European *Gypsy Moth* Update

FOR GEORGIA AND THE SOUTHEAST

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European gypsy moth (*Lymantria dispar*) is an economically important landscape and forest insect pest in the Northeastern United States. It was first introduced to the U.S. in 1868-1869 near Boston, Massachusetts, by E. Leopold Trouvelot, an artist and amateur entomologist. He introduced the species from France in an attempt to produce silk from the larvae, but he was unsuccessful and soon lost interest in the experiment. During this time, the pest escaped its housing and found shelter within the surrounding neighborhood vegetation. Over 30 years passed before the moth was recognized as a forest and landscape pest and several attempts to eradicate the pest soon began (Figure 1). The attempts were too few and too late, as the European gypsy moth had become established in the surrounding area. An epidemic had started with no viable means to stop the spread at the time. With limited control methods now, the species continues to flourish and spread south and westward (Figure 2).

Figure 1. European gypsy moth eradication attempts by residents of the Boston area.

Image: Gypsy Moths in North America. U.S. Forest Service, 2003.

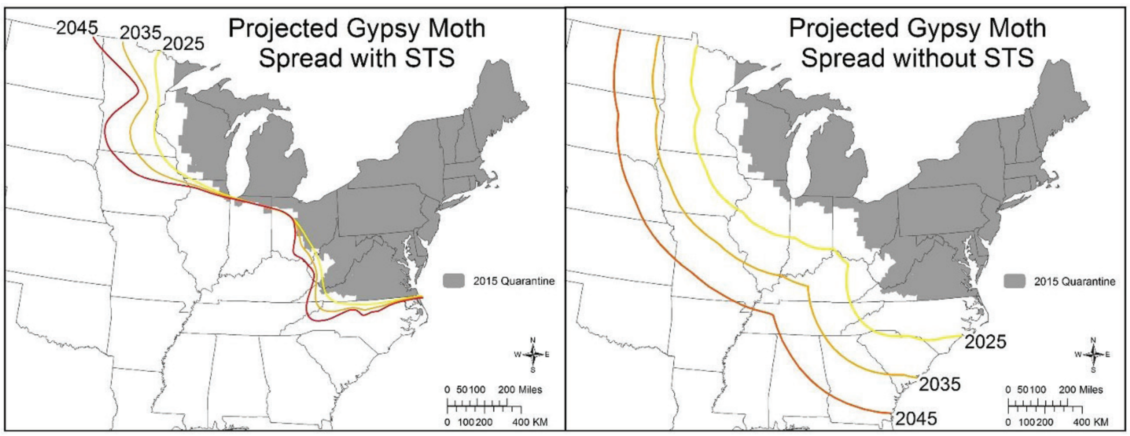

Figure 2. The predicted spread of European gypsy moth based on historic advancement of 13 miles per year (right) and predicted spread now that the Slow the Spread program has been implemented. The gray area indicates the current federal quarantine of European gypsy moths.

Image: Slowing the Spread of Gypsy Moth to Protect America's Hardwood Forest. STS Foundation, Inc. 2015. Retrieved from http://www.gmsts.org/fdocs/STS_brief_2015.pdf.

Currently, European gypsy moth is one of the top quarantine species in the U.S. and continues to be monitored heavily by the U.S Department of Agriculture and U.S. Forest Service. Thanks to the efforts of these government organizations and the Slow the Spread Foundation, the spread of European gypsy moth has slowed dramatically. However, residents and commercial landscape and nursery professionals should continually monitor for the pest and report any sightings to your local Cooperative Extension office. This publication provides an introduction to the pest, an update on control of the pest, and what we can expect in the Southeast if/when the insect arrives and becomes established.

Life Cycle

European gypsy moth has four life stages: egg, larva, pupa, and adult. Female European gypsy moths typically lay eggs in the fall as an overwintering stage. Eggs then hatch in spring (April in the Northeast but earlier in the mid-Atlantic and Southeast). Each egg mass generally contains 500 to 1000 eggs and is protected by a dense mat of brown or tan hairs (Figure 3). They are laid within layers of bark or on any outdoor object that provides some shelter from the elements. The larva (caterpillar) hatches from these

Figure 3. European gypsy moth egg masses.

Image: Leslie J. Mehrhoff, University of Connecticut. Bugwood.org eggs laid by the female and is the next life stage of the insect. While the color of the caterpillar may vary from tan to a darker brown, the caterpillar is rather easy to identify by the colored dots on its back: there are five blue dots on the thorax (behind the head) followed by six red dots along the abdomen (rear-end) of the caterpillar (Figure 4). Most damage to trees and vegetation is caused during the larval stage. The caterpillar constantly feeds on foliage to prepare for metamorphosis into a pupa. Most young caterpillars feed during the day, while older caterpillars feed at night. There are instances where all ages of caterpillars feed during day and night depending on the scarcity of food. To travel to new sources of food, the caterpillar attaches a silken thread to the top of trees and allows the wind to carry them to a new point on adjacent trees. After seven weeks, the larva has acquired enough nutrients to enter the pupa stage.

Figure 4. European gypsy moth larvae (caterpillar)

Image: Evgeny Akulov. Bugwood.org

The caterpillar enters the pupa stage between June and early July in the Northeast, and three to four weeks earlier in the mid-Atlantic. In the Southeast, due to an earlier spring, the transition could be even earlier, although this is speculative. In the pupa stage, the caterpillar surrounds itself in a dark-brown shell covered in small, tan hairs. The cocoons or shells can be found within sheltered areas, generally between the bark of trees or in leaf litter. The adult moth emerges 10 to 14 days later (Figure 5). The female moths have tan wings and a distinguishing 'V' on their wings. The female moths are larger than the males and cannot fly. The male moths have brown wings and a brown body. Unlike the females, they have feathery antenna. Despite having only one generation per year, European gypsy moth populations can reach epidemic proportions due to the large number of eggs laid by a single female.

Figure 5. Male (brown) and female (tan) gypsy moths.

Image: Milan Zubrik, Forest Research Institute, Slovakia. Bugwood.org

Range and Spread

The current U.S. quarantine for European gypsy moth is from northern Maine southward to the North Carolina/ Virginia border and northwestward through central West Virginia and Ohio, northern Indiana, northern Illinois, eastern Wisconsin, and the arrowhead of Minnesota (Figure 2). The current front of the pest on its south flank lies along the Virginia/North Carolina border. Since the release of the moth 130 years ago, it has spread at a historical rate of 21 kilometers per year (13 miles per year). At this rate, European gypsy moth would be knocking on Georgia's boarder in the next decade.

However, a congressionally funded control project, Slow the Spread (http://www.gmsts.org/index.html), was initiated in 2000 to reduce the southern and western progression of the pest. Using a combination of monitoring efforts and a variety of treatments (see "Containment and Preventative Strategies"), the rate of spread southwestward has been reduced from 13 miles per year to three miles per year (Figure 2). However, spot infestations across the Southeast still occur, and residents must be aware and vigilant in reporting any European gypsy moth sightings outside the current quarantine area.

There are several factors that contribute to the spread of the European gypsy moth, including both biological and physical traits of the moth. Its primary biological modes of travel include flight and crawling. Larva (caterpillars) can traverse several trees by crawling within the seven weeks before entering the pupa stage. Once the adult male emerges from the pupa stage, it has the ability to fly. The males and females both have wings, but only the males are able to fly. Due to the size of the wings, the distance that males are able to fly is minimal, but the help of wind currents enables them to travel a much farther distance. The caterpillar is also able to travel by attaching a silken thread to the tops of trees and then use the wind to travel to a neighboring tree. This mode of movement is both a biological and physical mode of travel. The next mode of movement is physical, with the most common form of physical movement being transport by humans. The caterpillars, along with egg masses, have been known to travel hundreds of miles outside of the established quarantine area due to human transport of the insect. Transport of firewood without proper treatment or checking for insects on or within the wood is the most frequent mode of transport outside of the quarantine area. In fact, it has been identified three times in Georgia prior to 2017 (Fannin, Rockdale, and White counties), all attributed to human-movement. In all three cases, rapid chemical treatment of adjacent areas seems to have prevented establishment and spread.

Damage Cycle

Since the introduction of the pest in the Northeastern U.S., European gypsy moth has become one of the most significant pests of ornamental and forest trees in the Eastern U.S. The European gypsy moth has the ability to fully defoliate a tree or forest (Figure 6) and create lasting damage, including mortality when a tree is repeatedly and completely defoliated over five or more years. During the larval stage, caterpillars must constantly feed on foliage to provide enough nutrients for a successful shift to the pupal stage. The caterpillar is a free feeder, meaning that it consumes the entire leaf without any constraints on its digestive system. Generally, an infestation of the European gypsy moth occurs over a four-year period. The defoliation is typically light in the first two years and then intensifies in the third year. By the fourth year the canopy is completely defoliated, and if total defoliation continues for a fifth or sixth year, the trees are typically not able to recover. The population of caterpillars then declines as the local food source decline,s and this forces subsequent generations to push outward to adjacent areas.

Figure 6. Aerial view of defoliation from European gypsy moth. The area of defoliation is progressing from the top right to the lower left of this image.

Image: Pennsylvania Department of Conservation and Natural Resources, Forestry Archive. Bugwood.org

The main food source of European gypsy moth larvae are mature hardwood trees. However, research from Maryland indicates that they can survive and reproduce when ingesting a mixed diet of hardwood and pine foliage, including some understory trees and shrubs. They feed on hundreds of forest and landscape species including both hardwoods and conifers. A comprehensive literature search was conducted to compile a list of economically important trees, which can be found in Table 1. However, some of the most preferred and affected trees include oak (*Quercus* spp.), alder (*Alnus* spp.), beech (*Fagus* spp.), and willow (*Salix* spp.). When infestations begin in an area, scouting for the insect should be done on or around these taxa.

The main concern for susceptible trees, besides the previously stated annual defoliation of the trees, is that constant defoliation and regrowth by the tree causes an immense amount of stress on the tree. The stress put on the tree by the constant defoliation weakens its ability to protect itself from environmental stress or secondary pests. When the tree is stressed, it is more likely to be attacked by different insects including bark beetles and boring insects. Along with increased attacks from insects, it is also susceptible to a variety of pathogens and bacterial infections.

Table 1. List of common landscape and forest species that have been classified as susceptible (greater than 75% plant damage or larval survival in research trials), tolerant (10-75% plant damage or larval survival in research trials), or resistant (less than 10% damage or larval survival in research trials) to European gypsy moth. This table does not include species that are suspected to be susceptible, tolerant, or resistant to European gypsy moth, listing only species included in formal research trials. See literature review for specific studies.

Susceptible	Tolerant	Resistant
Acer negundo	*Acer rubrum*	*Abies balsamea*
Alnus spp.	*Acer saccharum*	*Abies fraseri*
Amelanchier canadensis	*Amelanchier arborea*	*Acer penslyvanicum*
Betula nigra	*Aesculus* spp.	*Acer spicatum*
Betula papyrifera	*Asimina triloba*	*Camaecyparis thyoides*
Betula populifolia	*Betula alleghaniensis*	*Catalpa* spp.
Carpinus caroliniana	*Betula lenta*	*Fraxinus* spp.
Corylus spp.	*Carya* spp.	*Gleditsia triacanthos*
Crataegus spp.	*Castenea dentata*	*Gymnocladus dioicus*
Fagus americana	*Castenea pumila*	*Ilex opaca*
Hamamelis virginiana	*Celtis occidentalis*	*Juniperis virginiana*
Larix decidua	*Cercis canadensis*	*Kalmia latifolia*
Larix laricina	*Cornus florida*	*Ligustrum* spp.
Liquidambar styraciflua	*Diospyros virginiana*	*Lindera benzoin*
Malus spp.	*Jugulans* spp.	*Liriodendron tulipifera*
Ostrya virginiana	*Magnolia acuminata*	*Maclura pomifera*
Populus balsamifera	*Nyssa sylvatica*	*Morus alba*
Populus grandidentata	*Oxydendrum arboreum*	*Morus rubra*
Populus tremuloides	*Picea* spp.	*Platanus occidentalis*
Pyrus spp.	*Pinus* spp.	*Rhododendron* spp.
Quercus spp.	*Populus alba*	*Robinia pseudoacacia*
Salix spp.	*Populus deltoides*	*Rubus* spp.
Sorbus spp.	*Prunus avium*	*Taxodium distichum*
Tilia americana	*Prunus penslyvanica*	*Thuja occidentalis*
	Prunus serotina	*Ulmus rubra*
	Prunus virginiana	*Viburnum* spp.
	Sassafras albidum	
	Tsuga canadensis	
	Tsuga caroliniana	
	Ulmus spp.	
	Vaccinum spp.	

Expected Damage in the Southeast

Although the European gypsy moth hasn't yet become established across the Southeast, its progression southward will continue. The preferred hosts, oak, alder, beech, and willow, are plentiful in this region and the warmer climate offers the possibilities of smaller moth die-offs in winter and shorter moth generation lengths (in other words, more moths in less time). Moth eggs are susceptible to freezes early or late in the season, and cold, rainy weather can slow larvae development, feeding, and spread. The South's warmer weather could result in rapid moth population growth and massive forest dieback. Street trees—already under stress—will likely be targeted by the insects, along with trees in yards, parks, and other high-stress urban plantings. However, the primary economic concern is the hardwood lumber industry, which is largely based on European gypsy moth host species. The pine lumber industry could suffer as well, although losses should be lower, as pine is not a preferred host.

Containment and Preventative Strategies

European gypsy moth can cause serious damage to forest systems and can weaken even the strongest of forested areas. Several methods to slow the spread of this pest are currently underway, but it will likely never be possible to fully eradicate the species from the U.S. The main reason that this pest cannot be eradicated is due to the previously stated physical methods of spread. Humans continue to move the species outside the quarantine area and new infestations are a frequent occurrence. Complete eradication may not be possible, but the ability to slow the spread of the European gypsy moth has become a reality due to the efforts of the Slow the Spread Foundation. There are currently several methods to slow the spread and effects of the European gypsy moth including silvicultural practices, biological control, and chemical control. The first step is monitoring for the pest along its migratory front. To do this, pheromone traps are placed on the "front lines" of southwestward spread and known areas of infestation, reaching outward from the infested areas. Once a European gypsy moth is found using traps, federal and state agencies intervene and attempt to suppress or eliminate the pest through several different control methods.

The first methods that can be used to reduce the local spread of European gypsy moth or prevent an infestation are silvicultural practices. By removing and burning stressed or already damaged trees from the forest, it reduces the severity of an outbreak. Also, removing preferred host trees from the area reduces the population size and lessens the severity of an outbreak. However, these practices can remove valuable trees from the area, and in times of scarcity, European gypsy moth will move to surrounding trees that are typically not a preferred food source.

The second control method is biological. There are several parasitic or predatory insects, along with pathogens, that can remove European gypsy moth from an area. Several different types of predators have been identified as feeding on European gypsy moth including mice, shrew, and some bird species. These vertebrates generally feed on the young larval or pupa stages and can have a dramatic impact on local European gypsy moth populations. One of the greatest invertebrate predators are ants, which generally feed on young larva (Figure 7). Several pathogens are also being used to control the spread of European gypsy moth. The main pathogen being used is nucleopolyhedrosis virus, or NPV; this virus has been extensively researched as a product for controlling European gypsy moth outbreaks and has been released under the name of "Gypcheck."

Figure 7. Black carpenter ant, *Campontus pennsylvanicus*, feeds on gypsy moth pupa.

Image: Liebhold, Sandy. Gypsy Moths in North America. U+P+ Clobst Service, 2003.

The third form of control uses insect pheromone applications to forested areas. These pheromones were developed to mimic those produced by adult females to attract males during mating, and are typically aerially applied and nontoxic to other insects or mammals, making them a preferred method of control. The goal of pheromone application is to confuse the male moths and prevent them from finding and mating with females. This form of control has also proven to be very economical, at a cost of $5-6 per acre.

The last form of control is chemical control. The two most common forms of chemical control used in forest application are *Bacillus thuringiensis* var. *kurstaki*, or BTk, and Dimilin. BTk is a bacterium that is toxic to moths and butterflies and is commonly used as an aerial spray (Figure 8). Dimilin is an insecticide that can only by applied by licensed operators, and if applied properly, can be effective against large outbreaks of gypsy moth. The main concern when using BTK and Dimilin is mortality of nontarget insects. For this reason, in forested areas, these two options are generally used as a last resort or on a very localized basis.

Figure 8. Aerial application of *Bacillus thuringiensis* var. *kurstaki* to control European gypsy moth.

Image: John Ghent, U.S. Forest Service. Bugwood.org

In landscape and ornamental nursery situations, there are a number of insecticides that can be used to control European gypsy moth infestations on individual plants or larger landscapes or nurseries. A comprehensive listing of insecticides labeled for European gypsy moth control are listed by mode of action (Fungicide Resistance Action Committee, FRAC) codes in Table 2. Many of these chemicals are not available to homeowners, and can only be applied by persons holding (or supervised) by a certified pesticide applicator. Additionally, many of these chemicals have state-by-state restrictions. As always, consult the insecticide label and your state's department of agriculture to verify whether the insecticide is registered in your state. Always consult the insecticide label and material safety data sheet to determine what personal protective equipment should be worn when applying the insecticide.

Table 2. A comprehensive list of available insecticides (as of March 2018) labeled to treat European gypsy moth. Please refer to product labels for specific treatment protocols and applicator safety precautions.

IRAC Code [1]	Mode of Action	Chemical subgroup	Active Ingredient	Selected Trade Names [2,3]	Use Site [4]	REI (hrs) [5]
1A	Acetylcholinesterase inhibitors	Carbamates	carbaryl	Sevin SL	L, N, G	12
1B	Acetylcholinesterase inhibitors	Organophosphates	acephate	Orthene T&O	L, N, G	24
				Lepitect	L, N, G	24
				Inject-A-Cide B	L	N/A
			malathion	Malathion 5EC	L	12
3A	Sodium channel modulators	Pyrethroids / Pyrethrins	bifenthrin	Onyx	L	N/A
				OnyxPro	L, N, I	12
			dicrotophos	Decathlon	L, N, G, I	12
			beta-cyfluthrin	Tempo Ultra WP	L, I	N/A
				Tempo SC Ultra	L, I	N/A
			lambda-cyhalothrin	Scimitar CS; Scimitar GC	L ; L, N, G	24; 24
			tau-fluvalinate	Mavrik Aquaflow	L, N, G, I	12
			permethrin	Astro	L, G, I	12
				Permethrin Pro	L, I	N/A
				Perm-Up 3.2 EC	L, N, G, I	12
			pyrethrins	Tersus	N, G	12
				Pyganic	N, G	12
3A + 4A	Sodium channel modulators	Pyrethroids + Neonicotinoids	bifenthrin + clothianidin	Aloft LC G, LC SC	L	N/A
			bifenthrin + imidacloprid	Allectus SC	L, I	N/A
			cyfluthrin + imidacloprid	Discus N/G	N, G, I	12
			zeta-cypermethrin + bifenthrin + imidacloprid	Triple Crown T&O	L, I	N/A
3A + 27A	Sodium channel modulators	Pyrethroids + Piperonyl -butoxide (PBO)	pyrethrins + piperonyl butoxide	Pyreth-It	N, G	12
4A	Nicotinic acetylcholine receptor agonists	Neonicotinoids	acetamiprid	TriStar 8.5 SL	L, N, G	12
			dinotefuran	Transtect 70 WSP	L	N/A
4C + 5[20]	Nicotinic acetylcholine receptor agonists	Sulfoxaflor + Spinosyns	sulfoxaflor + spinetoram	XXpire	L, N, G	12
5	Nicotinic acetylcholine receptor allosteric activators	Spinosyns	spinosad	Conserve SC	L, N, G	4
				Entrust	L, N, G	4
6	Chloride channel activators	Avermectins, Milbemycins	emamectin benzoate	Arbormectin	L	N/A
				Tree-äge	L	N/A

IRAC Code [1]	Mode of Action	Chemical subgroup	Active Ingredient	Selected Trade Names [2,3]	Use Site [4]	REI (hrs) [5]
8C	Misc. non-specific (multi-site) inhibitors	Fluorides	cryolite (sodium alumino-fluoride)	Kryocide	L	N/A
11	Microbial disruptors of insect midgut membranes	*Bacillus thuringiensis* (*Bt*) & insecticidal proteins	*Bt* subsp. *Aizawai*	XenTari	L, N, G, I	4
			Bt subsp. *kurstaki*	Dipel Pro DF	L, N, G, I	4
15	Inhibitors of chitin biosynthesis, type 0	Benzoylureas	diflubenzuron	Dimilin 25W	L, N	12
				Dimilin 4L	L, N	12
16	Inhibitors of chitin biosynthesis, type 1	Buprofezin	buprofezin	Talus 70DF	L, N, G	12
18	Ecdysone receptor agonists	Diacylhydrazines	metho-xyfenozide	Intrepid 2F	L, N, G, I	4
			tebufenozide	Confirm 2F	N	4
20B	Mitochondrial complex III electron transport inhibitors	Acequinocyl	acequinocyl	Shuttle 15 SC	L, I	12
				Shuttle-O	N, G	12
22A	Voltage-dependent sodium channel blockers	Indoxacarb	indoxacarb	Provaunt	L	N/A
UK [6]	Unknown	Azadirachtin	azadirachtin[8]	Azatin O	L, N, G, I	4
				Azatin XL	N, G, I	4
				Azatrol EC	L, N, G, I	4
				Ornazin 3% EC	L, N, G, I	12
				TreeAzin	L, N, G	until dry
NC [7]	Various		*Beauveria bassiana*	BotaniGard ES; Mycotrol ESO; Mycotrol WPO	L, N, G, I	4
				BotaniGard 22 WP	L, N, G, I	4
				Naturalis-L	L, N, G	4
			Chromobacterium subtsugae	Grandevo PTO	L, N, G	4
			insecticidal soap	M-Pede	L, N, G, I	12

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