flowers and seeds, respiration and photosynthesis, conversion of metabolites and food reserves, hormone production, and fiber growth.

Recreation — As a people pest, the large caterpillars crawl over and into everything, often disrupting outdoor activities. This occurs particularly in campgrounds where the pest annoys campers and threatens the health of the trees and shrubs. In addition, control measures are difficult to apply in such areas without endangering people's health.

Aesthetics — The ornamental beauty of trees, or their utility as windbreaks or privacy barriers, is lessened.

A Positive Effect

Heavy defoliation over several consecutive years can kill host trees and encourage growth of less vulnerable species. In the long term, the stand may become less susceptible, although this natural process is slow and uncertain.

Control

The principal factors affecting gypsy moth population are related to the weather and the relationship between insect population density and the individual habitat.

Control efforts may be undertaken (1) during the buildup period when the insect is present in isolated infestation centers to prevent further buildup (although this may require repeated treatments); (2) during the infestation, to preserve the vegetation and decrease the insect population; or (3) during the latent period.

An excellent way to be aware of a new increase in gypsy moth population, its appearance in new areas, or the population level at the end of the latent period is to use pheromone traps (Figs 20–22). These traps of various shapes and materials are baited with a female sexual pheromone that specifically attracts adult male gypsy moths. The traps should be laid out yearly during the moth period to follow population trends; a high number (more than 10) of captured male moths in one or more traps could be the sign of buildup of a new local infestation or the moths could have been blown to the trap site by strong weather fronts. To be sure, scouting for egg masses should be undertaken and the eggs, if found, destroyed immediately if possible (Figs 23 and 24). In all cases, the requirement for a control treatment must be considered in the light of the economic consequences of an infestation, including its effects on forestry, agriculture, tourism, and aesthetics.

After a latent period of several years, during which the gypsy moth goes almost undetected, the insect begins a 3- or 4-year buildup period and its population increases without causing any truly noticeable damage. Treatment of large expanses of woodland is not recommended during this period, because such treatments are often ineffective in preventing explosive population growth shortly afterward. At the end of the buildup period, the insect multiplies rapidly until it becomes visibly harmful by causing heavy defoliation for 2 or 3 years.

Spraying, especially with chemical insecticides, will kill many caterpillars almost immediately. However, the remaining individuals will then be

Figure 20. Delta type pheromone trap for the capture of adult male gypsy moths. (L. Jobin)

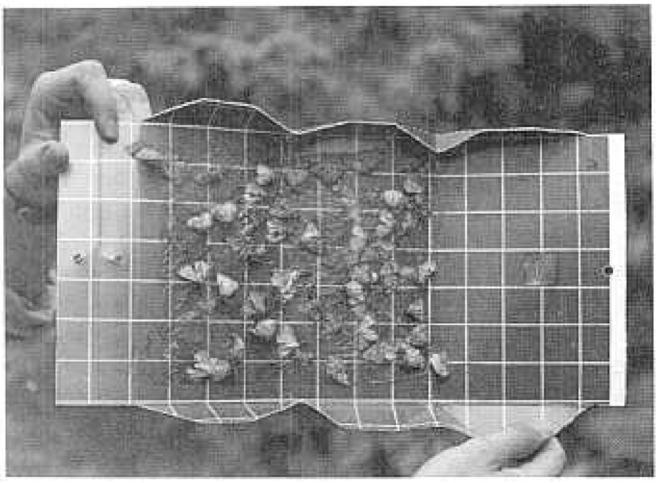

Figure 21. Opened delta trap showing captured moths on the sticky material spread on the inside. (L. Jobin)

Figure 23. Pile of stones, debris close to woodlands, wood piles, and fences are places sought by the gypsy moth for egg laying. (R. Gagnon)

Figure 22. Other type of pheromone trap used to capture adult male gypsy moths. An insecticide plaquette hangs inside, killing moths as they enter the trap. (L. Jobin)

Figure 24. Odd objects found in many backyards are also places sought by the gypsy moth for egg laying. (P. Benoit)

subjected to less competition, and will therefore have a better chance of surviving. In addition, the next egg laying will be more successful and, after a short delay, the infestation will reappear. In contrast, the use of biological control agents (parasites, predators, pathogens, and so on) can lessen the danger of a fresh outbreak because it does not reduce the competition among individuals that occurs during a heavy infestation. When agents such as bacteria, viruses,

Figure 25. Jute belts on ornamental trees used to trap caterpillars, pupae, or egg masses of the gypsy moth. (P. Benoit)

Figure 26. Caterpillars hidden under the jute during daytime. (L. Jobin)

parasites, or other natural agents are used, the infected caterpillars, which die off slowly, remain within the active population and thus continue to compete for space with the healthy insects. The survivors suffer the effects of this competition throughout their lives and produce fewer and often less hardy offspring.

Finally, it is noteworthy that even with non-silviculture control efforts we can't prevent the gypsy moth's buildup and decline cycles.

Physical Methods

For several trees or in small parks: (1) From the fall until early spring (September to April), collect egg masses by hand and destroy them or treat them by brushing with a creosote product. (2) In summer, if the population is not too high, coat bands of Tanglefoot® around tree trunks at about 1 m high to catch climbing larvae from other trees. Recoat the bands periodically to maintain their stickiness. (3) Install traps made of jute or similar material to provide shelter for the caterpillars during the day. Catch the caterpillars between morning and late afternoon. Caterpillars should not be handled with bare hands because their hairs cause irritation (Figs 25–29).

Silviculture Methods

For forests or large wooded areas: (1) In even-aged eastern white pine–grey birch stands, the presence of

Figure 27. Caterpillars hidden under a tarpaper trap during daytime. (L. Jobin)

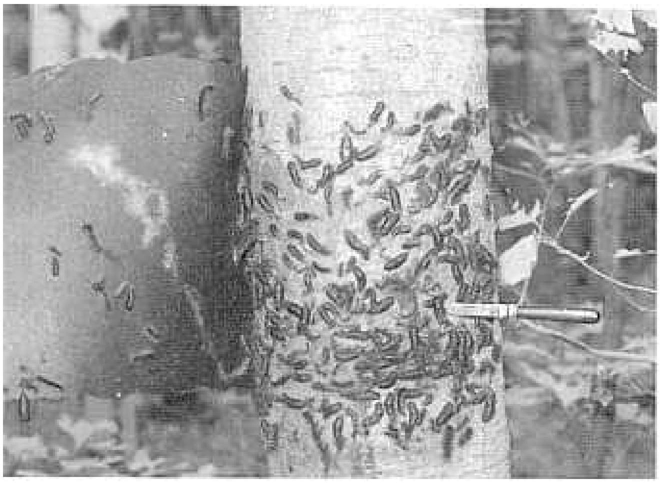

Figure 28. Numerous pupae under a tarpaper belt. (L. Jobin)

the grey birch is a constant threat. Progressive elimination of at least part of the birch population is recommended. (2) In young, even-aged eastern white pine–oak stands in dry soil, treatments to encourage the pine to the detriment of the oak are recommended. (3) Clear-cutting of vulnerable stands followed by replanting of resistant species is rarely economical or justified. It can, however, be desirable in limited areas subjected to intensive use.

When considering silviculture practices for improving a site, it is important to consider (1) stands of

Figure 29. Removing caterpillars hidden under the jute belt. Caterpillars should not be handled with bare hands because their hairs cause irritation. (C. Moffet)

trees favored by all larval stages (see list of host plants) are the hardest hit (for example, grey birch and aspen in Quebec); (2) dry, poor, rocky soils that are subject to various kinds of stress encourage the growth of host species favored by the gypsy moth; and (3) burning, grazing, and clear-cutting, especially on poor soils, make sites available to regeneration by pioneer plants prone to invasion by the gypsy moth.

Insecticides

When the foliage is about one-third developed (slightly earlier if the gypsy moth population appears to be excessively high and the insects are eating leaves as they appear), one of the following products may be applied, using an aircraft or helicopter for large areas, or a hydraulic pump or a mistblower for small areas or ornamental trees.

Products available in 1989 (substitutes are usually available when some products are removed from the market): polymerized butenes or natural gum resins (Tanglefoot®), which are sticky insecticide strips for domestic use; *Bacillus thuringiensis* (Bactospeine®, Dipel®, Envirobac®, Futura®, Thuricide®) for domestic, commercial, or restricted use[1] (20–30 Billion International Units [BIU]/ha, between second and third larval instar); acephate (Orthene®) for commercial and restricted use; carbaryl (Sevin®, Sevimol®) for domestic, commercial, or restricted use; diflubenzuron (Dimilin®) for restricted use; permethrin (Ambush®) for domestic use; phosmet (Imidan®) for domestic or commercial use; pyrethrins (Raid®) for domestic use; trichlorfon (Dylox®) for commercial and restricted use.

Conclusion

The gypsy moth is not native to Canada. It has been accidentally introduced in many locations in the country, and on several occasions eradication measures have been effective. Control and eradication measures are presently used in the West and in the extreme East. In Quebec and Ontario the insect seems to be established permanently. Therefore, we must understand its behavior, its impact on the forest, and the factors that govern its population cycles.

[1] Domestic use: Products may be used by everyone.
Commercial use: Some products or formulas may be used only by licensed applicators.
Restricted use: Products may be used only under the supervision of a government agency.

Bibliography

Benoit, P. 1980. La spongieuse une menace? Le Progrès forestier. June: 18-19.

Benoit, P. 1980. Moyens de protéger vos arbres contre la spongieuse. Le Progrès forestier. September: 20–21.

Bess, H.A.; Spurr, S.H.; Littlefield, E.W. 1947. Forest site conditions and the gypsy moth. Harv. For. Bull. No. 2. 56 p.

Brown, G.S. 1975. La spongieuse, *Porthetria dispar* (L.). Pages 231–236 *in* Traitements aériens pour combattre les insectes forestiers au Canada. Edited by M.L. Prebble, Dep. Environ., Ottawa. (Also available in English: Gypsy Moth, *Porthetria dispar* (L.). Pages 208-212 *in* Aerial Control of Forest Insects in Canada.)

Brown, M.W.; Cameron, E.A. 1982. Natural Enemies of *Lymantria dispar* (Lep.: Lymantriidae) Eggs in Central Pennsylvania, U.S.A., and a Review of the World Literature on Natural Enemies of *L. dispar* Eggs. Entomophaga 27: 311–322.

Burgess, A.F. 1913. The Dispersion of the Gypsy Moth. US Dep. Agric. Bur. Entomol. Bull. No. 119. 62 p., 16 plates, 6 figs.

Collins, C.W. 1915. Dispersion of gypsy moth larvae by the wind. US Dep. Agric. Bull. No. 273. 23 p.

Doane, C.C.; McManus, M.L., eds. 1981. The Gypsy Moth: Research Toward Integrated Pest Management. US Dep. Agric. For. Serv. Sci. Educ. Agency Tech. Bull. 1584. 757 p.

Felt, E.P. 1905. Insects Affecting Park and Woodland Trees. N.Y. State Mus. Mem. No. 8, N.Y. State Educ. Dep., Albany, N.Y.

Forbush, E.H.; Fernald, C.H. 1896. The Gypsy Moth. State Board Agric., Wright & Potter Printing Co. State Printers, Boston, Mass. 495 p.

Gerardi, M.H.; Grimm, J.K. 1979. The History, Biology, Damage, and Control of the Gypsy Moth, *Porthetria dispar* (L.). Fairleigh Dickinson University Press, Rutherford, N.J. 233 p.

Houston, D.R. 1979. Classifying Forest Susceptibility to Gypsy Moth Defoliation. US Dep. Agric. Handb. No. 542. 23 p.

Houston, D.R.; Valentine, H.T. 1977. Comparing and predicting forest stand susceptibility to gypsy moth. Can. J. For. Res. 7:447–461.

Leonard, D.E. 1974. Recent developments in ecology and control of the gypsy moth. Annu. Rev. Entomol. 19:197–229.

Mosher, F.H. 1915. Food Plants of the Gypsy Moth in America. US Dep. Agric. Bull. No. 250. 39 p.

Podgwaite, J.D. 1979. Diseases of the Gypsy Moth: How they help to regulate populations. US Dep. Agric. Handb. No. 539. 15 p.

Sippell, W.L.; Rose, A.H.; Gross, H.L. 1969. Annual Report of the Forest Insect and Disease Survey. Dep. Fish. For., Can. For. Serv., Ottawa, Ont. p. 52–71.

Société zoologique du Québec Inc., La. 1983. Noms français des oiseaux du Canada et des États-Unis continentaux. La Société zoologique du Québec, Charlesbourg, Quebec. 80 p.

Sterner, T.E.; Davidson, A.G. Ed. 1982. Insectes et maladies des arbres au Canada 1981. Dep. Environ., Can. For. Serv., Ottawa, Ont. 48 p. (Also available in English: Forest Insect and Disease Conditions in Canada 1981.)