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Gypsy Moth

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Gypsy moth, *Lymantria dispar dispar* (Linnaeus) (Lepidoptera: Erebidae), is an exotic invasive species introduced from Europe that is spreading south and west in North America. In spring and early summer, gypsy moth caterpillars feed on the leaves of many different tree species, especially oaks. During outbreaks, caterpillars defoliate entire forests. Most broadleaf trees produce new foliage in response to defoliation >50%, allowing them to resume photosynthesis. Defoliation weakens trees, which renders them more susceptible to secondary mortality agents. Gypsy moth can also directly kill trees, especially if severe defoliation persists for multiple successive seasons. In some years, outbreaks can be massive with defoliation exceeding several million acres. If extensive tree mortality occurs, outbreaks can contribute to shifts in forest species composition toward dominance by immune host species.

Several related moth species, including *L. albescens, L. mathura, L. monacha, L. postalba, L. umbrosa,* and two other subspecies of gypsy moth, *L. dispar asiatica* and *L. dispar japonica*, the Asian gypsy moth, do not have established populations in North America. Of these, Asian gypsy moth subspecies, *L. dispar asiatica* and *L. dispar japonica*, have been the most frequently intercepted and accidentally introduced subspecies in North America. Asian gypsy moth surveillance and eradication have been particularly critical because these subspecies have broader host ranges than their European counterpart, and unlike the European subspecies, females are capable of flight.

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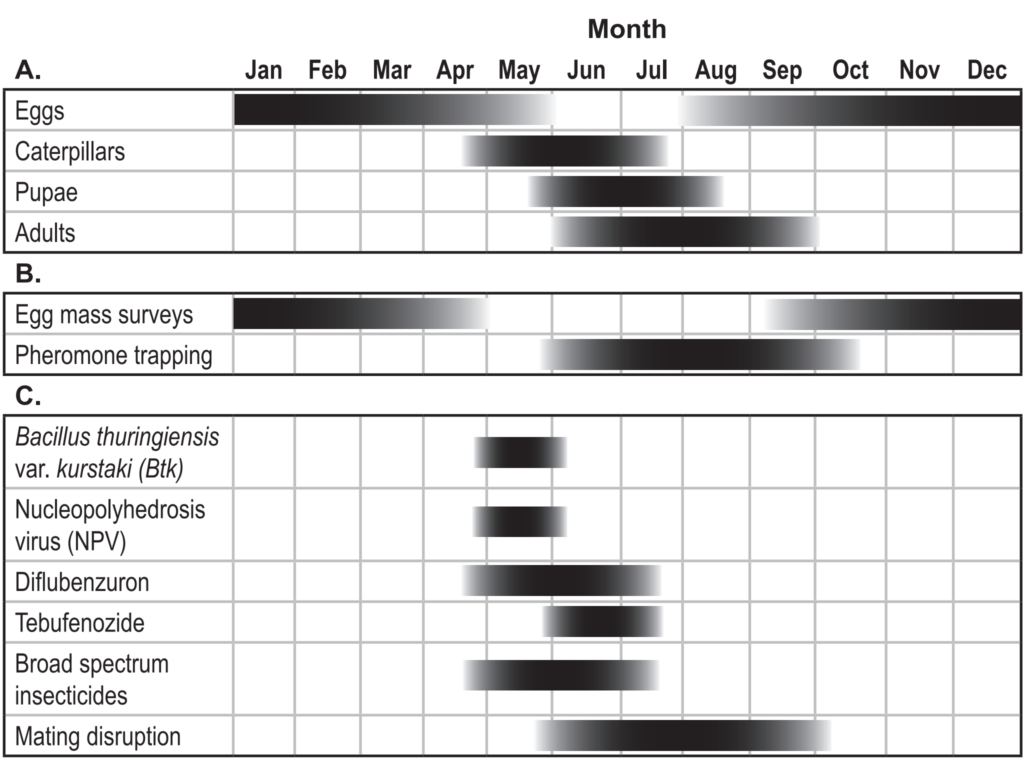
Identification

From fall through early spring, gypsy moth exists as eggs in brown to cream-colored hairy masses (approximately 1.5 inches long and 0.75 inches wide) located on tree trunks and large branches or other objects such as rocks, logs, homes, motor vehicles, and outdoor furniture (Figure 1). In spring, young caterpillars hatching from egg masses first appear dark and hairy, then develop characteristic markings on their dorsal (upper) surface as they increase in size (five and six pairs of raised blue and red spots, respectively, Figure 2). Mature caterpillars can range from 1.5 to 2.5 inches long and frequently seek sheltered areas to rest and ultimately pupate. Pupae are dark brown and affixed with silken thread to trees, rocks, and other structures (Figure 1.B). Pupal cases and old egg masses can remain on trees and other surfaces long after the moths have emerged. Adult moths appear from early June to early October throughout its current range, and are sexually dimorphic. Males are mottled brown in color with feathery antennae and black wing markings, whereas females are white or cream-colored with distinct black markings on the wings and thin, wire-like antennae (Figure 3). Females are larger than males with a wingspan of about 2.5

Table 1. *Approximate seasonal occurrence of gypsy moth life stages in the established areas of North America (A) and approximate timing of various monitoring methods (B) and suppression techniques (C).*



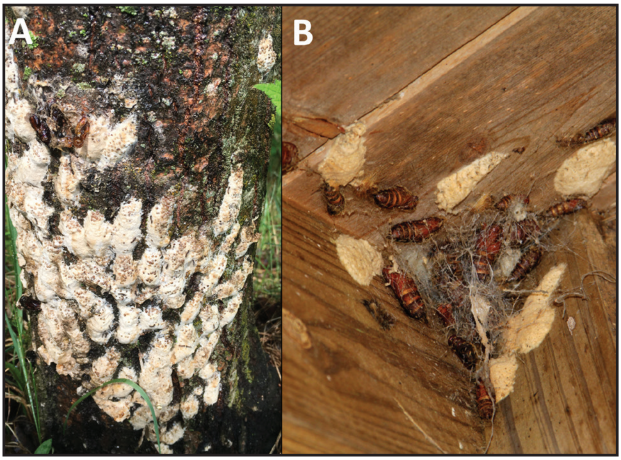


Figure 1 (left). *A high density of gypsy moth egg masses laid at the base of a tree (A) and laid under a human-made structure (trailhead sign) (B). Old pupal cases secured with silk webbing can be seen near the egg masses under the shelter in the second photo.*

Figure 2 (below). *Newly hatched first instar caterpillars resting on their egg mass (A). A dark-colored second-instar caterpillar (B) lacks the distinct red- and blue-colored markings possessed by fourth-, fifth- and sixth-instar caterpillars (C).*

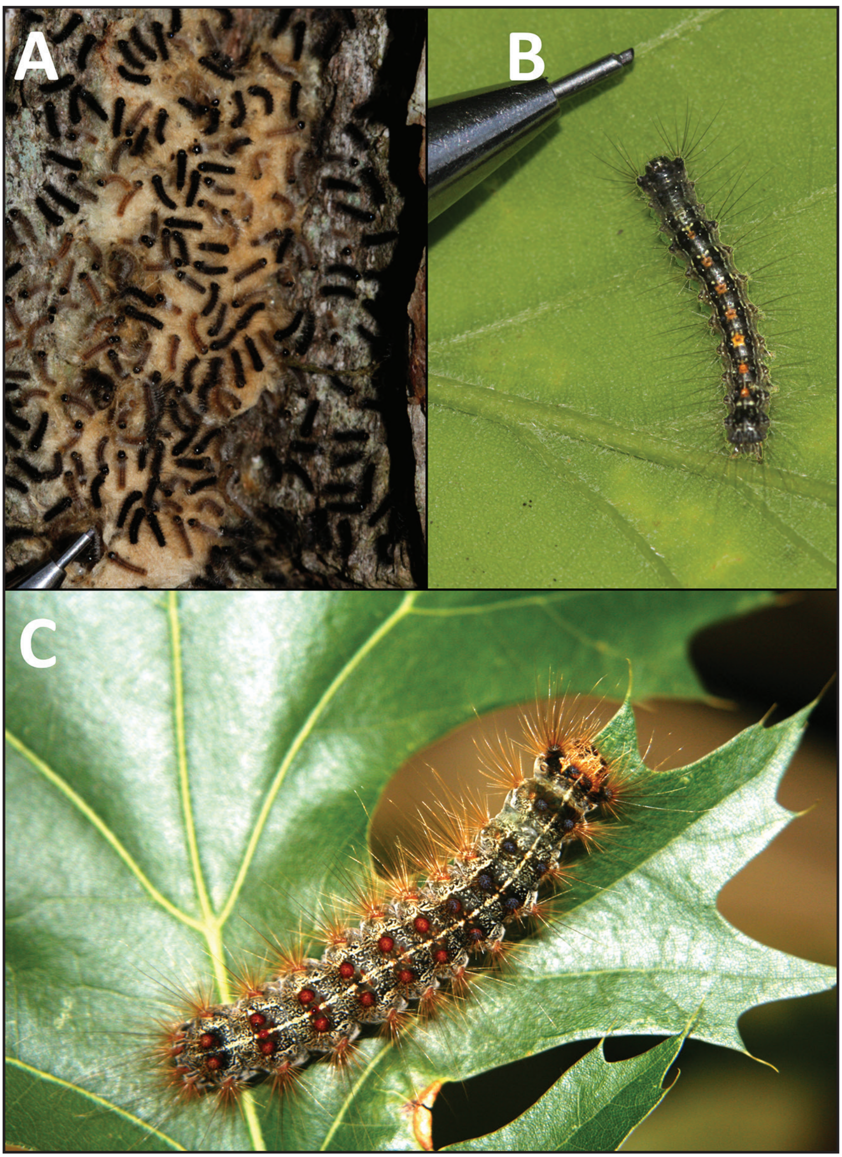


Figure 3. *Adult female gypsy moths lay eggs on the bark surface or in crevices. Note the brown to cream coloring of the egg mass under each female and at the bottom of the image. Brown-colored male moths can be seen mating with the white-colored females on the stem of a tree (inset). Female and male moths can lose their coloration on their forewings, as seen in the main image of the females, as they age and become more drab-colored.*

inches, compared to the 1.5 inch wingspan of males. Though they have wings, females do not fly.

Life History

Gypsy moth has one generation per year and the seasonal timing of its life cycle can vary across its wide range in North America depending on climate (Table 1.A). Eggs hatch in early spring (Figure 2.A) in synchrony with the bursting of tree leaf buds. Caterpillars grow 1,000-fold in weight as they progress through five (males) or six (females) larval instars (stages) during their six to eight week development period. After hatching, first-instar caterpillars are strongly photo-positive and crawl upward; some spin downward on long silken threads and disperse as their silken thread carries them on the wind. This behavior is called ballooning, and typically transports caterpillars for short distances (less than a mile), but sometimes further on strong wind currents. Young caterpillars chew holes in leaves in the upper canopy during the day and rest at night on foliage. Older caterpillars consume all leaf tissue aside from the midrib (Figure 4.A), and actively feed at night, crawling downwards to protected resting sites on or near the base of trees during the day. A significant fraction of late-instar larvae crawl to the forest floor, resting under objects such as rocks, stumps, and logs, and may crawl up a different tree the next morning. During outbreaks, caterpillars will feed throughout the day because of the competition for declining foliage. In early summer, gypsy moths enter the pupal stage for one to two weeks, typically located in their last larval resting site. These resting sites (Figure 1.B) are generally in branch and bark crevices and under rocks and human-made structures, but during outbreaks, when caterpillar densities are high, pupation may occur anywhere. Adults emerge from pupal cases in mid-summer and are active for one to seven days. Males detect the female-produced sex pheromone [(+)-disparlure] to locate females and mate. Male adult gypsy moths are diurnal (daytime) flyers and have a distinct erratic flight pattern. Flightless females lay eggs near where they pupated. In mid- to late summer, females lay 100-1,000 eggs in a brown to cream-colored hairy mass on tree trunks, or on other objects. Gypsy moth overwinters as a fully developed larva within the egg (embryos develop into larvae in four to six weeks but remain in the eggs over winter). Dense hairs, the red and blue coloration on caterpillars, lack of web- or tent-building, and feeding primarily during the early growing season can distinguish gypsy moth larvae from other leaf-feeding forest pests in the eastern USA, such as tent caterpillars, spanworms, cankerworms, and webworms.

Hosts

Gypsy moth caterpillars are known to feed on the foliage of hundreds of different tree and shrub species. Nevertheless, within North America, there is considerable variation in suitability among tree species, which can be classified as susceptible, resistant, or immune (Table 2). Susceptible tree species are those which caterpillars are capable of feeding on from the first instar through completion of larval development. Typical North American susceptible species include oaks, aspen, apple, willow, basswood, hawthorns, and some birches and alders. During outbreaks, susceptible species are generally the most heavily defoliated in mixed stands. Feeding by early instar larvae does not occur on species classified as resistant; most feeding on resistant species is only by late instar larvae and these hosts are generally only utilized once larvae have depleted most of the foliage of susceptible trees.

Table 2. *Tree and shrub species susceptible, resistant, and immune to gypsy moth feeding in the USA. This is not a complete list of host genera and species for gypsy moth.*

Susceptible	Resistant	Immune
alder, *Alnus* spp.	beech, *Fagus* spp.	arborvitae, *Thuja* spp.
apple, *Malus* spp.	dogwood, *Cornus* spp.	ash, *Fraxinus* spp.
aspen and poplars, *Populus* spp.	elm, *Ulmus* spp.	black cherry, *Prunus serotina*
basswood, *Tilia* spp.	hemlock, *Tsuga* spp.	fir, *Abies* spp.
paper birch, *Betula papyrifera*	hickory, *Carya* spp.	holly, *Ilex* spp.
hawthorn, *Crataegus* spp.	maple, *Acer* spp.	juniper, *Juniperus* spp.
hazelnut, *Corylus* spp.	pine, *Pinus* spp.	locust, *Robinia* spp.
larch, *Larix* spp.	*Prunus* spp.	redbud, *Cercis* spp.
mountain-ash, *Sorbus* spp.	serviceberry, *Amelanchier* spp.	sumac, *Rhus* spp.
oak, *Quercus* spp.	spruce, *Picea* spp.	sycamore, *Platanus* spp.
willow, *Salix* spp.	*Viburnum* spp.	tulip poplar, *Liriodendron tulipifera*
witch-hazel, *Hamamelis* spp.	walnut, *Juglans* spp.	tupelo, *Nyssa* spp.

See Liebhold et al. (1995) for a more complete gypsy moth host list.

Resistant species include maple, beech, hickory, and black walnut. Immune species include tulip poplar, ash species, American sycamore, and black cherry. Larvae essentially never feed on immune trees and even during outbreaks, these trees are completely free of defoliation. Most conifers are immune, though some (e.g., hemlock, white pine, blue spruce) are resistant and can be defoliated by late instar larvae;

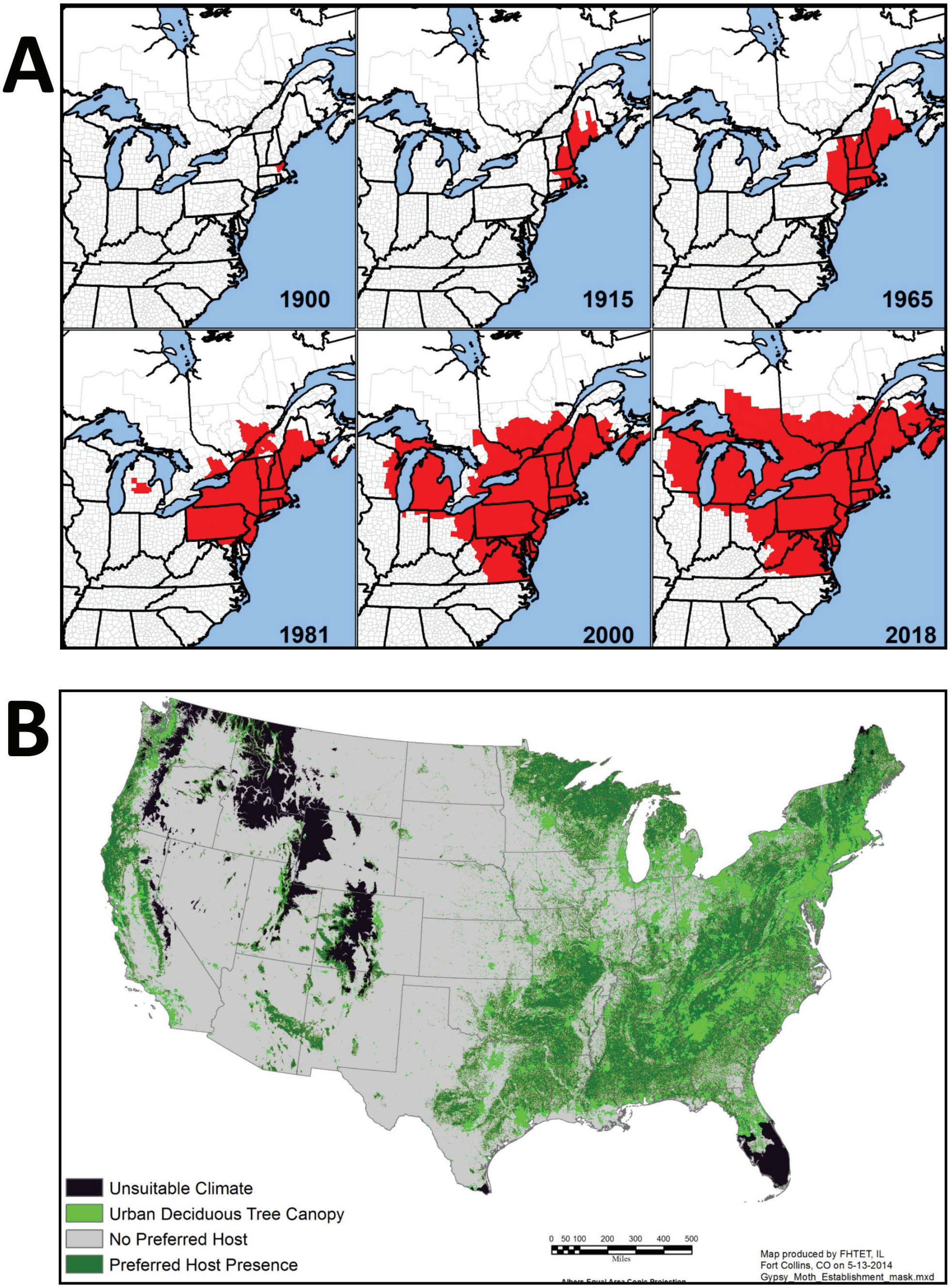
Figure 4. *Mature caterpillars can feed extensively on oak leaves (A) and cause severe defoliation and subsequent tree mortality especially of oaks (B). Uninjured resistant and immune host species can be seen in the understory (B) following a gypsy moth outbreak in the northeastern USA.*

deciduous conifers (e.g., larch, bald cypress) are generally susceptible.

Distribution and Spread

The amateur entomologist Éttiene Léopold Trouvelot, an immigrant to the USA from France living in Medford, MA, obtained gypsy moth egg masses from Europe and reared gypsy moth larvae in

Figure 5. *Historical spread of the gypsy moth from 1900 to 2018 to the south and west in North America (A). Range of susceptible hosts and habitat suitability of gypsy moth found in the USA (B).*



cages on trees in the backyard of his home. They escaped in 1868 or 1869. Recognizing the potential for damage, Trouvelot alerted entomologists to this incident but no action was taken until 1890 when the State of Massachusetts initiated an unsuccessful campaign to eradicate the population. Since then, the gypsy moth has been slowly expanding its North American range (Figure 5.A). The historically slow rate of spread can be attributed to the lack of female flight as well as to several intensive efforts to limit its spread. Beginning in 1912, the US Department of Agriculture (USDA) implemented a quarantine that limited the movement of objects, such as nursery stock, from the invaded area; this and other management activities (see below) have greatly limited gypsy moth range expansion. Gypsy moth often colonizes new areas when objects carrying egg masses (e.g., outdoor furniture, firewood, recreational vehicles, and trailers) are transported outside of the generally infested area. As described below, networks of pheromone traps monitored annually by state and federal agencies are used to detect these populations so that they can be eradicated or contained to prevent additional spread. The current gypsy moth range only encompasses about one-third of the potentially susceptible forests in the USA (Figure 5.B).

Ecological and Economic Impacts

Outbreaks of the gypsy moth have primarily impacted susceptible host tree species (Figure 4.B). Defoliation from young caterpillars can be difficult to detect, but feeding can resemble small holes in the interior of the leaf. Young caterpillars need foliage from susceptible trees and shrubs to survive and commonly begin feeding on these species in the understory. As caterpillars mature, leaf feeding becomes more extensive and the entire leaf can be consumed. Following low levels of defoliation (<50%), most broadleaf trees will experience only a minor reduction in radial growth. Healthy trees can withstand one or two consecutive years of severe defoliation and will frequently re-foliate by mid-summer even after experiencing >50% defoliation. However, stressed trees and trees with poor crowns are more likely to succumb to high levels of defoliation. Crown dieback can occur following extensive feeding from gypsy moth and tree mortality can result from repeated bouts of severe defoliation (>75%). Drought and secondary mortality agents on oaks, such as twolined chestnut borer (*Agrilus bilineatus*) and fungal root diseases (e.g., *Armillaria* spp.), can interact with gypsy moth defoliation to cause additional tree mortality three to five years later. Conifer species (e.g., pines and hemlock), although generally less preferred hosts of gypsy moth, are less tolerant of defoliation and can be killed following a single year of complete defoliation. Forest stands dominated by oaks, particularly

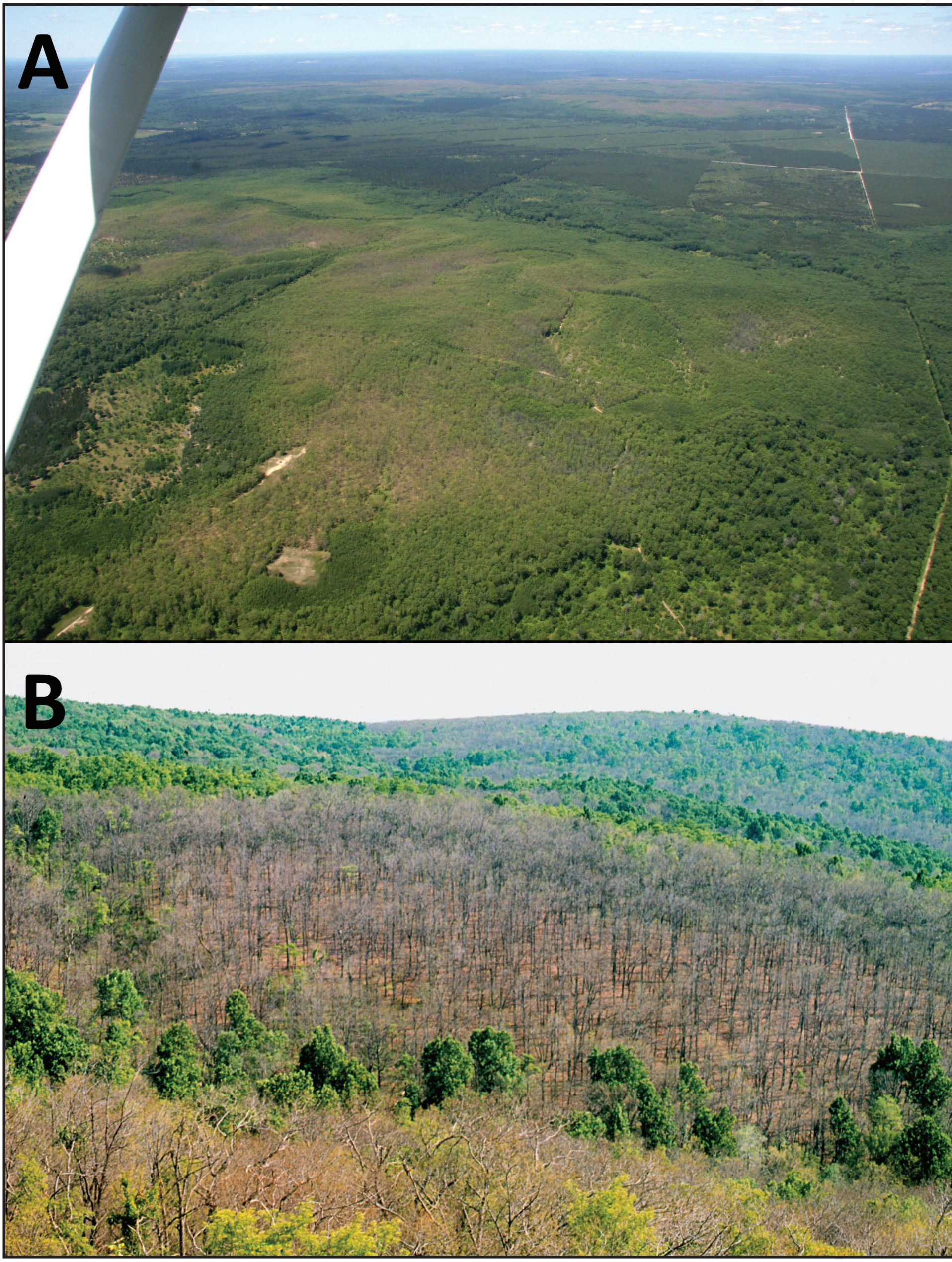


Figure 6. *Oak-dominated stands that experience repeated bouts of defoliation can lead to high levels of defoliation and tree mortality (>90%). Defoliation can be extensive across the landscape. Note the brown patches of trees in the foreground and background of the image (A). Interacting stressors (e.g., insects, disease, and dry sites) can result in tree mortality being delayed for three to five years following an outbreak (B).*

chestnut oak, or other susceptible hosts (>50% of the forest canopy), experience the most defoliation and mortality (Figure 6.A). In addition, forests located on xeric sites, such as south- and west-facing aspects, and ridge-tops with sandy or rocky soils and a preponderance of hiding places (e.g., bark flaps) for caterpillars can contribute to multi-year defoliations and high-levels of tree mortality caused by gypsy moth (Figure 6.B). Tree mortality can exceed 90% following gypsy moth outbreaks when additional stressors (e.g., drought, secondary mortality agents) are present, though, generally, <15% of the total basal area is lost following most gypsy moth outbreaks. Losses to the forest canopy can result in changes in understory vegetation and long-term canopy composition where more shade-tolerant and less susceptible tree species, like red maple, typically gain canopy dominance. Defoliation and tree mortality from gypsy moth can delay mast production in oaks, thus reducing food availability for wildlife such as squirrels, mice, and deer. During and following outbreaks, there may be short-term changes in the microclimate (e.g., higher sun exposure, temperature, and wind) on the forest floor and in water quality because of the substantial loss of canopy cover and the leaching of nutrients with leaf material and frass (insect excrement) to the forest floor and ultimately forest streams.

Figure 7. *During outbreaks, high densities of caterpillars can be a nuisance and a health concern to homeowners, especially those in or adjacent to forested areas.*

In North America, regional gypsy moth outbreaks typically occur every 8 to 12 years and may persist for one to three years. From 1920 to 2020, gypsy moth has defoliated >95 million acres. Economic impacts associated with tree mortality include the loss of timber revenues and removal/replacement costs for homeowners, businesses, and governments. The most serious impacts are felt by private landowners who experience loss of aesthetic and property values when ornamental trees are defoliated or killed. High densities of caterpillars can also be a nuisance when frass rains down from defoliated trees on homeowners and in recreation areas (Figure 7). Hairs from caterpillars can trigger respiratory problems, skin irritations, and allergic reactions in some people.

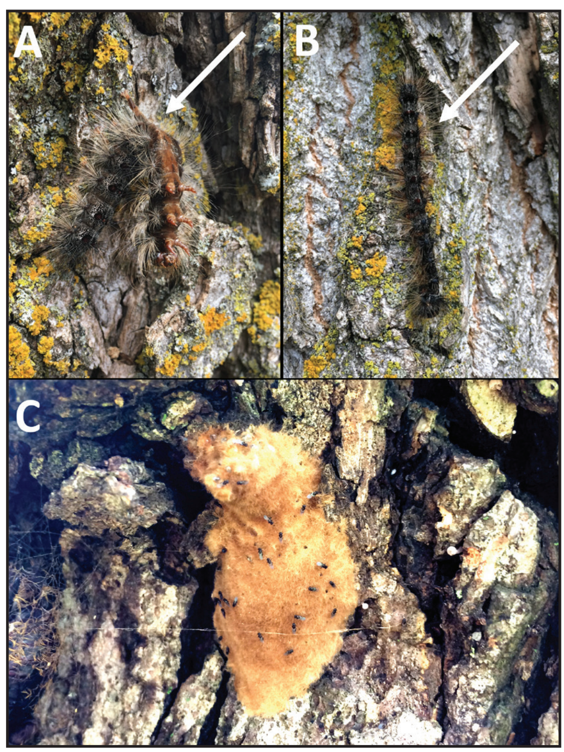
State and federal governments have directed >$282 million dollars from 1980 to 2020 to suppress gypsy moth outbreaks on >14 million acres. As gypsy moth continues to spread south and west from currently infested areas, counties are placed under a federal quarantine to restrict the movement of gypsy moth life stages, resulting in additional costs to governments and business to institute new monitoring, management, and regulatory protocols. Since 2000, federal and state agencies have contributed >$7 million annually to monitor and manage low density gypsy moth populations at the transition zone between invaded and uninvaded areas to reduce its natural and human-assisted spread rate through a national program (see below).

Natural Enemies

There are multiple pathogens, parasitoids, and predators, introduced in the early 19th century from Europe and Asia, that attack gypsy moth in North America. The most important mortality agents affecting high density populations are two diseases: a viral pathogen, gypsy moth nucleopolyhedrosis virus (NPV), and a fungal pathogen, *Entomophaga maimaiga* Humber, Shimazu, and R.S. Soper (Entomophthorales: Entomophthoraceae), both of which can contribute to outbreak collapse. Both diseases can infect all stages of larvae and have multiple infection cycles in a season but are typically most prevalent and noticeable with later instar larvae.

Gypsy moth NPV is specific to gypsy moth, and has been present in North America since the early 1900s. It likely arrived from Europe with parasitoids introduced for biological control. Gypsy moth NPV infects developing caterpillars upon ingestion of viral bodies present on the leaf surface or residing on the surface of egg masses. After being consumed, the virus quickly replicates and ruptures cells throughout the internal organs

Figure 8. *General symptoms of caterpillars killed from gypsy moth nucleopolyhedrosis virus (A, the arrow points to the "V" shape of the infected caterpillar) and the fungal pathogen* Entomophaga maimaiga *(B, the arrow notes the straight and limp infected body). These symptoms are not definitive nor mutually exclusive, as co-infection by both pathogens can occur, as well as attack by parasitoids (C, eggs parasitized by an introduced wasp,* Ooencyrtus kuvanae*).*



of the caterpillar, resulting in death. The virus is transmitted when the dead caterpillar's cuticle ruptures and viral bodies are either spread by rainfall or drop onto leaves below. These viral bodies are then eaten by uninfected caterpillars. The diagnostic symptom of NPV-caused mortality in gypsy moth caterpillars is an inverted "V" body position (Figure 8.A). Interactions between NPV and host gypsy moth populations are considered to be one of the main drivers of the quasi-periodicity of gypsy outbreaks. Gypsy moth NPV has been formulated into an aerially applied biopesticide, Gypchek. This product is costly and time-consuming to produce because it requires the large-scale rearing of virus-infected caterpillars. Gypchek is used only in USDA Forest Service-sponsored treatment areas where there are concerns about non-target effects, particularly to threatened or endangered native butterflies and moths (Lepidoptera).

Entomophaga maimaiga is a fungal pathogen largely specific to gypsy moth and was first documented causing significant mortality in eastern North America in 1989. The introduction date or origin of this important pathogen is unknown; it may have been introduced accidentally or intentionally at an earlier date but remained undetected for many years. Infection by *E. maimaiga* is facilitated by wet conditions, especially during early spring, which are ideal for spore propagation and caterpillar infection. This fungus produces two types of spores: large resting spores that overwinter in the soil and are viable for >10 years and smaller, short-lived conidia which disperse in the wind. Caterpillars are infected upon contact by airborne conidia after which the fungus begins consuming the caterpillar. Mortality typically occurs within a few days and four to nine cycles of infection can occur within one season. The general diagnostic symptom of *E. maimaiga*-caused mortality in late-instar gypsy moth are thin, shriveled caterpillars in a downward facing position (Figure 8.B).

Early gypsy moth management efforts in North America included introducing a variety of insect natural enemies (e.g., parasitic flies and wasps, and predatory beetles). At that time, there was little regulation or research on the effectiveness or non-target effects of these introduced natural enemies. At least ten species established, and several of them were generalist predators and parasitoids that offered little control of gypsy moth. However, some were specialist parasitoids that may contribute to regulation of low-density gypsy moth populations (Figure 8.C).

Small mammals, particularly white-footed mice, feed on both larvae and pupae, and are typically the most important cause of gypsy moth mortality in low-density gypsy moth populations. Temporal and spatial variation in their abundance, which may be related to timing of mast seeding, appears to be associated with the release of low-density populations to outbreak levels.

Management and Treatment Options

There are many management tactics available to suppress gypsy moth populations and reduce risk of tree mortality from repeated gypsy moth defoliation. When developing a management plan, it is important to consider the extent, severity, and context of the outbreak. For homeowners, direct manual control measures targeting outbreak

Figure 9. *Many historical treatment options for gypsy moth [e.g., insecticide fogging (A), branch pruning and egg mass removal (B), tree banding (C), egg mass treatments, sterile male release, biological control augmentation, and mass trapping] are no longer extensively used primarily because more effective and environmentally safe measures are available.*

populations may be feasible for protecting high-value trees, but are generally ineffective at changing the course of regional gypsy moth outbreaks. Management of outbreak gypsy moth populations has been conducted for over a century in North America, and many previous treatment options (e.g., broad spectrum insecticide applications, branch pruning, egg mass removal and destruction, tree banding, egg mass treatments, sterile male release, augmentation biological control, and mass trapping) have been deemphasized because they are too tedious and economically impractical over large areas, ineffective for controlling gypsy moth populations or reducing defoliation, or environmentally unacceptable (Figure 9). Pesticides are an effective choice for treating invading or outbreak gypsy moth populations. Ground applications are appropriate for small acreages; otherwise, most pesticides are applied aerially via helicopter or fixed-wing aircraft. Large-scale aerial treatments for gypsy moth are typically conducted in areas of high recreation value, residential neighborhoods, high-value timber, along the leading edge of gypsy moth expansion, or in state/federal cooperative programs (Table 3).

Suppression strategies

Bacillus thuringiensis var. *kurstaki* (*Btk*) is a naturally occurring soil bacterium that has been formulated into a commercial biological insecticide for gypsy moth control. It is favored in many large-scale treatment programs because it is effective against high-density populations and has limited non-target effects. This product primarily targets foliar-feeding, early instar Lepidoptera and is active in the environment for less than two weeks. *Btk* is typically applied from aircraft but can also be applied to the canopy from the ground, such as in small eradication projects. Gypchek, which has a greater specificity, has similar impacts and application timing as *Btk* and can be used in treatment programs where impacts on sensitive species of Lepidoptera are a concern (Tables 1 and 3).

Insect growth inhibitors (e.g., diflubenzuron and tebufenozide) are also effective at suppressing high gypsy moth populations (Tables 1 and 3). When ingested or contacted by caterpillars, diflubenzuron inhibits the formation of chitin, a major component of the insect exoskeleton, during molting. Tebufenozide is also active at disrupting molting, but it mimics the action of a molting hormone in various terrestrial and aquatic insects; however, moths are generally more sensitive to the insecticide than non-target insects and arthropods.

Application of broad spectrum insecticides to the tree crown can be used to target feeding caterpillars, but these materials are rarely used in large-scale treatment programs. Immediate and persistent toxicity may make these products ideal for

Table 3. *Frequently applied treatment options for gypsy moth population suppression.*

Treatment Option	Timing of application	Non-target Effects	Biological Pesticide (Y/N)	Mode of Action and Comments
Bacillus thuringiensis var. *kurstaki (Btk)*	Mix of 1st and 2nd instars	Feeding caterpillars of all butterflies and moths	Y	A naturally occurring soil bacterium that breaks down the gut lining of feeding caterpillars. Bacteria must be ingested to cause mortality. Applications have a short period of efficacy; commonly applied twice in a season.
Gypsy Moth nucleopolyhedrosis virus (NPV)	Mix of 1st and 2nd instars	None, specific to gypsy moth	Y	Formulation of the naturally occurring gypsy moth nucleopolyhedrosis virus that ruptures internal organs. Manufacturing can be costly and time-consuming as it requires the rearing of live caterpillars. Product is only available for use in USDA Forest Service-sponsored programs.
Diflubenzuron	3rd instar	Especially toxic to aquatic invertebrates	N	A commercially available insect growth regulator that prevents caterpillars from molting.
Tebufenozide	1st to 3rd instars	Feeding caterpillars of all butterflies and moths	N	A commercially available insect growth regulator that prevents caterpillars from molting.
Broad spectrum insecticides (carbaryl, bifenthrin)	All larval instars	Most arthropods that contact the insecticide	N	Broad spectrum contact insecticides that inhibit normal function of the nervous system. These products are no longer used in large-scale treatment programs.
Mating disruption	Pupation, prior to moth emergence	Non-lethal, specific to gypsy moth in North America	Y	Pheromone-based product that limits male moth ability to locate females. Used in the National Gypsy Moth Slow the Spread program and occasionally in eradication; effective primarily for low density populations.

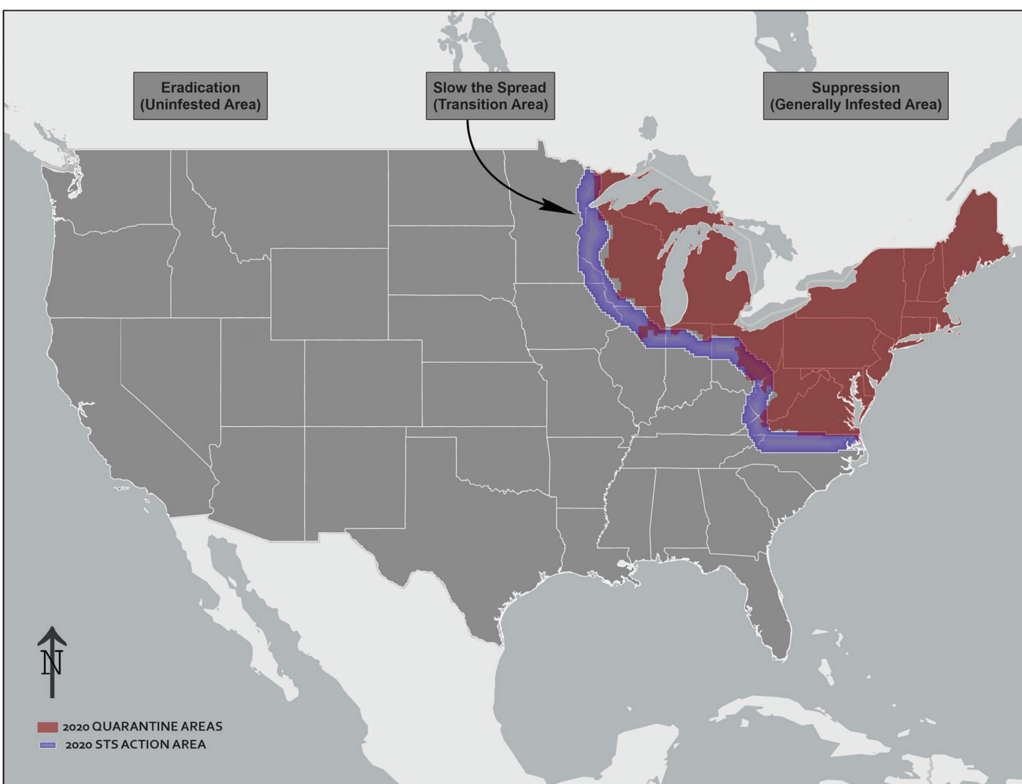
homeowners, but the non-target effects of these insecticides on arthropods makes them unfavorable for use in larger treatment programs.

Broad spectrum insecticides were used frequently in earlier gypsy moth treatment programs, but have not been used in large gypsy moth treatment programs since the late 1980s. Mating disruption is a non-lethal control strategy that saturates an area with a species-specific, synthetically-produced sex pheromone to inhibit mate finding and subsequent reproduction. This control strategy is only effective in areas with low and isolated populations, and is used primarily along the invading edge of the infestation in the National Gypsy Moth Slow the Spread (STS) program (see below).

Prevention strategies

Preventative silvicultural measures are a component of an effective long-term management strategy for larger woodlots, particularly within generally infested areas with a history of gypsy moth defoliation or in high-risk stands adjacent to the gypsy moth invasion front. Specific plans should be tailored more precisely for an individual

Figure 10. *Four strategies of the USDA National Gypsy Moth Management Program include 1) suppressing outbreak populations of European gypsy moth in quarantined areas, 2) slowing the spread of new populations of European gypsy moth along the expanding invasion front, 3) eradicating all new populations of the Asian and European subspecies, and 4) monitoring and regulating the movement of European life stages from quarantined areas (not pictured).*



site, though general strategies to reduce the risk of outbreak include thinning to reduce basal area of susceptible host species (e.g., oak, paper birch, aspen) and increasing basal area of resistant and immune species (e.g., conifers, maple, black cherry, black walnut). Maintaining general tree vigor is also important for reducing stand vulnerability to tree mortality following outbreaks. Intermediate cuttings targeting trees with poor crowns can reduce stand vulnerability. Homeowners can water trees during periods of drought stress and remove ailing or undesirable understory trees that are susceptible hosts.

National Monitoring and Management Programs

There is a comprehensive U.S. national monitoring and management program for both the European and Asian gypsy moth subspecies. The USDA National Gypsy Moth Management Program is comprised of four strategies: 1) suppress building populations of European gypsy moth in quarantined areas; 2) slow the spread of new populations of European gypsy moth along a 62 mile (100 km) wide action area along the expanding invasion front; 3) eradicate all new populations of the Asian subspecies and new populations >62 miles from quarantined areas for the European subspecies; and 4) monitor and regulate the movement of the European subspecies life stages from quarantined areas with regulatory inspections and certifications (Figure 10). USDA Forest Service and state agencies cooperate to suppress gypsy moth outbreaks in quarantined areas across all land ownerships (though not all states participate). Whereas, USDA Forest Service and Animal and Plant Health Inspection Service (APHIS) and state agencies cooperate to slow the spread of European gypsy moth and eradicate new populations of both subspecies. The USDA

Figure 11. *Networks of pheromone-baited traps are used to monitor gypsy moth populations, direct treatment actions, delineate treatment blocks, and determine treatment efficacy (A). Aerial applications (B) are frequently used to suppress gypsy moth populations for the three national program areas (suppression, slow the spread, and eradication).*

Forest Service manages the STS program, which is carried out in collaboration with multiple state agencies in the central and eastern USA, a non-profit foundation, two universities and APHIS. The STS program, implemented in 2000, represents a culmination of several previous pilot programs during which the monitoring and management protocols used in STS were developed.

STS is data intensive. It relies on tens of thousands of sex pheromone-baited monitoring traps (e.g., delta and milk carton) deployed annually in quarantined areas and along the transition zone of infested and uninfested areas (62 mile action area) to monitor population growth and to detect new populations, respectively (Figure 11.A). High densities of traps are used in some areas to detect isolated growing populations, delimit treatment boundaries, and assess treatment efficacy. Biorational pesticides are then applied aerially to suppress isolated populations in the transition zone, which reduces the rate of spread (Figure 11.B). Trap locations and catch data are used to compute the program boundaries, highlight potential problem areas (i.e., growing populations), adjust trapping densities, and recommend treatment applications. The STS program has reduced the annual rate of gypsy moth spread by >60% during the 20 years that the program has been in place.

The USDA APHIS collaborates with state agriculture and/or natural resource agencies to detect and eradicate new gypsy moth populations outside the quarantined area. Approximately 100,000 pheromone-baited traps are deployed annually nationwide to provide early detection of new populations. Human-assisted dispersal frequently results in the movement of European gypsy moth out of quarantined areas in the eastern USA, whereas egg masses of Asian gypsy moth are sometimes introduced with cargo and ships originating from eastern Asia. Eradication efforts have successfully eliminated every new population of both subspecies since 1970. Dense trapping grids are typically deployed around newly detected European gypsy moth populations in uninfested areas prior to eradication in order to confirm the persistence of populations as well as to delimit their spatial extent. Asian gypsy moth populations are typically treated the year following detection; these eradication efforts occur most frequently near US ports. APHIS also provides regulatory certification of articles (e.g., nursery stock, shipments of lumber, firewood, plant material, mobile homes, and household items) that may contribute to spread of European gypsy moth out of quarantined counties.

References

Doane, C.C., M.L. McManus (Eds). 1981. The Gypsy Moth: Research Toward Integrated

Research. USDA Forest Service, Washington, D.C. 757 p.

Elkinton, J.S., A.M. Liebhold. 1990. Population dynamics of gypsy moth in North America. Annual Review of Entomology 35: 571-596

Liebhold, A.M., K.W. Gottschalk, R. Muzika, M.E. Montgomery, R. Young, K. O'Day, and B. Kelley. 1995. Suitability of North American Tree Species to the Gypsy Moth: A Summary of Field and Laboratory Tests. USDA Forest Service, Northeastern Forest Experiment Station, Gen. Tech. Rep. NE-211

Liebhold, A.M., K.W. Gottschalk, E.R. Luzader, D.A. Mason, R. Bush, D.B. Twardus. 1997. Gypsy moth in the United States: An Atlas. USDA Forest Service, Northeastern Forest Experiment Station, Gen. Tech. Rep. NE-233

Tobin, P.C., L.M. Blackburn. 2007. Slow the spread: a national program to manage the gypsy moth. Gen Tech Rep NRS-6. Newtown Square, PA; USDA Forest Service, Northern Research Station. 109 p.

USDA Forest Service and Animal and Plant Health Inspection Service. 2012. Gypsy Moth Management in the United States: A Cooperative Approach, Final Environmental Impact Statement, Vol 1-4., Newtown Square, PA, NA-MB-01-12

USDA Forest Service, Region 9, State and Private Forestry. Gypsy Moth Digest. https://www.fs.usda.gov/naspf/programs/forest-health-protection/gypsy-moth-digest (last accessed 20 March 2020)

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