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BioForest

2019

Gypsy Moth Monitoring Program

Town of Pelham

2019 Population Assessments and 2020 Forecasts

Prepared For:

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Gypsy Moth in North America

Gypsy moth (*Lymantria dispar*) is native to Europe and Asia and was introduced to North America from Europe in 1869. Interested in developing a silkworm industry in North America by crossing European gypsy moths with North American silkworms, Professor L. Trouvelot brought gypsy moths from France to Massachusetts. In 1870, a small number of gypsy moths escaped and, within 20 years, gypsy moth had become a serious regional pest.

Although the United States government has had a quarantine in place since the early 1900s, gypsy moth has been advancing slowly westward from the northeastern United States. In the United States, gypsy moth has spread from western Pennsylvania, through Ohio, Michigan, and Illinois and is now in central Wisconsin. It is estimated that gypsy moth is currently spreading at a rate of 21 km/year (USDA 2003). To address the gypsy moth invasion in the United States, the U.S. Forest Service has implemented the Slow the Spread (STS) project. The STS project is a large integrated pest management program that aims to eradicate or suppress colonies of gypsy moth detected along the expanding front of the population.

In Canada, the first gypsy moth was detected in British Columbia in 1912, but it did not become established. The first gypsy moth infestation in Canada happened in southwestern Quebec in 1924 and the second in New Brunswick in 1936. These eastern detections were the result of the expanding gypsy moth population in the northeastern United States. Intensive egg mass removal programs were used to eradicate both infestations. Since 1955, when gypsy moth was detected again in Quebec, gypsy moth has become established in southern Ontario, Quebec, Prince Edward Island, New Brunswick, and Nova Scotia (Natural Resources Canada 2003). In Canada, the Canadian Food Inspection Agency (CFIA) is responsible for preventing the introduction and spread of invasive pest species, including gypsy moth. Figure 1 (below) shows the areas of Canada that CFIA regulates for gypsy moth.

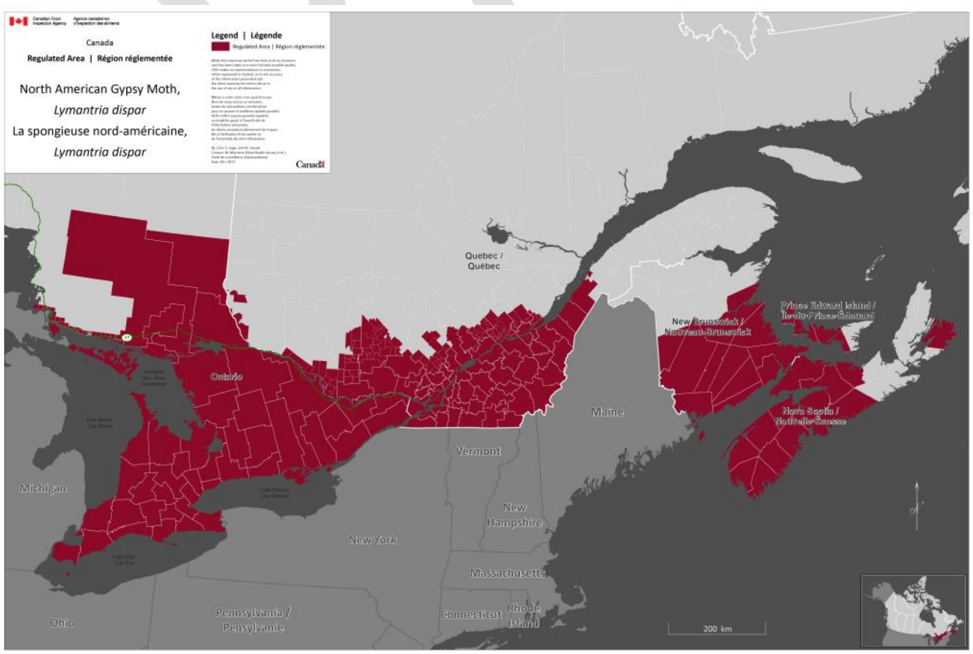

Figure 1. Areas in Canada currently regulated for gypsy moth by the Canadian Food Inspection Agency (Source: CFIA 2017).

Gypsy Moth in Ontario

Gypsy moth is a relatively new pest to Ontario. After its accidental release into Massachusetts in 1870, gypsy moth expanded its range over the next 100 years and was first detected in Ontario in 1969 on Wolfe Island, south of the city of Kingston. In 1981, the first major area of gypsy moth defoliation in the Province was detected near Kaladar in eastern Ontario. By 1985, gypsy moth was a serious problem throughout southeastern Ontario. As of 1996, the distribution of gypsy moth larvae includes the southern third of the Province and the northern boundary runs from North Bay to Sault Ste. Marie.

In Ontario, gypsy moth populations have peaked in 1985, 1991, and 2002, according to the 2019 Forest Health Conditions Report produced by the Ontario Ministry of Natural Resources and Forestry (OMNRF 2019). The last outbreak in Ontario, in 2008, was much less severe than previous ones.

Gypsy moth defoliation has been up and down since 2011, peaking at 23,335 hectares in 2014 and collapsing in 2016, but in 2017 this invasive defoliator caused 10,856 hectares of moderate-to-severe defoliation (Figure 2). All defoliation was mapped in Southern Region, 81% of it in Guelph District and the remaining areas in Peterborough and Aylmer Districts. In the Regional Municipality of Niagara, defoliation was mapped throughout woodlots around Smithville south to Wellandport in West Lincoln, and from the Welland River south to Hwy 3 in Wainfleet Township. Large swaths of moderate-to-severe defoliation were also mapped through the Town of Pelham, particularly around Ridgeville, and Effingham. In many of these areas, gypsy moth larvae were observed feeding alongside populations of fall cankerworm larvae, particularly in Hamilton (including communities of Copetown, Dundas, and Ancaster) and areas of Haldimand County.

Figure 2. Gypsy moth defoliation mapped by Ontario Ministry of Natural Resources and Forestry, 2017.

In 2018 (Figure 3), gypsy moth defoliation increased by 4,081 hectares in Southern Region compared to 2017. Extensive defoliation was recorded throughout the Golden Horseshoe, from St. Thomas to St. Catharines and up through Cambridge to Mississauga. In Guelph District, 11,154 hectares of moderate-to-severe defoliation were aerially mapped from the Cambridge area through to the Niagara region. The largest areas of defoliation were recorded south of Brantford in the eastern part of Six Nations Reserve close to Hwy 6, in Haldimand County near Hwy 3, west of Hamilton in the Lancaster area, and east of Brantford along Hwy 403. Smaller, more scattered areas of defoliation were observed east of Oswego Park to Niagara Falls and south to southwest of Cambridge.

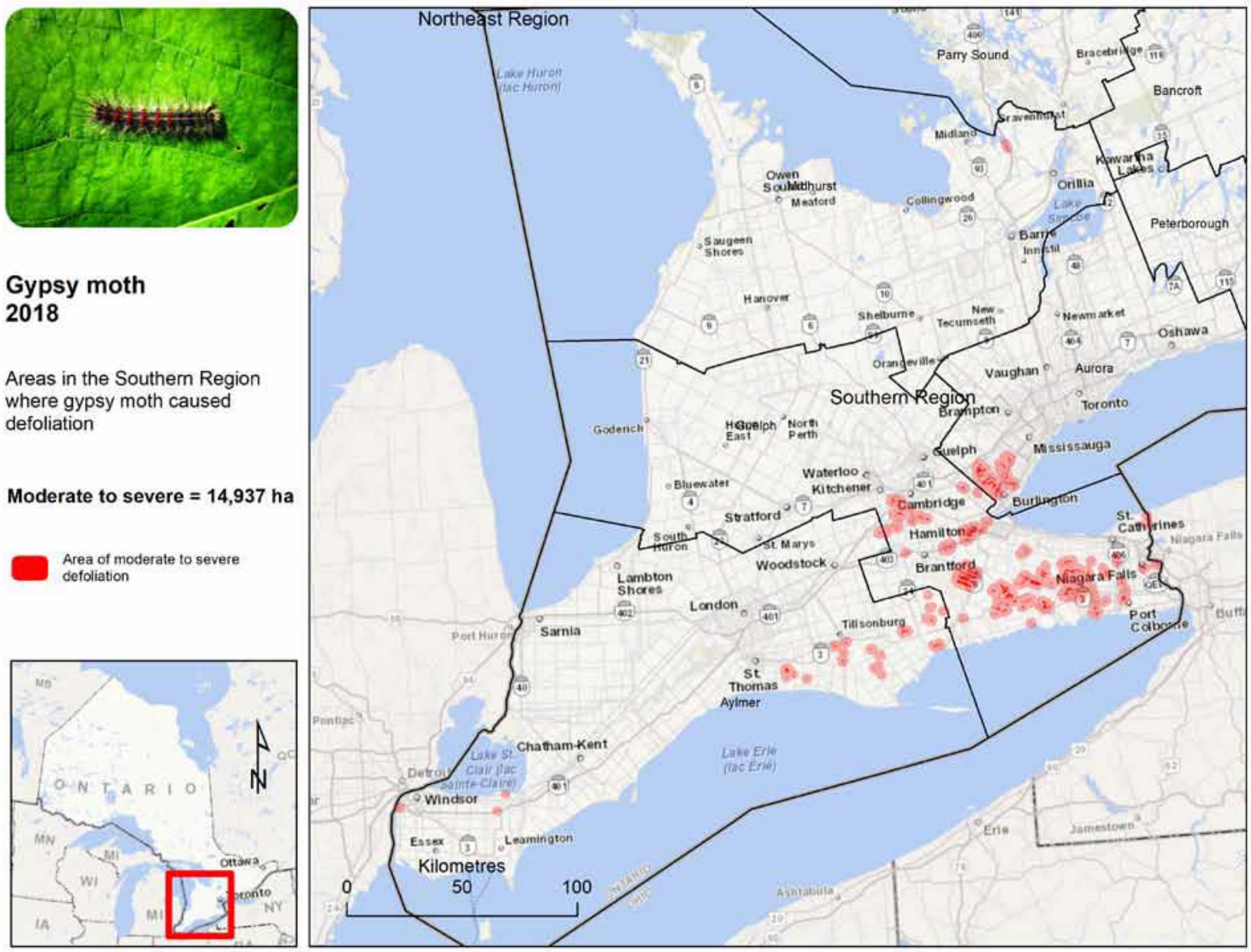

Figure 3. Gypsy moth defoliation mapped by Ontario Ministry of Natural Resources and Forestry, 2018.

In 2019, that number rose to more than 43,000 hectares (Figure 4). Defoliation was observed all throughout southern Ontario; notable locations included Hamilton, Niagara Peninsula, London, Sarnia, Norfolk Peninsula, Windsor, Guelph, west of Barrie and the Midland area. These maps show the expansion and progression of gypsy moth throughout southern Ontario over the past three years and fairly significant repeated defoliation in parts of the Niagara Region.

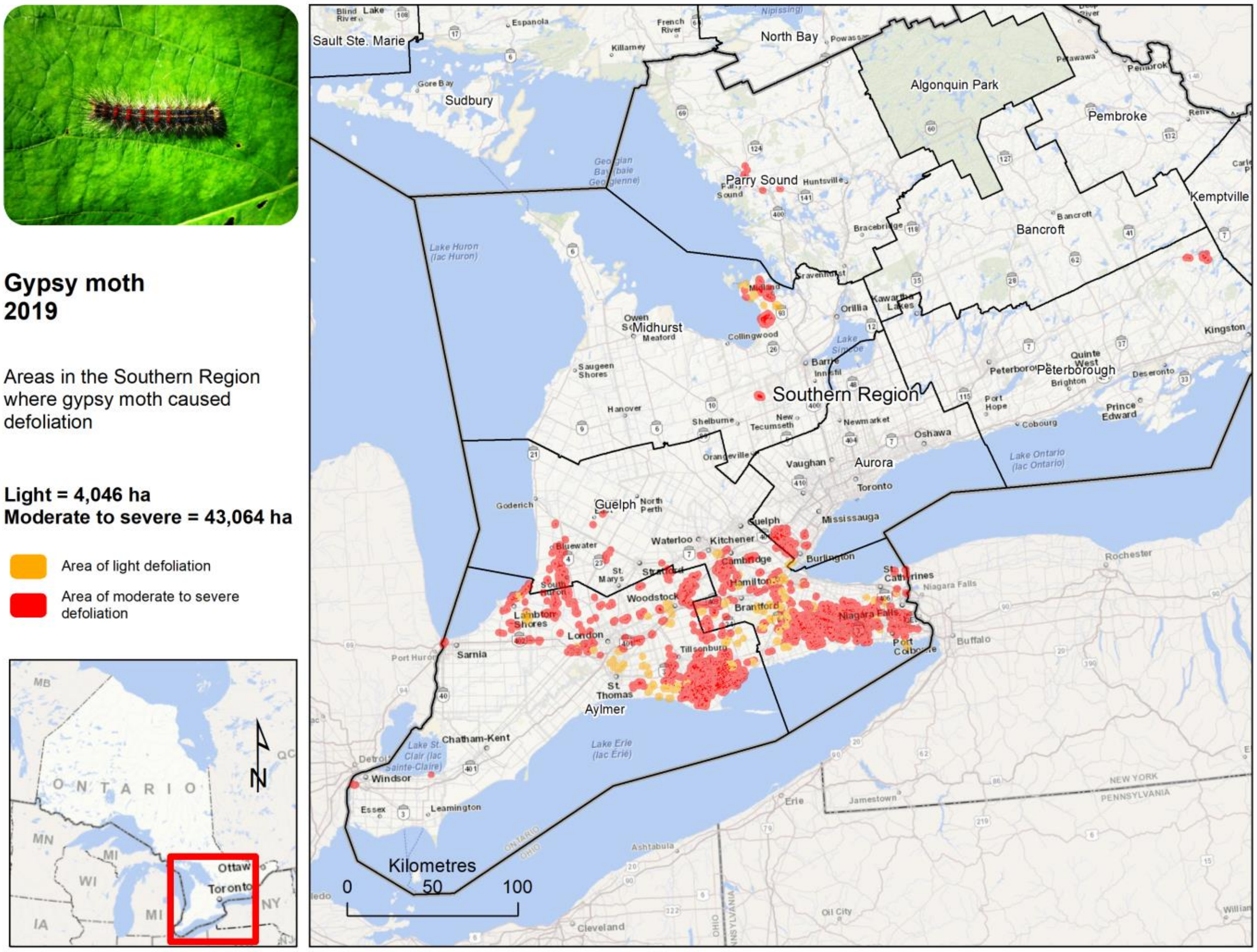

Figure 4. Gypsy moth defoliation mapped by Ontario Ministry of Natural Resources and Forestry, 2019.

Gypsy Moth Biology and Life Cycle

Figure 5 presents the life cycle of the gypsy moth. Gypsy moth is in the order Lepidoptera, which consists of moths and butterflies, and has one generation per year with four life stages: egg, larva, pupa, adult. Gypsy moth eggs are laid in late July or early August. Weather, food sources, and factors such as diseases all affect the exact time that eggs are laid. Eggs are usually laid in dark, sheltered areas such as in bark crevices, on the underside of branches, or in leaf litter, although they can be also be found on a wide variety of surfaces such as rocks, buildings, lawn furniture, and automobiles. The eggs are covered with fine brown hairs from the female's abdomen, giving the egg mass the appearance of a small piece of chamois (OMNR, undated). Egg masses can vary in size from being about the size of a dime to being larger than a one-dollar coin and may contain from 100 to 1,000 eggs. Smaller egg masses tend to indicate that a gypsy moth population is in decline, while larger egg masses indicate a stable or growing population.

Fully formed, dormant larvae, or caterpillars, spend the winter inside the eggs. Generally, egg masses are resistant to drying and cold temperatures. However, if temperatures drop below –32^{o}C for an extended period, egg masses above the snow line may be susceptible to winter kill. Eggs below the snow line are likely able to avoid winter mortality (Leonard 1974). When temperatures are warm enough in late April or early May, buff-coloured larvae chew through the egg mass coverings and emerge. Shortly after emerging, the larvae turn black. If conditions are favourable, larvae, attracted by light, begin moving upward towards foliage. If conditions are not favourable, the larvae will remain clustered on the egg mass until conditions improve.

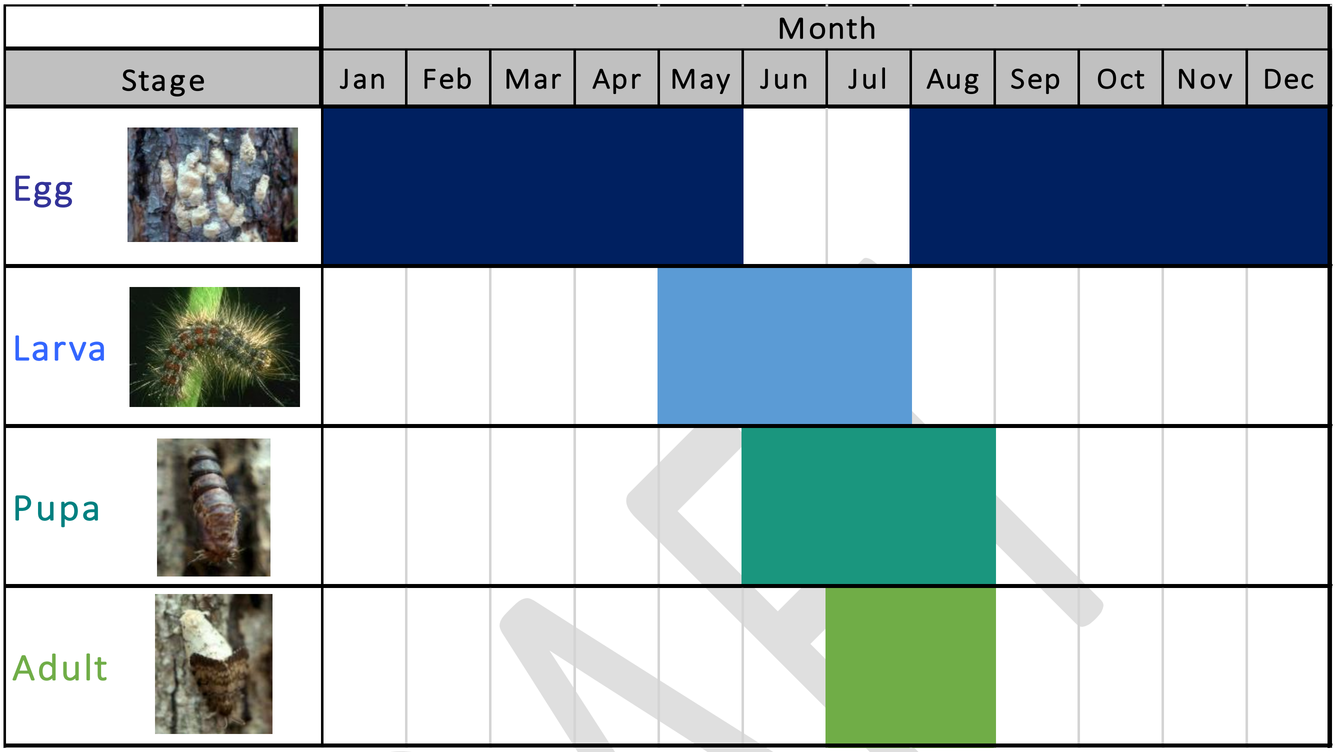

Figure 5. Gypsy moth life cycle in Ontario.

Of the four life stages of the gypsy moth, the larval stage is the only one that feeds. As a larva develops, it passes through stages called instars, separated by molts during which the larva's skin is shed and replaced with a new one. The male gypsy moth has five larval instars, while the female has six. Depending on weather, the first larval instar lasts five to 10 days, the next three (male) or four (female) instars last about a week, and the fifth (male) and sixth (female) instars last about 10 to 15 days (OMNR, undated). First instar larvae are approximately 4 mm long. Full-grown larvae are hairy and range in length from 35 to 90mm and have pairs of five blue and six red dots along their backs.

First instar larvae are very lightweight and covered with an abundance of fine hairs. While feeding throughout the crown of a tree, the larvae spin silken threads that can be caught by the wind, dispersing the larvae to new host trees. This form of dispersal is known as "ballooning." Some larvae balloon several times before they start feeding (Liebhold et al. 1992). Ballooning generally transports larvae short distances, moving gypsy moth larvae up to 1km. Gypsy moth are generally dispersed greater distances by people moving objects such as firewood, recreational vehicles, Christmas trees, and boats that have larvae, pupae, or egg masses on them. Although people can inadvertently disperse all gypsy moth life stages, they most commonly transport egg masses.

Figure 6. Gypsy moth defoliation (Source: Ontario Ministry of Natural Resources and Forestry).

First instar larvae begin feeding by cutting small holes in the surface of leaves. As the larvae develop, they feed on the edge of leaves (Figure 6). The first three larval instars remain on the foliage and feed day and night. When populations are very low (i.e. fewer than 250 egg masses/ha), larvae in instars four through six feed at night and at dawn look for shelter where they spend the day protected from the sun and predators. At higher populations (i.e. more than 1,250 egg masses/ha), shelter becomes less important and all larvae feed in the day and night (Brooks and Hall 2005). When the host plant is depleted, larvae crawl to find another suitable host (USDA 1995a).

Gypsy moth larvae are active from approximately early May to mid-July. During that time, one larva is able to consume an average of $1m^2$ of foliage, which is roughly the equivalent of 10 to 15 entire red oak leaves (Nealis and Erb 1993). Males generally eat slightly less than $1m^2$ and females eat slightly more. Larvae in the last instar cause the most defoliation, consuming three quarters of the total amount of foliage that they eat (OMNR, undated). Sixth instar female larvae are the most ravenous feeders and are often twice the size of full-grown male larvae.

After feeding is complete around mid-July, pupation occurs in a cocoon that can be found in many places including trees, rocks, houses, boats, trailers, fences, picnic tables, and firewood. In 13 to 17 days, the moths emerge. Male moths usually emerge one to two days before females (USDA 1995a). Both sexes have wings, but only the male can fly. The female is too heavy bodied to fly, so gypsy moth relies on the larval stage for dispersal. The male moth is dark brown to beige, is medium-sized, flies during the day, and is a very erratic flyer. Dark wavy lines cross the male moth's forewings and its wingspan ranges from 35 to 40mm. The female is mostly white and has a wingspan between 60 to 70mm. Dark wavy lines also cross the female moth's forewings but, because the female is lighter in colour, these lines are more prominent.

Figure 7. Female gypsy moth laying eggs.

To attract males, female moths emit a powerful pheromone, or sex attractant. Males have large feathery antennae for detecting the pheromone, and can do so from about 1.5km away. Within about 24 hours of mating, the female lays eggs in a mass of 100 to 1000 on tree trunks, branches, houses, and fences and under rocks and forest floor debris (Figure 7). Since the female cannot fly, eggs are laid close to where pupation occurred. The female dies about one day after egg laying and the male survives about one week, after mating with several different females (Nealis and Erb 1993).

Although in Europe and Asia there is evidence of cyclical outbreaks of gypsy moth, a clear pattern of outbreaks in North America has not yet been established (Liebhold et al 1994). However, gypsy moth populations do appear to exist in one of four phases: innocuous, release, outbreak, decline (Elkinton and Liebhold 1990). The innocuous phase is characterized by very low population levels. The release phase usually takes places over the course of one or two years and can result in population density increases of several orders of magnitude. During the outbreak phase, populations are high enough to cause noticeable defoliation and damage to host trees. After this point, high levels of gypsy moth mortality are observed usually due to starvation or disease and the population crashes. This is considered the decline phase.

Area-wide outbreaks can last up to ten years, but generally population densities in localized areas remain high for two to three years (Cloyd and Nixon 2001).

Gypsy Moth Natural Controls

Natural factors such as weather, predators, parasites, and pathogens significantly influence gypsy moth population densities.

Weather conditions can favour either low or high density populations. Extreme weather conditions characterized by prolonged periods of cold temperatures (colder than –32°C) can kill unprotected eggs, which can help to keep low density populations low or decrease high density populations. In contrast, warm, dry conditions tend to accompany increases in gypsy moth populations (Skaller 1985). Heavy rainfall during egg hatch may result in drowning of larvae; rainy weather during the first instar can delay migration and cause larvae to congregate on the underside of leaves (National Parks Service 2010). The conditions can also increase the duration of this instar.

Low density populations are normally kept in check by natural enemies such as predators and parasites (Brooks and Hall 2005). Predators that feed on gypsy moth larvae include about 40 species of birds such as vireos, chickadees, tanagers, orioles, robins, blue jays, grackles, starlings, blackbirds, and cuckoos (OMNR, undated); other insects; and small mammals such as skunks, white-footed mice, squirrels, and raccoons. Insect parasitoids kill gypsy moth by laying their eggs in gypsy moth eggs, larvae, and pupae.

At the start of a gypsy moth outbreak, natural enemies have little effect on the gypsy moth population (Brooks and Hall 2005). Populations increase when suitable conditions exist such as favourable weather and abundant foliage. Population decreases tend to happen in cooler, wetter conditions that favour pathogens. Gypsy moth is susceptible to a variety of naturally occurring infectious diseases that are caused by bacteria, fungi, and the nucleopolyhedrosis virus (NPV) (Campbell and Podgwaite 1971). *Entomophaga maimaiga* and NPV, the most significant natural enemies of gypsy moth, are capable of killing large numbers of gypsy moth larvae and represent the largest and most important factors in high density gypsy moth population crashes. *E. maimaiga* is a fungus that is specific to gypsy moth and is prevalent throughout low-to-high density gypsy moth populations. Although it is not completely clear how *E. maimaiga* first became established in North America, it was first recovered from North American gypsy moth in the northeastern United States in 1989. It was recovered from gypsy moth in southern Ontario in 1990. A late larva killed by *E. maimaiga* hangs vertically with its head pointed downward and its body tight to the trunk of the tree (Figure 8). An early larva killed by *E. maimaiga* generally remains on the foliage (Reardon and Hajek 1998). NPV was inadvertently introduced to North America with the gypsy moth or its parasites. Like *E. maimaiga*, NPV is specific to gypsy moth. NPV is often referred to as "wilt" due to the soft, limp appearance of the diseased larvae (Nealis and Erb 1993). A larva killed by NPV hangs on the tree in the shape of an inverted “V” (Figure 9).

Figure 8. Gypsy moth larva killed by *Entomophaga maimaiga* (Source: Steven Katovich, USDA Forest Service, Bugwood.org).

Figure 9. Gypsy moth larva killed by nucleopolyhedrosis virus.

No single natural enemy or combination of natural control agents can completely eliminate a gypsy moth population. Natural control agents can keep gypsy moth populations low, however, at times, outbreak conditions occur and the natural enemies are not able to control the growing gypsy moth populations (OMNR, undated).

Gypsy Moth Hosts and Impacts

Gypsy moth has been found on approximately 500 different tree species (OMNR, undated) and is a major defoliator of forest, ornamental, and orchard trees. Gypsy moth defoliates mainly hardwoods and some conifers. Table 1 lists the most common host species for gypsy moth and categorizes them by ‘most preferred’, ‘preferred’, and ‘least preferred’.

A gypsy moth infestation can impact an area in a number of ways. In the short term, high populations of larvae cause defoliation that affects the aesthetic and recreational value of an infested area. Generally, leaf loss becomes noticeable when a tree sustains 30 to 40% defoliation. Also in the short term, egg masses can be a nuisance because they can be laid on such a wide variety of surfaces including tree trunks, branches, rocks, logs, fences, picnic tables, and buildings. In the long term, a gypsy moth infestation can cause twig, branch and, in some cases, whole tree mortality, invasion from secondary pests such as rot, and thin tree canopies.

Several factors affect how a tree responds to gypsy moth defoliation including the amount of foliage removed, the weather, the number of years of repeated defoliation, the timing of defoliation in the growing season, the presence and number of other insects and diseases, and the health and vigor of the tree at the time of defoliation (OMNR, undated). For example, damage from gypsy moth may increase substantially if trees are growing on poor sites or if defoliation occurs during the same period as drought.

Most healthy trees can withstand a single year of moderate to severe defoliation, but two to three years of heavy defoliation (less than or equal to 50%) can result in branch or whole tree mortality. A tree’s crown condition plays an important part in its ability to survive gypsy moth defoliation. A tree with less than 25% dead branches in its crown is more likely to survive defoliation than a tree with more than 50% dead branches in its crown (Gottschalk 1993). Trees that are diseased, crowded, or stressed may die after one or two years of defoliation (OMNR, undated).

Table 1. Most preferred, preferred, and least preferred gypsy moth tree hosts (Source: GM-06-105).

Most Preferred	Preferred	Least Preferred
Oak (all species)	Beech	Black ash
Largetooth aspen	Yellow birch	Green ash
Trembling aspen	Cherry (all species)	White ash
White birch	Butternut	Black locust
Grey birch	Chestnut	Mountain maple
Basswood	White elm	Red spruce
Tamarack	Eastern hemlock	White cedar
Alder	Ironwood	Eastern red cedar
Apple	Maple (most species)	Sumac
Hawthorn	White spruce	Red mulberry
Willow	Norway spruce	Tulip-tree
Manitoba maple	Pine (all species)	Balsam fir
Mountain ash	Hickory	Sycamore
Carolina poplar	Black walnut	
Larch	Sassafras	
	Serviceberry	

The impact of an outbreak on an area can be influenced by when the defoliation occurs. Defoliation that happens in mid-season can be more damaging than that which occurs in the spring because in mid-season, trees do not have time to replenish food reserves and new buds do not have time to harden before colder temperatures start (Gottschalk 1993).

Tree location can also play a role in how susceptible a tree is to gypsy moth defoliation. Gypsy moth generally prefers ridge top sites and steep, south or west facing slopes. These sites tend to have the tree species that gypsy moth prefers and the trees are often crooked, are low in vigour, and have deep fissures in their bark, providing good gypsy moth habitat. In the winter, the temperature on these sites rarely drops below –32ºC, the threshold below which gypsy moth egg masses die. Therefore, more eggs survive to hatch in the spring. In the spring, these sites are not likely to be exposed to late spring frosts that would kill young gypsy moth larvae. In the summer, these sites tend to be hot and dry, which helps gypsy moth larvae to survive and thrive (Gottschalk 1993).

Healthy, vigorous trees on lower, north or east facing slopes are likely going to be less susceptible to gypsy moth defoliation. These sites tend to have deep, fertile soils and tend not to be stressed by drought. Trees on these sites are often straight and fast-growing with smooth bark and healthy crowns, making them more resistant to gypsy moth damage (Gottschalk 1993).

The composition of trees in an area can affect the amount of damage that gypsy moth causes. For example, areas with mostly oak, birch, or poplar are more susceptible than areas with predominately sugar maple, ash, spruce, or pine (OMNR, undated).

Objectives

The objectives of this report are to provide the Town of Pelham with: 1) an assessment of the gypsy moth situation in selected areas of the Town, 2) forecasts of likely defoliation for these areas in 2020, 3) short- and long-term management options applying a philosophy of Integrated Pest Management (IPM), and 4) specific recommendations for management in the affected areas in 2020. All options will be considered and evaluated.

Assessment of Gypsy Moth Population

An essential component of any pest management action is a thorough assessment of the distribution and density of the pest population (i.e. where is it and how bad is it). A number of sampling methods have been developed for gypsy moth and are discussed below. The results of these surveys are used to define the suite of actions best suited for management of the pest.

Gypsy Moth Population Assessment Methodologies

A variety of sampling methods have been developed for assessing gypsy moth populations and forecasting potential damage to host trees. Gypsy moth is a difficult insect to sample accurately because of its association with many host species, the activity of the insect during the larval stage, and the dramatic fluctuations between low endemic and high outbreak populations over a relatively short period of time (Nealis and Erb 1993). Another factor that can complicate gypsy moth population assessments and forecasts is the tendency of early instar larvae to disperse by ballooning over the landscape, often in large numbers. This can result in areas suffering high defoliation rates even though egg mass densities were low, or in some cases, non-existent.

Sampling methods have been developed for each stage of the gypsy moth life cycle.

Larvae: Burlap or sticky bands placed around the main stem of the tree can be used to trap gypsy moth larvae and pupae. Gypsy moth larvae seek shelter under the bands during the later feeding stages and often will pupate under these bands. Larval densities can vary greatly from day to day, and even during the day. Weather, tree species, larval density, and larval development can affect numbers, therefore, this method is not considered a reliable method for population assessment.

Larvae can also be sampled from foliage collected from the tree canopy. The accuracy of this method has not been assessed but can be used to determine the presence or absence of gypsy moth larvae, especially during the early instars.

A third method for assessing gypsy moth larvae populations is the collection of frass in containers placed on the ground (Liebhold and Elkinton 1988a and Liebhold and Elkinton 1988b). This is the most accurate method but is a time-consuming process that requires some expertise and therefore is usually restricted to research and not reliable in an urban environment because of potential sample tampering by pedestrians.

Adults: Female gypsy moth adults do not fly but attract the male moths by releasing a powerful airborne attractant called a pheromone. This pheromone has been synthetically reproduced and is used to lure male moths to a variety of sticky or bucket-like traps. This is an effective method for detecting the presence of low level gypsy moth populations and is widely used in the United States and Canada (Gage et al. 1990). Because this pheromone is so efficient, gypsy moth pheromone traps are less effective during periods of high populations when they tend to become saturated with moths, making it difficult to develop relationships between trap catches and subsequent populations and forecasted host damage.

Egg Masses: Gypsy moths lay their eggs in masses of up to 1,000 eggs on the stems and branches of trees, as well as on the forest floor and man-made objects in July and August each year. They will remain in the egg mass until hatch begins sometime in April or May the following year. This provides the longest period for assessing gypsy moth populations and is considered the most reliable method. Egg masses are easily counted, especially following leaf fall in the autumn, and old egg masses are generally easily distinguishable from new egg masses, allowing for more accurate counts of the current year population. Egg mass size can also be measured and is a good indicator of outbreak status – large egg masses (greater than 30mm) indicate a healthy, increasing population and small egg masses (less than 20mm) indicate a decreasing population (Nealis and Erb 1993). Moore and Jones (1987) provide a simple equation for estimating the number of eggs per mass based on a measure of egg mass length.

A number of sampling methods have been developed for estimating egg mass densities and forecasting host defoliation in the following year:

1. **Walkthroughs:** Observers count all egg masses visible during a walkthrough of an area. This method can be used as a quick survey tool but is often imprecise and is usually followed-up with a more detailed survey.
2. **Fixed-area plots:** Observers count all egg masses within a standardized area. Results can be extrapolated into numbers per hectare, which allows comparison between years. In the United States, the fixed-area plot (5.4m radius) of 1/40 acres (0.01ha) is the most commonly used. In Ontario, the 10m by 10m Modified Kaladar Plot (MKP) has been used since the gypsy moth was detected in the Kaladar region of eastern Ontario in the early 1980s.

Egg Mass Surveys in Forest vs. Urban Environments

Definitions of urban and suburban environments may vary but Fleischer et al. (1992) defined these areas as having a minimum of one house per ten acres (4.04ha). With the exclusion of some municipal parks, this would apply to most of the areas surveyed within the urban areas of the Town of Pelham. Use of fixed-area plots is the most accurate method for assessing gypsy moth densities and is the most frequently used method in forest environments. Generally, groups or clusters of three to five MKPs were used in Ontario to estimate average egg mass densities and forecast defoliation in specific areas. In urban or suburban environments, however, the 10m by 10m fixed-area plot may not be practicable when egg mass surveys are limited to street trees, and when access to private property and backyards is a constraint.

The urban environment is influenced by man-made objects and the distribution of gypsy moth egg masses is more clumped than in the forest (Fleischer et al. 1992). This probably reflects the distribution of preferred host species and the discontinuous nature of treed areas in urban environments. Sample methods for urban and suburban environments need to reflect this difference in egg mass distribution.

BioForest has developed the **'Modified MKP'**, a version of the original MKP that is more suited to the constraints of the urban and suburban environment. The Modified MKP uses five trees in close proximity to each other, which would be typical of the number of mature trees found in a 0.01ha fixed-area MKP plot. One tree, preferably a mature oak, is selected to be the plot center and the four next closest appropriate host trees are surveyed as one "plot".

Gypsy Moth Egg Mass Surveys in Pelham

In 2009, the Town of Pelham partnered with Trees Unlimited and Zimmer Air to implement control measures when gypsy moth populations reached outbreak levels. Those measures were successful in reducing the population to acceptable levels.

In 2017, the Town began receiving concerns from citizens regarding the re-emergence of gypsy moths and in the spring of 2018 the Town conducted an aerial spray in Hillcrest Park (6.47 hectares). Throughout the summer of 2018, staff continued to receive reports and concerns regarding gypsy moth activity throughout the urban boundary. Trees Unlimited was again contracted to conduct egg mass surveys in early 2019, and 17 residential, park and cemetery properties were surveyed. Six of the properties surveyed had severe defoliation forecasts (Canboro Road at Concord Street, Hillcrest Park, Pancake Lane south to Beechnut Court, Oak Lane, Kunda Park, and Fonthill Cemetery). In response, the Town sprayed 161.2 hectares of public and private property within the urban boundary. Post spray surveys conducted in all treated areas indicated a significant reduction in caterpillars and tree defoliation (with some exceptions).

Throughout the summer and fall of 2019, the Town continued to receive reports of gypsy moth activity throughout the urban boundary. The Town received and logged all service requests and resident calls related to gypsy moth.

2019 Gypsy Moth Egg Mass Surveys

In order to cover a large area in a systematic manner, BioForest recommended a grid-based approach, using a combination of previously reported gypsy moth activity and high-risk areas to prioritize grids to be surveyed. A desktop review resulted in a total of 45 grids (1km by 1km) to be surveyed at varying intensities based on: 1) historical gypsy moth activity, 2) host distribution and availability, 3) connectivity through natural areas or continuous forest canopy, and 4) land use and classification (urban vs. rural).

BioForest crews established plots based on host availability and distribution, with the aim of obtaining good coverage and fair representation throughout all grids. The urban areas of Fonthill and Fenwick were surveyed with the greatest intensity. The survey was focused on mature oak trees where possible, with highest priority given to addresses (or addresses in close proximity) that logged a service request during the summer of 2019, or in some cases 2018. Street trees were surveyed and crews ensured that the trees surveyed were an adequate representation of the general tree composition (both public and private), in order to gather unbiased data. Where oak trees were not present, crews surveyed other preferred hosts of gypsy moth such as apple, aspen, beech, birch, black walnut, hickory and maple.

Plot trees were surveyed by examining the trunk and scanning the entire tree, from base to crown, using binoculars. At least two opposite sides of each tree were surveyed. All egg masses observed on the tree, both old and new, were recorded.

The total number of egg masses on each tree were summed. In a separate count, egg masses that were easily distinguishable as old or new were tallied. As many intact egg masses within reach were measured and recorded as old or new, in order to obtain 2019 egg mass size data. A total of 133 plots were established and a total of 665 trees were surveyed.

All gypsy moth egg mass data was entered and managed in a Microsoft Excel database. In addition, a point shapefile of all plots was created in ArcMap. All plot centers were drawn in ArcMap, and categorized based on the adjusted number of egg masses present within that plot and the defoliation forecast for 2020. The predicted defoliation values were obtained using a USDA defoliation prediction model (Gansner et al. 1985) based on egg mass counts.

Gypsy moth egg mass age (new vs. old ratio): The proportion of new and old egg masses is an indicator of population vigor. A low proportion of old egg masses (i.e. less than 25% old) indicates a healthy, building population while a high proportion of old egg masses (i.e. more than 50% old) suggests a population in decline (Liebhold et al. 1994). Crews distinguished the age of all egg masses on each tree trunk and summed both old and new egg masses observed for each grid cell.

Figure 10. Large new egg mass measured by BioForest staff.

In 2019, approximately **58%** of egg masses surveyed by BioForest crews were new. This represents a fairly large proportion of new egg masses, and points to a potentially healthy gypsy moth population.

Gypsy moth egg mass size: The actual size of the egg mass is a vital statistic for assessing gypsy moth populations. Larger egg masses (more than 500 eggs per mass, greater than 30mm) indicate a healthy, increasing population whereas smaller egg masses are characteristic of a decreasing population (less than 20mm in size) (Nealis and Erb 1993). The number of eggs per mass can be estimated by measuring the length of egg masses in the field.

Within each property surveyed, BioForest crews measured as many egg masses as possible to provide more information on the infestation status.

In 2019, **84%** of all new egg masses measured were considered to be "large" (25mm or greater) (Figure 11). As no data from previous years' exists, this can serve as a baseline measurement for future year's surveys. The average size of all new egg masses was 33.5mm (n=309), which is a potential indicator of a healthy population.

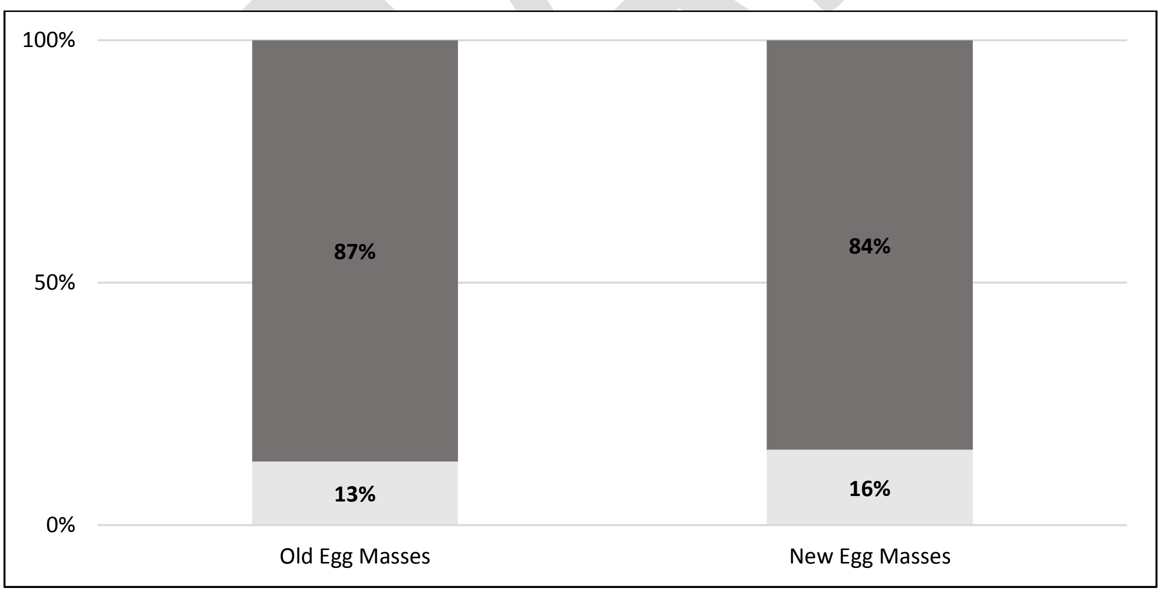

Figure 11. Relative size distribution of old and new egg masses in Pelham, 2019.

Natural controls: BioForest crews observed a small number of caterpillars affected by *E. maimaiga* and NPV during the egg mass surveys.

2020 Gypsy Moth Defoliation Forecasts in Pelham

Gypsy moth forecast surveys using egg mass densities to predict defoliation are difficult to conduct in the urban environment. Most of the methodologies developed to date are suitable for continuous forested environments, but are not easily adapted to the city where tree species and tree densities can vary considerably and where access is often limited. In 2019, BioForest crews conducted surveys in residential neighbourhoods on public trees, in a selection of parks and along rural roads to assess egg mass densities and egg mass size. A 2020 forecast map was developed based on a calculation of the density of gypsy moth egg masses per hectare, the standard measure for temporal and spatial comparisons of populations and defoliation forecasts in forests.

Gypsy moth defoliation is difficult to predict with a high degree of probability. As noted earlier, populations are subject to a wide variety of biotic and abiotic factors that complicate the forecasting process. Some degree of defoliation is likely to occur in all areas where egg masses have been observed. However, the data collected in the 2019 surveys does indicate clear areas that are likely to be affected in 2020. It should be noted that the forecasts presented in this report are based **only** on observed egg masses occurring on public trees in residential neighbourhoods, within those parks and along those rural roads that were surveyed. Private property was not surveyed, with the exception of a few front yard or private woodlot trees where necessary.

The 2019 survey focused on areas where gypsy moth populations were observed and reported on during the summer of 2019, and in some cases 2018, as well as areas that were connected to these locations through significant natural corridors or continuous forest canopy. It is likely that other areas of the Town, including parks, natural areas and large private property that were not included in this survey are also harbouring gypsy moth populations, just not yet reported. Depending on the composition and geographic characteristics of these areas (i.e. species, age class, slopes, etc.), they could potentially be a breeding ground for gypsy moth populations next year and into the future.

Table 2 illustrates the egg mass density thresholds that were used for defoliation forecasts, and the anticipated management impacts associated with each level of defoliation. It is important to remember, however, that these are just estimations and that the actual level of defoliation and damage is dependent on a variety of other factors such as tree condition, previous years' defoliation, presence of other pests, etc.

Table 2. Gypsy moth defoliation predictions based on egg mass densities per hectare and associated management impacts. Thresholds derived from USDA defoliation prediction model developed by Gansner et al. 1985.

Egg Mass Density (Em/Ha)	Defoliation Forecast	Defoliation Forecast Range (%)	Management Impacts
0	Nil	0 to 5	None
1 to 1,250	Light	6 to 25	Up to 20% Defoliation
1,251 to 3,750	Moderate	26 to 65	Nuisance and Aesthetics; Noticeable Defoliation
3,751 to 5,000	Heavy	66 to 90	Wildlife and Recreation; Growth Loss
> 5,001	Severe	91 to 100	Tree Mortality

Intervention thresholds are defined by the management objectives and could include nuisance abatement, foliage protection, and prevention of tree mortality or a combination of these objectives. The relationships between egg mass density and subsequent damage (defoliation) will guide the manager in establishing these thresholds, which in turn will determine when and where treatments are needed. Some helpful guidelines for hardwood forests include:

- Damage is not noticeable from the air until defoliation levels reach about 30%;
- Growth loss in trees begins when defoliation reaches about 40%;
- Re-foliation occurs when about 60% of the trees' foliage is lost. This can cause a reduction in the tree's overall health and survival.

Managers may choose to modify tolerance thresholds to lower levels if these neighbourhoods have been subjected to other stresses that may predispose trees to mortality, or if unusually high value or specimen trees are involved (Liebhold et al. 1994). General stand condition and vigour can be influenced by tree age and human-related disturbances to the environment that negatively affect tree health.

Tree mortality is of course normal in any environment, and typically averages between 1 to 2% per year in natural forests, and 5% or more in the urban environment (Nowak et al. 2004). Insect and disease outbreaks can accelerate tree mortality, thus reducing the benefits to residents and the urban environment. Damage to forests can be increased when insect outbreaks occur during periods of environmental stress. Short and long term climate changes can increase stress levels on trees making them more susceptible to pests such as the gypsy moth.

The density at which gypsy moths become a nuisance in residential or recreational areas is not well established. The sight of one or two larvae may be intolerable for some individuals, while others may be comfortable with much higher populations. According to Liebhold et al (1994) an intervention threshold of 600 egg masses per hectare has been widely used in the past for intervention in both general forest and residential areas. While this value may be justified for reducing certain nuisance impacts (such as service calls or resident complaints), it may not be justified for other management objectives (Liebhold et al 1994).

In this discussion of management intervention thresholds, it must be noted and understood that it is impossible for managers to predict defoliation levels without a certain amount of error.

Results

Figures 12 and 13 provide an overview of the location of all plots surveyed in 2019 and the 2020 defoliation forecasts for each plot surveyed. Figure 14 and 15 show close up maps of Fonthill and Fenwick, the urban areas within Pelham.

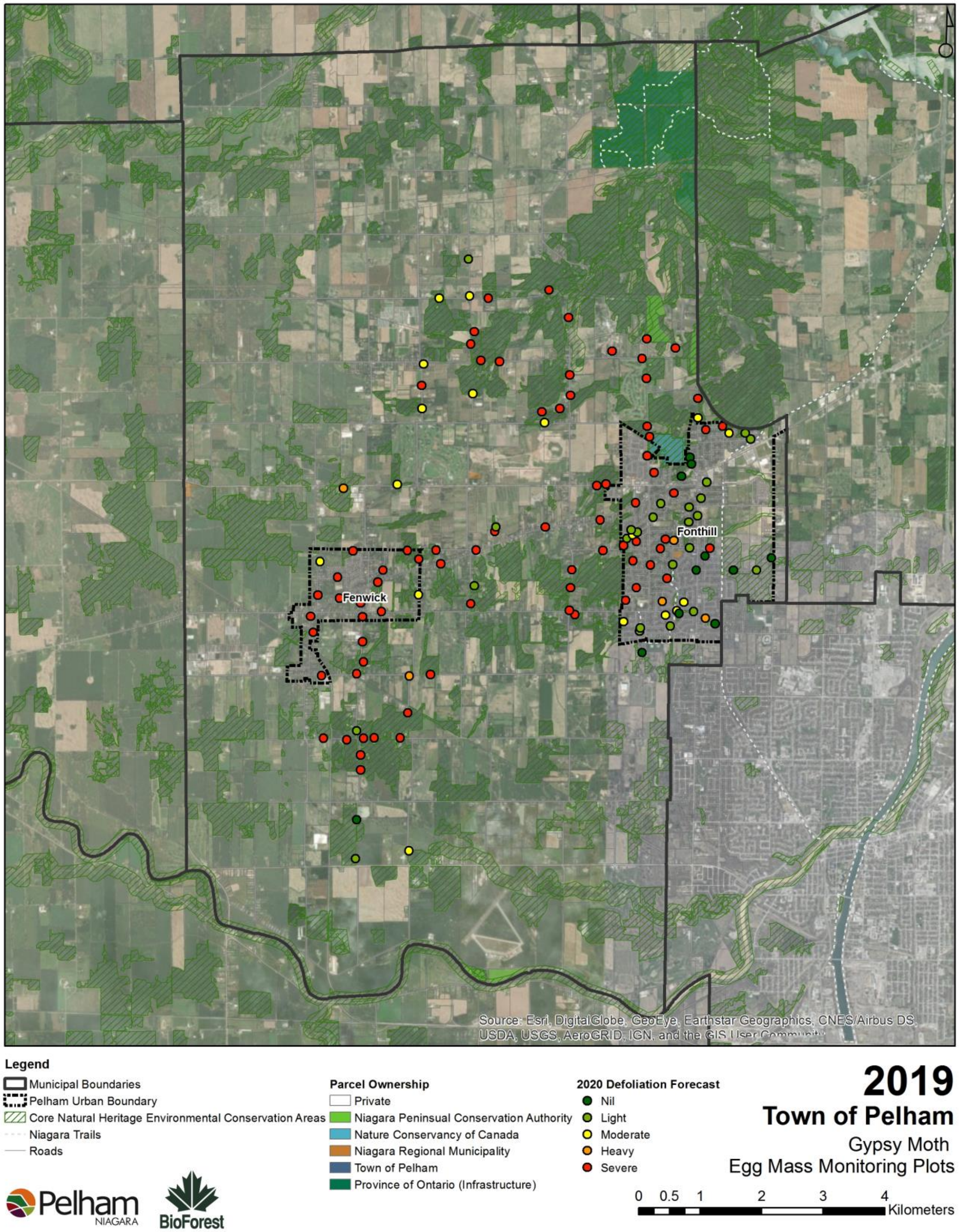

Figure 12. All gypsy moth egg mass monitoring plots surveyed in January 2020, Town of Pelham.

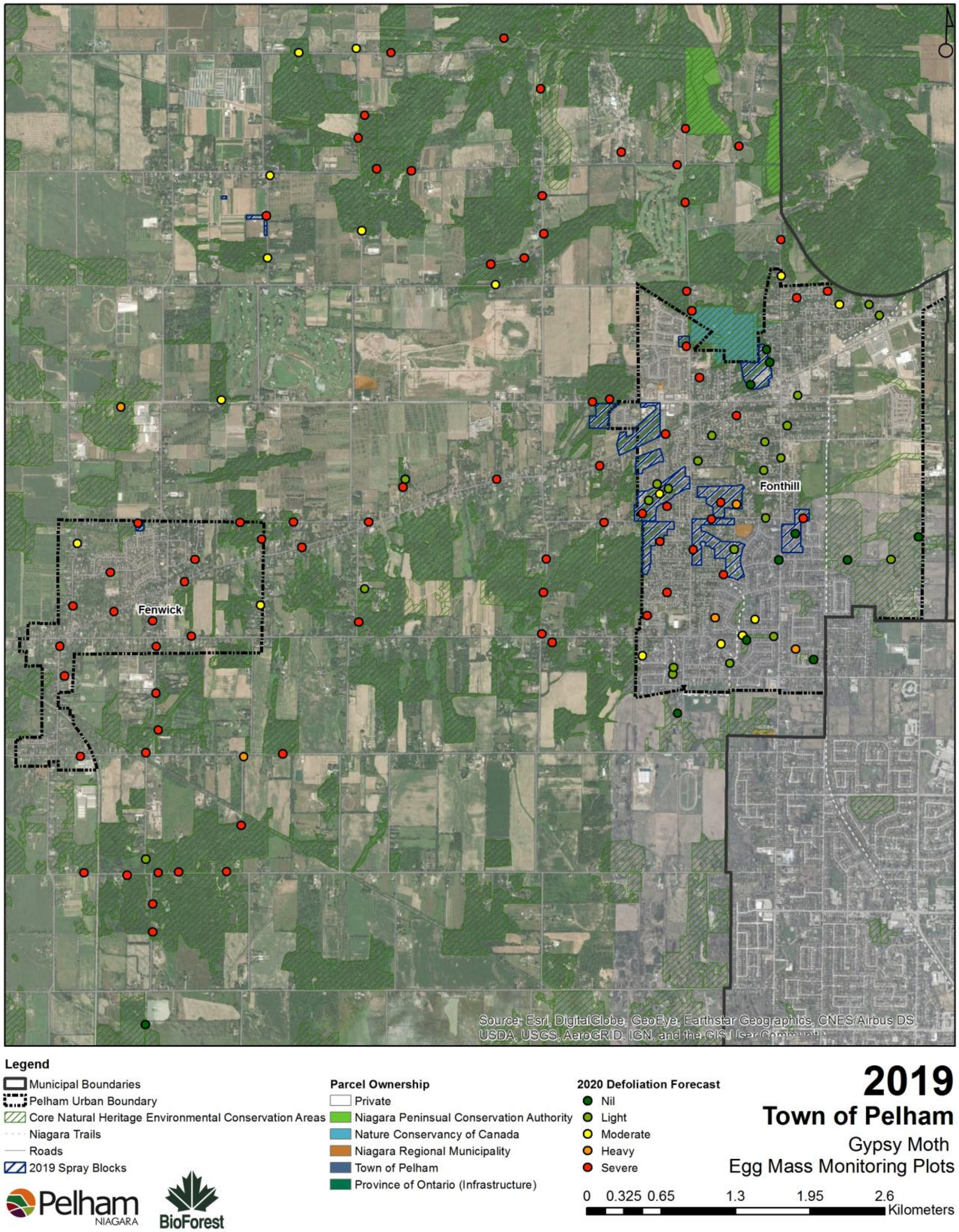

Figure 13. All gypsy moth egg mass monitoring plots surveyed in January 2020 and all blocks sprayed in May-June 2019, Town of Pelham.

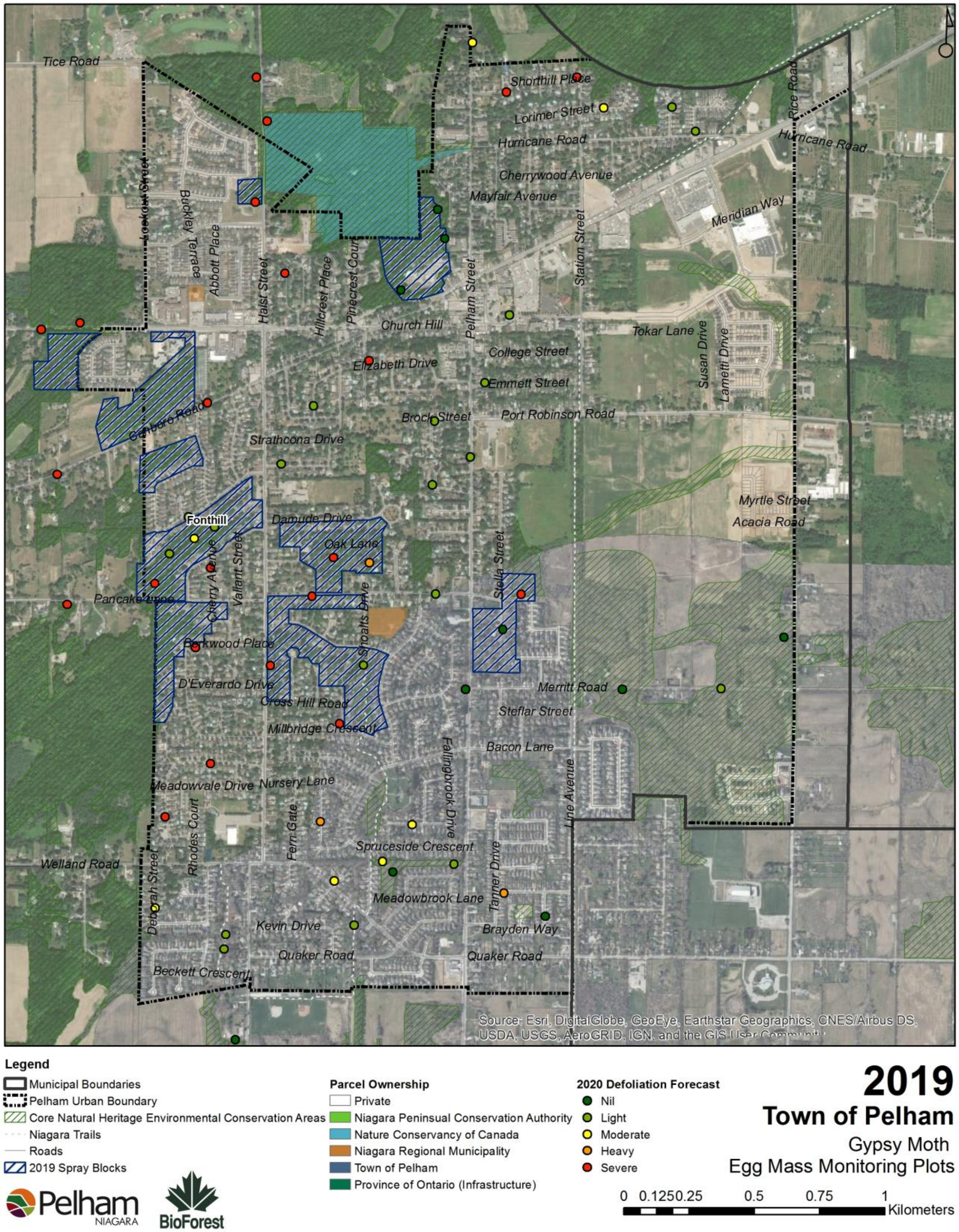

Figure 14. All gypsy moth egg mass monitoring plots surveyed in January 2020 and all blocks sprayed in May-June 2019, Fonthill, Town of Pelham.

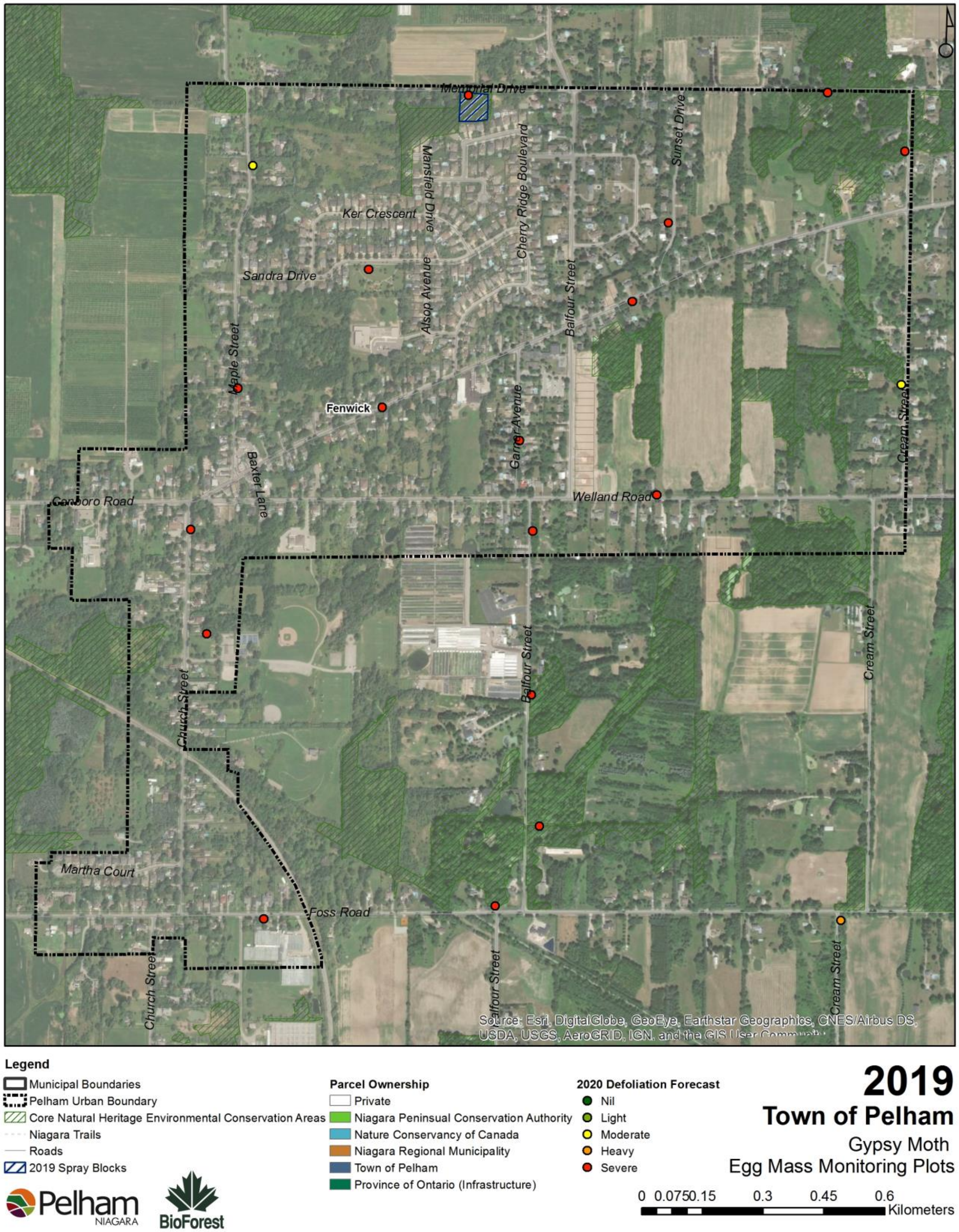

Figure 15. All gypsy moth egg mass monitoring plots surveyed in January 2020 and all blocks sprayed in May-June 2019, Fenwick, Town of Pelham.

The 2020 defoliation forecast results for the entire area surveyed (Figure 12) show high gypsy moth egg mass densities, or moderate-to-severe defoliation forecasts (represented by yellow, orange and red dots on the map), occur in 98 plots out of 133, or 74% of plots with the majority of those being severe (76 plots). Light defoliation (represented by the light green dots on the map) is forecasted in 24 out of 133 plots, or 18%, and no defoliation (represented by the dark green dots on the map) is forecasted in 11 plots, or 8%.

The most severe defoliation is anticipated to occur throughout Fenwick, south of Fenwick (Balfour Road, Foss Road and Sumbler Road), the area between Fenwick and Fonthill (Canboro Road, Effingham Street and Pancake Lane), the northwest areas of Fonthill, and northwest of Fonthill (Centre Street, Effingham Street, Haist Street, Kilman Road, Metler Road and Moore Drive).

Table 3. Summary of grids and plots surveyed in 2019 Town of Pelham Gypsy Moth Egg Mass Surveys.

Location	Grid	Plot	Plot Centre Address	Total Egg Masses	Adjusted Total Egg Masses	New Egg Masses/Hectare (Em/Ha)	2020 Defoliation Forecast
Fenwick							
	73	73.3	1159 Maple Street	1,246	935	93,450	Severe
	73	73.2	746 Canboro Road	1,047	785	78,525	Severe
	73	73.4	73 Cherry Ridge Boulevard	989	742	74,175	Severe
	74	74.1	612 Memorial Drive	1,065	623	62,292	Severe
	63	63.5	1043 Church Street	700	582	58,154	Severe
	73	73.1	90 Sandra Drive	698	524	52,350	Severe
	73	73.5	1115 Garner Avenue	637	478	47,775	Severe
	64	64.1	663 Welland Road	508	399	39,914	Severe
	74	74.2	1284 Cream Street	664	388	38,838	Severe
	74	74.4	688 Canboro Road	549	321	32,111	Severe
	63	63.2	698 Welland Road	297	247	24,674	Severe
	63	63.4	999 Church Street	287	238	23,843	Severe
	74	74.5	1160 Sunset Drive	216	126	12,634	Severe
	73	73.6	1229 Maple Street	25	19	1,875	Moderate
	74	74.3	1144 Cream Street	29	17	1,696	Moderate
Fonthill							
	78	78.5	38 Pancake Lane	901	790	78,992	Severe
	88	88.2	Hillcrest Park	1,355	468	46,832	Severe
	78	78.4	1183 Haist Street	489	429	42,871	Severe
	88	88.11	173 Canboro Road	1,026	355	35,461	Severe
	78	78.3	22 Berkwood Place	403	353	35,332	Severe
	88	88.1	15 Blackwood Crescent	775	268	26,786	Severe
	98	98.4	16 Marlene Stewart Drive	308	252	25,200	Severe
	78	78.1	55 Rolling Meadows	276	242	24,197	Severe
	78	78.2	18 Rolling Meadows	218	191	19,112	Severe
	78	78.6	72 Millbridge Crescent	173	152	15,167	Severe
	79	79.1	43 Stella Street	204	115	11,530	Severe
	88	88.12	7 Highland Avenue	332	115	11,475	Severe
	99	99.3	6 Shorthill Place	130	107	10,739	Severe

Location	Grid	Plot	Plot Centre Address	Total Egg Masses	Adjusted Total Egg Masses	New Egg Masses/Hectare (Em/Ha)	2020 Defoliation Forecast
	88	88.7	10 Oak Lane	302	104	10,438	Severe
	99	99.2	23 Shorthill Place	82	68	6,774	Severe
	98	98.1	18 Peachtree Park	77	63	6,300	Severe
	69	69.3	27 Tanner Drive	54	49	4,860	Heavy
	88	88.6	8 Bruce Wood	124	43	4,286	Heavy
	78	78.8	13 Deer Park Crescent	45	39	3,945	Heavy
	68	68.3	1081 Deborah Street	44	33	3,335	Moderate
	88	88.4	Hillcrest Park	83	29	2,869	Moderate
	109	109.2	Across 1708 Pelham Street	75	28	2,750	Moderate
	68	68.5	88 Woodside Square	30	23	2,274	Moderate
	68	68.4	1 Arbor Circle	29	22	2,198	Moderate
	99	99.1	5 Leslie Place	22	18	1,817	Moderate
	79	79.4	11 Fallingbrook Drive	27	15	1,526	Moderate
	88	88.9	28 Concord Street	36	12	1,244	Light
	88	88.3	Hillcrest Park	34	12	1,175	Light
	88	88.13	127 Daleview Drive	33	11	1,141	Light
	68	68.2	1077 Edward Avenue	13	10	985	Light
	69	69.4	Behind 52 Woodside Square	9	8	810	Light
	88	88.8	42 Strathcona Drive	18	6	622	Light
	78	78.7	Behind 19 Parkhill Road	6	5	526	Light
	89	89.1	1 Petronella Parkway	8	5	509	Light
	88	88.5	Hillcrest Park	13	4	449	Light
	89	89.2	14 Donahugh Drive	5	3	318	Light
	89	89.3	1353 Pelham Street	5	3	318	Light
	80	80.2	220 Merritt Road	3	3	300	Light
	100	100.2	11 Scottdale Court	4	3	267	Light
	68	68.1	1077 Edward Avenue	3	2	227	Light
	89	89.4	1 Emmett Street	3	2	191	Light
	79	79.5	2 Pancake Lane	2	1	113	Light
	99	99.6	20 Pelham Town Square	1	1	83	Light
	68	68.6	Along trail behind Maureen Court	1	1	76	Light
	100	100.1	1 Stonegate Place	1	1	67	Light
	69	69.1	88 Woodside Square	0	0	0	Nil
	69	69.2	15 Mason Drive	0	0	0	Nil
	79	79.2	57 Stella Street	0	0	0	Nil
	79	79.3	Across 1253 Pelham Street	0	0	0	Nil
	79	79.6	90 Merritt Road	0	0	0	Nil
	80	80.1	1304 Rice Road	0	0	0	Nil
	99	99.4	Trail behind 10 Elm Avenue	0	0	0	Nil
	99	99.5	Trail behind 1532 Pelham Avenue	0	0	0	Nil
	99	99.7	33 Park Lane	0	0	0	Nil

Location	Grid	Plot	Plot Centre Address	Total Egg Masses	Adjusted Total Egg Masses	New Egg Masses/Hectare (Em/Ha)	2020 Defoliation Forecast
Rural							
	75	75.1	546 Memorial Drive	2,664	2131	213,120	Severe
	67	67.2	273 Welland Road	2,335	1843	184,342	Severe
	75	75.3	554 Canboro Road	1,704	1363	136,320	Severe
	87	87.1	250 Canboro Road	1,688	1249	124,912	Severe
	53	53.3	910 Balfour Street	1,171	1171	117,100	Severe
	77	77.1	1139 Effingham Street	1,967	852	85,237	Severe
	44	44.1	617 Sumbler Road	830	830	83,000	Severe
	118	118.1	Across 155 Metler Road	1,273	821	82,129	Severe
	107	107.2	Across 307 Moore Drive	934	657	65,726	Severe
	118	118.2	1936 Haist Street	957	617	61,742	Severe
	43	43.5	625 Balfour Street	807	605	60,525	Severe
	87	87.2	250 Hwy 20 W	799	591	59,126	Severe
	43	43.4	595 Balfour Street	732	549	54,900	Severe
	117	117.1	1974 Effingham Street	1,511	525	52,465	Severe
	43	43.2	716 Sumbler Road	607	455	45,525	Severe
	98	98.3	1615 Haist Street	498	407	40,745	Severe
	115	115.2	1934 Centre Street	673	404	40,380	Severe
	43	43.3	725 Balfour Street	507	380	38,025	Severe
	63	63.3	925 Balfour Street	410	341	34,062	Severe
	97	97.1	245 Hwy 20 West	660	337	33,702	Severe
	125	125.2	461 Kilman Road	724	336	33,577	Severe
	115	115.1	1951 Centre Street	525	315	31,500	Severe
	63	63.1	961 Balfour Street	379	315	31,486	Severe
	126	126.1	350 Kilman Road	301	301	30,100	Severe
	115	115.3	1951 Centre Street	482	289	28,920	Severe
	106	106.1	345 Tice Road	443	271	27,072	Severe
	98	98.2	1636 Haist Street	316	259	25,855	Severe
	44	44.2	631 Sumbler Road	229	229	22,900	Severe
	67	67.1	1005 Effingham Street	282	223	22,263	Severe
	77	77.3	230 Pancake Lane	478	207	20,713	Severe
	117	117.2	205 Metler Road	571	198	19,826	Severe
	86	86.3	353 Canboro Road	301	180	17,963	Severe
	77	77.2	1160 Effingham Street	387	168	16,770	Severe
	116	116.1	1951 Centre Street	202	152	15,150	Severe
	53	53.1	764 Foss Road	151	151	15,100	Severe
	118	118.3	1902 Hansler Street	229	148	14,774	Severe
	104	104.2	1780 Cream Street	391	123	12,347	Severe
	54	54.2	770 Groen Road	115	115	11,500	Severe
	86	86.1	451 Canboro Road	191	114	11,398	Severe
	107	107.3	315 Moore Drive	140	99	9,852	Severe

Location	Grid	Plot	Plot Centre Address	Total Egg Masses	Adjusted Total Egg Masses	New Egg Masses/Hectare (Em/Ha)	2020 Defoliation Forecast
	43	43.1	775 Sumbler Road	129	97	9,675	Severe
	54	54.1	Across 586 Foss Road	96	96	9,600	Severe
	107	107.1	1770 Effingham Street	129	91	9,078	Severe
	75	75.5	Across 1116 Centre Street	101	81	8,080	Severe
	108	108.1	Across 1861 Haist Street	157	79	7,850	Severe
	109	109.1	1747 Pelham Street	149	55	5,463	Severe
	75	75.2	491 Canboro Road	68	54	5,440	Severe
	83	83.1	740 Hwy 20 W	139	41	4,107	Heavy
	54	54.3	586 Foss Road	39	39	3,900	Heavy
	104	104.3	1732 Cream Street	118	37	3,726	Moderate
	125	125.3	591 Kilman Road	79	37	3,664	Moderate
	94	94.1	653 Hwy 20 W	27	23	2,314	Moderate
	104	104.1	1895 Cream Street	70	22	2,211	Moderate
	106	106.2	345 Tice Road	33	20	2,017	Moderate
	34	34.1	Across 310 Cream Street	16	16	1,600	Moderate
	105	105.1	1797 Centre Street	25	15	1,500	Moderate
	125	125.4	485 Kilman Road	31	14	1,438	Moderate
	53	53.2	725 Balfour Street	10	10	1,000	Light
	86	86.2	451 Canboro Road	14	8	835	Light
	33	33.2	Behind 701 Webber Road	7	7	700	Light
	125	125.1	2180 Centre Street	7	3	325	Light
	75	75.4	1165 Centre Street	3	2	240	Light
	33	33.1	Behind 700 Chantler Road	0	0	0	Nil
	68	68.7	940 Haist Street	0	0	0	Nil

Fonthill

Public and private trees along many streets are expected to experience severe levels of defoliation in 2020, especially in the north and west areas of the community (Figure 14). Large numbers of new egg masses were observed on numerous streets in this area.

Those streets most at risk are north of Welland Road, west of Pelham Street. New egg masses were observed on a wide variety of species, and appeared on both large diameter and small diameter trees on both public and private property. Given the density of egg masses, combined with the fact that this is the second or third year of significant defoliation in this location, defoliation in 2020 has the potential to negatively impact tree health.

Fenwick

Public and private trees throughout the community of Fenwick are likely to experience severe levels of defoliation in 2020 (Figure 15). There is not a significant amount of forested area throughout Fenwick, but new egg masses were observed on a wide variety of species, and appeared on both large diameter and small diameter trees on both public and private property. Like Fonthill, given the density of egg masses, combined with the previous years of defoliation, trees are likely to experience a decline in 2020.

Rural Areas

Rural, forested property south of Fenwick, between Fenwick and Fonthill, as well as northwest of Fonthill are also at risk of severe defoliation in 2020. Surveys in these areas were conducted primarily along roadways along the perimeter of these properties, in order to not trespass on private land (unless homeowners were on-site and gave permission), therefore the forecasts are representative of edge populations, which can be higher than more interior forests (Bellinger et al 1989). It is possible that these perimeter plots are an over-representation of the counts throughout the property, however the counts are so extreme (ranging from 5,440 up to 213,120 egg masses per hectare) that it is very possible that interior counts are still high.

Potential Impacts of No Intervention

Despite its arrival in North America in 1869, gypsy moth is a relatively new pest in the forests of Canada. It joins a number of other native insect pests, such as the forest tent caterpillar (*Malacosoma distria*) and the spring and fall cankerworms, as a potential defoliator of many different tree species and is, therefore, another potential stress on our forests.

The urban environment, while in many ways similar to forested environments, generally involves several unique features that influence pest problems (Coulson and Witter 1984) and consequently management strategies. For example, in urban environments:

- The diversity of valued host species is generally greater;
- Host trees consist of both native and exotic species;
- There is usually a greater range of age-class of host trees;
- Mature, and often senescent trees, are especially valued.

Urban trees are under considerable stress. The urban forest is subject to a wide variety of disturbance factors that generally reduce tree vigour and increase susceptibility to pests. These disturbances include: road construction, transmission line clearing, building construction, sidewalks, driveways, poor soil nutrients, compaction, high salinity and pH, and photochemical oxidation. Therefore, predicting the full impacts of a gypsy moth outbreak in the natural forest is different than in the urban setting.

Environmental Impacts

Environmental impacts of a gypsy moth outbreak will be greatly influenced by a number of factors including urban canopy composition, forest age, stand vigour, soils, and climate. Some general observations from previous outbreaks are:

- Generally, areas of mature to overmature forests with a high composition of host tree species will be the most heavily impacted by gypsy moth defoliation;
- Vigourous trees can usually withstand severe defoliation for a few years. Eventually, however, these trees will become more susceptible to attack by secondary pests such as two-lined chestnut borer (*Agrilus bilineatus*), oak decline, *Armillaria* root rot, etc.;
- Heavy defoliation over large areas of urban forest reduces water use by the trees and can result in increased fluctuations in run-off (Benoit and Lachance 1990);
- In heavily defoliated areas, sunlight falls directly onto ground vegetation and soils, raising temperatures. This may drive away predators such as snakes, lizards and frogs and may cause root damage and increase the effects of drought;
- Some thin-barked tree species may be damaged by the sudden increase in sunlight penetration;

- The aesthetic value of treed areas within the city is lessened and their utility as windbreaks and privacy barriers is reduced;
- Several years of heavy defoliation may kill host trees and, therefore, reduce the proportion of susceptible host trees in an area. This is a slow process, but may ultimately reduce the susceptibility of the stand by increasing the proportion of less susceptible tree species;
- Less favoured food species and understory vegetation may benefit indirectly from gypsy moth defoliation through increases in light, moisture and nutrients (Campbell 1979). Conversely, increased light, moisture and nutrient availability in the understory can provide the right conditions to allow for the spread of invasive understory species such as buckthorn (*Rhamnus cathartica*), garlic mustard (*Alliaria petiolata*), dog strangling vine (*Vincetoxicum rossicum*), etc.;
- Gypsy moth infestations can have positive and negative effects on wildlife. Defoliation of the overstory can result in more growth of shrubs, grasses, and herbs, which provides additional habitat for some wildlife species. In some cases, however, defoliation may reduce or compromise habitat for some wildlife species. For example, defoliation may make bird eggs vulnerable to predation due to the reduction in protection from a tree's foliage (Gottschalk 1993);
- Outbreaks can also impact waterways. For example, increases in frass, or droppings, and leaves into streams can reduce the quality of the water. Loss of canopy cover due to gypsy moth defoliation can cause the temperature of streams to increase, which can have harmful effects on organisms in the streams (Gottschalk 1993).

Human Health Impacts

During low population periods there is little human exposure to gypsy moth life stages. However, as populations increase, children and others who spend a lot of time outdoors can be affected in a number of ways (USDA 1995b):

- Allergic reactions in some people to the gypsy moth larval hairs, the hairs that coat egg masses, and wing scales have been reported;
- Rashes or other skin irritations from contact with larvae;
- Eye irritation;
- Respiratory tract irritations;
- Some individuals may be psychologically affected by high numbers of caterpillars or adverse effects of the outbreak on local aesthetics;
- Safety hazards may be created when larvae and their droppings make walkways and roads slippery;
- Dead or dying trees caused by gypsy moth defoliation can pose a hazard as tree crowns deteriorate and dead limbs break and fall to the ground.

Damage caused by gypsy moth in the urban environment can result in an increase in factors that can indirectly harm human health. These include:

- Increased air pollution;
- Local climate extremes;
- Increased noise pollution.

Economic Impacts

Gypsy moth outbreaks can impact local or regional economies. Outdoor activities can be reduced significantly when populations of either pest are high, thus impacting recreation and tourism businesses. Repeated defoliations can affect the aesthetics of an area, reducing the numbers of visitors for periods of several years beyond the duration of the outbreak. Property owners may incur costs for:

- Treating gypsy moth with a pesticide;
- Removing larvae or their droppings;
- Removing egg masses;
- Repainting buildings;
- Pruning or removing declining or dead trees;
- Replacing damaged or dead trees and shrubs;
- Increased liability for damage or injuries sustained from falling trees and branches.

Studies have also shown the contribution of trees to the overall property value of a residence. In an early study, Payne (1971) evaluated the contribution of trees to property values of homes in Massachusetts and found that they contributed an average of 7% and as much as 15% to the value of a residence. More recent valuations can be found in Miller (1996) and Pandit et al. (2013).

Economic impacts to the Town of Pelham could include:

- Increased tree removal and replacement costs;
- Loss of aesthetics in parks and woodlands resulting in reduced usage;
- Increased tree inspection costs;
- Increased tree pruning and maintenance costs;
- Potential liability costs for damage to property and personal injury.

Management Options: An Integrated Pest Management Approach

While definitions of Integrated Pest Management (IPM) vary, it is essentially a philosophy, concept and methodology for dealing with destructive insects and diseases affecting trees either in an urban environment or in the natural forest (Coulson and Witter 1984). Waters (1974) provides a good definition:

"IPM is the maintenance of destructive agents, including insects, at tolerable levels by the planned use of preventive, suppressive, or regulatory tactics and strategies that are ecologically and economically efficient and socially acceptable."

Components of an IPM strategy include: pest surveys and monitoring, and a decision-making process based on surveys and other supportive data (Reardon et al. 1987). In the case of gypsy moth this could include:

- Egg mass densities and quality;
- Larval and pupal counts;
- Male moth captures;
- Defoliation estimates;
- Area affected;
- Stand susceptibility;
- Environmental sensitivity; and
- Parasite and disease incidence.

The decision-making process in an IPM strategy results from an evaluation of available treatment options and an analysis of impacts. Information requirements include knowledge of pest biology and population dynamics, tree impacts and stand dynamics. The final component of the IPM strategy is a benefit-cost analysis. In the urban forest everyone is a potential participant in the implementation process.

The options described in this report reflect the philosophy of an IPM system for gypsy moth control. The overall strategy is to maintain pest populations at tolerable levels in terms of tree impacts and effects on human health and safety. The tactics employed will be influenced by the status of the gypsy moth population at any point in time but, to be effective, strategies and tactics must be communicated and implemented.

The application of an IPM system will not eradicate gypsy moth from the forests and streets of the Town of Pelham. That is not the goal of an IPM system and it would imply a degree of knowledge about this pest that scientists and pest management practitioners do not have. Outbreaks of this pests will most certainly occur again in the future. The objective of an IPM system is to reduce the frequency and severity of future outbreaks.

Do Nothing

The "Do Nothing" option is the one most often chosen for most pest outbreaks in Canada. A review of major pest outbreaks and control efforts in North America between 1985 and 1997 showed that of the 156,549,000 hectares infested by pests such as gypsy moth, spruce budworm and hemlock looper, only 13,841,000 hectares, or 9%, were actually treated with an aerial application of an insecticide (Hayes et al. 1998). Doing nothing is always an option to be considered and may be the most practical option in specific areas of the current gypsy moth population.

Pest outbreaks come and go. Based on the historical record of gypsy moth in North America and Ontario, it is likely that the current outbreak in the Town of Pelham will collapse naturally over the next several years. As described earlier in this report, predators, parasites and pathogens will bring about a significant decrease in gypsy moth populations to low endemic levels. The pest will exist at these low population levels until conditions allow for another rapid rise to outbreak levels.

Potential consequences of the "Do Nothing" option are described in the section of this report entitled *Potential Impacts of No Intervention.* It should be noted, however, that the nuisance factor resulting from gypsy moth/human contacts and experiences in the outbreak will be variable but frequent in some areas, forcing residents to respond with their own management efforts. This is a concern because in some cases residents will choose to mitigate impacts to their properties by applying pesticides on their own or through a commercial tree care company. The end result of potentially hundreds of property owners taking their own control measures is a significant increase in the overall use of pesticides within the Town of Pelham, and the consequent increased risk of exposure for users, bystanders and the environment. Homeowners with a lack of sufficient training or knowledge of pesticide application may also apply pesticides incorrectly. Thus, in urban and suburban areas, the "Do Nothing" option may actually result in an increase in pesticide use. Other innovative control measures employed by homeowners may not be very effective and some may actually cause more harm than good to trees.

Gypsy Moth Management Options

Maintain or Enhance Tree Health

Trees stressed by other factors such as drought or disease are more vulnerable to defoliation caused by insect pests such as gypsy moth, or to attack by secondary pests such as the two-lined chestnut borer and *Armillaria* root rot. Therefore, efforts should be made to maintain or improve tree vigour and property owners should be encouraged to consider the following (McManus et al. 1979):

- Maintain good soil conditions to encourage the development of the tree's fine feeder roots. Many activities such as construction, cutting and filling, paving, changing grades and tree removal can have harmful effects on soil/moisture relations;
- In wooded areas or in transition zones between lawns and forested areas, keep the forest floor as natural as possible. Oaks thrive under acidic soil conditions, so removal of the organic acid-rich leaf litter can be harmful;

- Maintain the natural layers of leaf litter to reduce drying in the surface soils where most of the tree's feeder roots occur. This will also provide natural habitat for mice and shrews, predators of gypsy moth larvae and pupae;
- Mulching isolated trees growing on lawns will also improve growing conditions. Mulch out to the edge of the canopy drip line to reduce competition from grasses which compete for soil moisture and nutrients;
- Water trees during periods of drought. A light pruning will thin the crown and reduce moisture demands.

Low Population Strategies

During periods when gypsy moth populations are low, homeowners can mitigate future outbreaks by:

- Cleaning yards of objects that may provide shelter for gypsy moth larvae, pupae and egg masses (e.g. dead branches and trees, stumps, and debris such as boxes, tires, containers etc.);
- Diversifying the tree species in an area to reduce the proportion of preferred gypsy moth host species. Select tree species most compatible with the local climate and soil conditions to encourage tree vigour.

Destroying Egg Masses

Finding and destroying egg masses is a management technique that homeowners can use to reduce gypsy moth damage on their properties. Finding egg masses on trees is easiest from fall until early spring when the leaves are off the trees. Egg masses can be found on tree trunks, under branches, on rocks, woodpiles, fences, or almost any other surface. Egg masses can be scraped into a container of soapy water (e.g. one teaspoon of detergent in 1 litre of water) and soaked for one week or scraped into containers of household bleach or ammonia. Egg masses should not be simply scraped onto the ground because this will not prevent them from hatching. It is important to wear gloves when removing and destroying egg masses because many people are sensitive to the hairs that cover egg masses.

Sticky Barrier Bands

Barrier bands intercept early instar larvae crawling up and down trees. Barriers can be created using sticky material applied to bands wrapped around tree trunks. To make barrier bands, wrap duct tape (sticky side towards bark) or tar paper around the trunk of a tree in overlapping bands about 1.5m from the ground. The total width of the band should be at least 12.5cm. Press the band into the bark crevices so that the larvae cannot crawl underneath the band. Tuck the edges of the tape or paper into the bark and apply a vegetable-based sticky material to the band. Do not apply sticky substances directly to the tree trunk. Sticky substances can kill thin-barked trees and will leave permanent dark stains on all trees. Avoid petroleum-based products because they may cause swelling and cankering on thin-barked trees. The small insects will get caught in the sticky material as they crawl on the trees. Replace the sticky bands as they get covered with larvae and dirt. Larvae can be destroyed by dropping them in buckets of soapy water (e.g. one teaspoon of detergent in 1 litre of water) and letting them soak for one week. For gypsy moth, it is important to wear gloves when removing and destroying larvae because many people are sensitive to the larval hairs. Barrier bands can be removed when they are no longer catching larvae or when the larvae have pupated.

Burlap Barrier Bands

Burlap bands wrapped around trees is a control method that takes advantage of the movement of gypsy moth larvae during the day. Fourth, fifth and sixth instar larvae do most of their feeding at night and seek protection from the sun and predators during the day by, in some cases, crawling to the ground for shelter in dead leaves and underbrush. Burlap bands wrapped around trees will intercept larval movement and the larvae will seek shelter in the bands. The larvae can then be removed from the bands and destroyed.

Hiding bands can be made using cloth or burlap. Bands should be 30 to 45cm wide and fastened to trees at chest height. Use twine to loosely tie the middle of the bands to the trees and fold the tops of bands over the bottoms. Bands must be checked and larvae removed daily because the bands will neither kill the larvae nor keep them from crawling back up the tree. Late afternoon is the best time to remove larvae. Larvae can be destroyed by dropping them into buckets of soapy water (e.g. one teaspoon of detergent in 1 litre of water) and letting them soak for one week. It is important to wear gloves when removing and destroying larvae because many people are sensitive to the larval hairs. Burlap banding is a popular method of control but, if done improperly, can cause more damage to trees than gypsy moth. For example, foil and plastic wrap should never be wrapped around a tree in place of burlap or cloth because they can scar or kill the tree.

Homeowner Sprays

Homeowners can use insecticides for small scale treatment of shrubs and small trees on their properties to protect them from gypsy moth defoliation. Insecticides registered in Canada for control of gypsy moth include *Bacillus thuringiensis* (Btk), carbaryl, pyrethrin, phosmet, and permethrin. Homeowners should follow all pesticide label instructions, or call a licensed applicator to perform the treatment where necessary.

Ground treatments with TreeAzin® Systemic Insecticide

Ground treatments with TreeAzin® will help to reduce feeding pressure from gypsy moth on individual trees. The product targets the larvae as they feed on the foliage, and as it is applied systemically through the trees' vascular system via micro-injection technology, there is no exposure risk to the public. Treatments must be applied post-bloom and at the time when gypsy moth eggs are starting to hatch.

Ground/Aerial Application of *Bacillus thuringiensis* (Btk)

Bacillus thuringiensis var. *kurstaki* (Btk) is the most common commercial product used to control large-scale gypsy moth infestations and has been extensively used in previous aerial control programs against gypsy moth in both Canada and the United States. This product targets only Lepidoptera larvae feeding at the time, and is non-toxic to birds, animals, humans, honeybees, fish, and most other insects. The spray must be applied while the early instar larvae are actively hatching and feeding on the foliage, usually early to mid-May. Within about two to three hours of consuming the product, the larvae stop feeding and die within a few days (City of Regina 2016). Ground applications tend to be most effective when the spray is able to cover a high percentage of the canopy – effectiveness tends to decrease significantly if spray equipment does not reach the upper canopy.

In terms of environmental safety, Btk is considered to be a very safe option. It is a naturally occurring bacteria found in the soil, not a chemical, and it works by producing proteins that are toxic to larvae. It degrades rapidly in the environment (within 1 to 4 days) due to sunlight and other microorganisms, so the exposure window is limited. It does not travel into the soil beyond 25 cm, therefore there are no concerns with leaching into groundwater (Perez 2015). In fact, pest control products containing Btk have been registered for use in Canada for 40 years and it is the most widely used pest control product in the world and can be used on certified organic farms.

Btk specifically targets immature insects (larvae) in the Lepidoptera family. An extensive literature exists on the consequences of non-target organisms to Btk, including reports of several long-term field studies. The data have been reviewed periodically (e.g. Melin and Cozzi 1990, Otvos and Vanderveen 1993) and the range of non-target species that have been found to be susceptible to direct toxic action of Btk has remained small. Spring feeding Lepidoptera species (leafrollers, fruitworms, cankerworms, and budmoths) may be affected and species richness may be locally and temporarily reduced following a spray event. Significant Lepidoptera species such as monarchs and swallowtails are not affected as they are not in the susceptible life stage when the spray is applied.

According to the World Health Organization, Btk has been sprayed over populated areas in several countries including the USA, Canada, and New Zealand. Some of these applications have been followed by public health surveillance programs and in general no (or very few) harmful effects have been reported among residents of the sprayed communities. A large epidemiological study conducted by the University of British Columbia concluded that "the largescale spray program of Btk in the lower mainland for control of the Asian and European gypsy moth did not cause any measurable increase in serious community unwellness that could be attributed to the spray" (Otvos and Vanderveen 1993).

Conclusions and Recommendations for 2020

The objective of this report was to provide the Town of Pelham with: 1) an assessment of the gypsy moth situation in selected areas of the Town, 2) forecasts of likely defoliation for these areas in 2020, 3) short and long term management options applying a philosophy of Integrated Pest Management (IPM), and 4) specific recommendations for management in the affected areas in 2020.

A large proportion (**58%**) of gypsy moth egg masses observed in January 2020 were new, and of these new egg masses a great percentage (**84%**) were considered to be large. As no recent comparable historical data exists for gypsy moth in Pelham, it is not possible to draw conclusions about the trend of the current gypsy moth population, however the egg mass size data suggests that the existing gypsy moth population is robust in all areas surveyed in 2019.

Based on the gypsy moth data collected during January 2020, the Town is likely to experience severe levels of defoliation throughout Fenwick, the northwest area of Fonthill as well as forested areas south of Fenwick and northwest of Fonthill. It is possible the defoliation will extend beyond the areas surveyed, especially north of Kilman Road west of Effingham Street throughout these continuous heavily forested areas and west into Thorold.

Anecdotal evidence from Town staff and residents encountered throughout the surveys would suggest that 2020 will be the second or third year of defoliation in many of these locations, therefore a subsequent year of defoliation may start to negatively impact tree health, depending on a variety of other compounding factors such as previous year defoliation (prior to 2019), environmental conditions, additional pest pressure (i.e. cankerworm), etc. The effects are likely to be noticeable given the high percentage of dominant oak trees on private property. If no action is taken in 2020, and populations are as high as forecasted by these models, there is the risk of gypsy moth migration beyond the current infestation boundary into new territory in search of additional trees on which to feed.

Numerous small blocks were sprayed in the spring of 2019, including many private rural properties for which we do not have the geographical boundaries. In some cases these treatments appear to have reduced population levels (in the absence of data from 2019, the reduction is an assumption), especially in Marlene Stewart Street Park, but in the majority of cases moderate-to-severe egg mass counts remain throughout the 2019 spray blocks. This lack of efficacy could be the result of spray timing, weather conditions, or populations migrating from nearby untreated areas.

The Town has three management options for 2020 which are outlined below: 1) "Do Nothing", where the Town does not intervene and allows the gypsy moth population to run its natural course, 2) targeted treatment of areas within urban boundaries of Fonthill and Fenwick, with the option of adding the forested areas directly adjacent to the urban boundaries, or 3) large-scale treatment including areas within urban boundaries of Fonthill and Fenwick as well as rural regions of the Town.

Option 1: The Town takes no action on public trees and executes a strong communication and engagement program throughout the communities of Fenwick and Fonthill, as well as rural landowners. Landowners should be educated on what their treatment options are (ground treatments with Btk or TreeAzin®, manual egg mass removal, or burlap banding) as well as the pros and cons associated with each option, focusing on cost and efficacy. Communication should be executed through a variety of avenues in order to reach as many people as possible. A combination of public open houses, direct mailings/letter drop-off/door hanger, website and social media (Twitter, Facebook, Instagram) will reach a wide audience. Open houses should be hosted on multiple evenings in early spring (March/April), and distributed materials should include a gypsy moth fact sheet and options summary, burlap band and twine, as well as information on what the Town is doing. This option requires much less time and fewer resources than the subsequent options, however with a population as severe as this it is very unlikely that management on private property alone would control the current outbreak. As a result, varying levels of defoliation will still occur and there is the risk that the gypsy moth population will persist for another year, thus prolonging the cost of management. Additionally, since this is likely the second or third year of high population levels, some decline in tree health may start to be observed such as branch dieback or reduced vigor, and tree mortality in some cases. Finally, given the political context of the gypsy moth issue over the past few years, this option may not be acceptable.

The consequences associated with inaction may result in overall tree health decline and further expenses required due to hazard tree removal, service requests, pruning, etc. as a result of a persisting and severe gypsy moth population and all of the impacts described under the section “Potential Impacts of No Intervention”. The upside of this approach is the reduced immediate cost to the Town in 2020.

Option 2: The Town implements a targeted aerial spray program within the urban boundaries of Fonthill and Fenwick, supported by a strong public outreach and communications program as described in Option 1, targeted towards private landowners with moderate-to-severe defoliation forecast plots located on their property. An aerial spray program including both public and private property would be the most effective method of controlling the gypsy moth population and reducing the risk to tree health in Fonthill and Fenwick. The downside of such a program includes significant staff time and upfront costs associated with organization, communication and implementation. The upside would be the immediate and dramatic reduction in gypsy moth populations, reduced number of resident complaints, and preservation of tree health. This approach may be cost-prohibitive if Pelham is the sole municipality undertaking an aerial spray program. However, there may be the opportunity to work with other southern Ontario municipalities who are also interested in a spray program to achieve some cost-effectiveness through cooperation. Private landowners located outside of the spray blocks, especially those with moderate-to-severe forecast plots on their property, should be communicated with in a similar manner as described below in Option 1. They should be encouraged to take action on their property using one of the management options available to the public.

High value trees (i.e. significant and/or mature trees) that have high 2019 egg mass counts, but do not get included in the spray blocks, should be considered as candidates for alternative control methods such as ground treatments with Btk or TreeAzin®, manual egg mass removal, or burlap banding. These measures will help to mitigate the effects of gypsy moth defoliation on these individual trees.

This option could limit the spray to public property, however, due to the landscape nature of this pest it is possible that the sprayed public areas could be re-infested by populations in neighbouring untreated private areas. This option could also include the treatment of forested areas directly adjacent to the urban boundaries in order to provide more comprehensive and effective landscape control and avoid re-infestation from properties just on the other side of the geographical urban/rural boundary.

Option 3: The Town implements a large-scale, extensive aerial spray program within the urban boundaries of Fonthill and Fenwick, as well as throughout rural areas of Pelham that have high defoliation forecasts. The downside of such a program include all those mentioned in Option 2, though the cost increases due to the inclusion of rural areas.

Regardless of the option selected, timely and comprehensive communication with the public about the Town’s plan and the expected role of private landowners is key to a successful program. If left untreated, the current gypsy moth outbreak has the potential to impact a significant component of Pelham’s urban forest. Therefore, given the results from the 2019 egg mass surveys in combination with the historical gypsy moth activity in the area, the Town should strongly consider implementing a gypsy moth-focused tree protection program in 2020, with the goal of reducing unacceptable levels of defoliation and mitigating the overall impact to the health and sustainability of Pelham’s urban forest.

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