For most of the 20th century, gypsy moths (*Lymantria dispar*) were by far the most serious insect threat to forests and shade trees across the Northeast. Gypsy moth caterpillars feed on the leaves of many tree species, especially oaks, and this defoliation can result in reduced tree growth and eventual mortality. Two years ago, an article in Massachusetts Wildlife (No. 3, 2016) described the recent outbreak of gypsy moths in Massachusetts. This outbreak came as a surprise to the authors because gypsy moth populations had been at low-density, non-outbreak status in New England almost everywhere since 1981, due to a fungal pathogen *Entomophaga maimaiga* that was accidentally introduced into New England in 1989. Prior to that year, gypsy moth outbreaks had occurred about every 10 years.

*Entomophaga maimaiga* spores spread all over New England in 1989 and 1990. This fungus, which kills gypsy moth larvae, does not kill the vast majority of other moth and butterfly caterpillars, making it an ideal biological control agent. We thought the effects of this fungal biocontrol would persist indefinitely and prevent outbreaks from ever occurring again in New England, but we were wrong! The Achilles heel of *E. maimaiga* is that it requires rainfall in May and June for successful transmission of the airborne fungal spores from gypsy moth cadavers killed by the fungus to healthy caterpillars. Under normal rainy conditions, this process happens repeatedly week by week through May and June. However in 2014, drought conditions in May and June began (Fig. 1) and persisted through 2015 and 2016.

In 2016, Elkinton and Boettner predicted that if rainy conditions returned to normal in 2017, a widespread epidemic caused by the fungus would kill off
gypsy moth larvae and the population would collapse back to low density. With any luck, gypsy moths would then retreat to non-pest status in the future. Elkinton and Boettner also predicted, however, that high density defoliating conditions would recur in 2017, because mortality from the fungus usually reaches a peak at the end of the larval stage in late June after defoliation has already occurred. Both predictions were borne out in 2017.

A Tale of Two Pathogens

In May and June 2017, there was ample rainfall, indeed higher rainfall than normal for period. As predicted, however, widespread defoliation was observed across Southern New England, even more widespread than in 2016. It was also clear there was a major epidemic among gypsy moth caterpillars caused by the fungus. Homeowners from all across Massachusetts observed thousands of caterpillars dying head down at the base of their trees—a behavior most commonly associated with mortality from the fungus (pages 30 and 32). Though most caterpillars appeared to have died from the fungus, another pathogen, a virus disease known as LdNPV, (Lymantria dispar Nucleopolyhedrosis Virus) was also present. The virus also causes the caterpillars to die either head down or in an inverted “V” shape in various locations, however, older larvae were mostly observed on the trunks of trees. The larvae killed by the two pathogens look very similar, but the pathogens can be easily distinguished by dissecting the cadavers and examining them under a microscope.

Larvae killed by the fungus can be verified under a light microscope by the presence of spores. E. maimaiga produces two kinds of spores. Younger or mid-size gypsy moth larvae infected with E. maimaiga produce conidia (Fig. 2A, page 33), short lived spores that blow in the wind and infect other caterpillars. When the conidia land on a healthy caterpillar, the spores germinate and penetrate the

Figure 1. Massachusetts Rainfall in May and June 2013–2017

![Rainfall chart](Photo by Bill Byrne/MassWildlife)
skin of the caterpillar, provided it is wet. This is why rainfall is so important. Older caterpillars infected with the fungus produce resting spores (Fig. 2B), which can persist in the environment, mostly in leaf litter, for decades. These spores are the overwintering form of the fungus. The spores fall to the forest floor inside the larval cadaver and germinate when wet conditions are favorable (the following spring or even many years later), to infect a new generation of gypsy moth larvae. These spores have a clear double-walled character, shown in Fig. 2B, which allow them to survive for many years.

Larvae killed by the LdNPV virus can also be verified under a light microscope (Fig. 2C,D), because, although the viruses themselves are too small to see, they are embedded in a protein matrix called an occlusion body. The occlusion bodies serve to protect the virus particles when they are released into the environment. These occlusion bodies are large enough to see under a light microscope (Fig. 2C), but they are significantly smaller than the spores produced by the fungus. This virus has been present in gypsy moth populations since the early 20th century. Prior to the introduction of *E. maimaiga* in 1989, it was the main agent responsible for the collapse of gypsy moth outbreaks. Unlike the fungus, however, whose spores are blown in the wind, the virus is only transmitted when the gypsy moth caterpillar consumes foliage contaminated with the LdNPV from other cadavers. The virus actually contains a gene that dissolves the gypsy moth skin and causes the cadaver to liquefy and spread occlusion bodies over the foliage.

Gypsy moth caterpillars in outbreak populations occur in very high densities with many thousand larvae per tree or one or more caterpillars per leaf. In such populations, gypsy moth larvae frequently encounter cadavers infected with LdNPV, and as a result, epidemics of the virus exceeding 90% mortality often occur in high-density populations. In low-density populations, you might have a handful of caterpillars per tree, one for every 10,000 leaves. In that situation, gypsy moth larvae almost never
encounter cadavers and there is little to 
no mortality in low-density populations. 
By contrast, *E. maimaiga* is transmitted 
via airborne spores or long-lasting spores 
in the leaf litter. Even in low-density 
populations it is the main cause of gypsy 
moth mortality. *E. maimaiga* has served 
to keep gypsy moth population at low 
density for more than 30 years nearly 
everywhere in New England.

**Prognosis for 2018**

Defoliation in 2017 was more wide-
spread than 2016. However, analyses of 
potential gypsy moth damage conducted 
by Valerie Pasquarella at the University of 
Massachusetts using imagery from Land-
sat satellites (inset, page 34) revealed 
that the overall magnitude of defoliation 
in 2017 was less severe than in 2016. This 
pattern makes sense because in most 
places, most of the larvae died at the end 
of June before defoliation was complete.

Elkinton and his colleagues collected 
data on larval survival and cause of 
death week by week from 10 sites across 
Massachusetts and Rhode Island through 
the month of June. They found high levels 
of mortality, mostly from *E. maimaiga*, 
but also from the virus, that exceeded 
90% in the vast majority of populations. 
This occurred in addition to mortality 
that would have occurred in May among 
younger larvae and also among pupae 
in July.

Mortality from fungus and virus during 
the larval stage of gypsy moth coupled 
with mortality during the pupal stage 
(mostly from predators) exceeded 99% 
in many populations. These populations, 
particularly those in southeast Massa-
chusetts which have been defoliated 
for several years in a row, are likely to 
retreat to low density next year, and little 
defoliation is expected. Indeed, in some 
of these populations mortality among 
gypsy moth caterpillars was sufficiently 
high in May 2017 to prevent defoliation 
from occurring at all. In other locations, 
especially in central Massachusetts, how-

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*Figure 2. Entomophaga maimaiga (A) airborne conidia and (B) resting spores. LdNPV (C) occlusion bodies and (D) occlusion body cross section at higher magnification showing virus particles inside.*

Photos © Ann Hajek (Fig. 2, A/B) Photos by Kathleen Shields and Roger Zerillo/USFS (Fig. 2, C/D)
ever, mortality from all these agents was less than 99% and the density of gypsy moths will be even higher in 2018. At one research site in Amherst, for example, we observed only 40% mortality from the fungus and virus in June, and densities at this site are expected to be many-fold higher in 2018. This occurred even though we saw lots of dead caterpillars at the base of trees at this site. There were many more live caterpillars that remained out of sight up in the tree. This illustrates that seeing dead caterpillars at the base of trees, which occurred nearly everywhere across Massachusetts, does not necessarily mean that gypsy moth densities everywhere will be low in 2018.

Thus, the prognosis for 2018 varies from one site to the next. You can predict what may happen in your neighborhood by looking for gypsy moth egg masses on the trunks of trees. These were laid in July or August, after the larval and pupal mortality had occurred. The egg masses are tan in color and about the

Mapping when and where gypsy moth defoliation occurs is critical for understanding outbreak dynamics and assessing future defoliation and tree mortality risk, and Landsat time series analysis provides a new tool for researchers and land managers looking to identify the location and severity of defoliation over large areas. The Landsat series of satellites have been collecting regularly repeated observations of the earth’s land surface since the 1970s. However, high image costs historically limited the use of Landsat data to only a handful of carefully selected images. In 2008, a change in data policy opened the Landsat archive for free public use, enabling scientists to finally utilize the full Landsat record to study how landscapes change over time. The gypsy moth defoliation assessment maps shown here use time series of Landsat observations to detect changes in vegetation greenness for individual 30-meter-by-30-meter pixels (about the size of a baseball diamond). This approach makes use of both historic and newly acquired Landsat images for two “scenes” in Southern New England (WRS-2 Path/Rows 12/31 and 13/31). By using all possible dates of imagery to look for changes in vegetation greenness, we are able to track the progress of gypsy defoliation through the growing season then produce averaged estimates of overall changes in forest condition for individual years of the outbreak.
size of a quarter. This year’s egg masses (laid in 2017) can be distinguished from last year’s egg masses (laid in 2016) by touching them. The 2016 egg masses, which hatched in May 2017, and which may still persist on some trees, are very soft. This year’s egg masses (hatching in May 2018) will be firm to the touch. Homeowners with many fresh egg masses on their backyard trees might consider protecting their most valuable shade trees with pesticide sprays when the caterpillars hatch in May 2018 especially if the trees were defoliated in 2017. Trees that are defoliated two or more years in a row are especially prone to mortality.

We recommend that homeowners who wish to take preventative action should confer with local arborists or tree-care professionals. These individuals have both the training and equipment to apply the pesticides safely and correctly at the right times after hatch. They also have the training to select the appropriate pesticides with limited impact on other species, and to properly dispose of any unused material.

The locations and severity of gypsy moth defoliation in 2018, of course, will again depend on getting a normal amount of rainfall during May and June. If rainfall is at or above average during these months, we expect gypsy moth populations to return to low-density, non-outbreak levels. Even before *E. maimaiga* was introduced, there were many years when gypsy moth densities were low and no defoliation occurred. With *E. maimaiga* present, those intervals between outbreaks extended over several decades. Some climate models for New England predict that, if anything, we will get more rainfall in May and June in the future. If this prediction holds true, we can expect that gypsy moth will once again retreat to non-pest status. It may, however, take another year or two for populations to decline across all of southern New England, so we may continue to see significant gypsy moth defoliation in some areas in 2018.

**Flightless female gypsy moths leave their pupal casings and walk just a few inches up an oak tree to lay their eggs.**

**About the Authors**

Joe Elkinton, Ph.D., is a Professor of Environmental Conservation at the University of Massachusetts, Amherst. Jeff Boettner is the Lab Manager at Elkinton Lab at the University of Massachusetts, Amherst. Valerie Pasquarella, Ph.D., is a Postdoctoral Fellow with the Northeast Climate Science Center at the University of Massachusetts, Amherst. In her research, Valerie uses imagery from the Landsat series of satellites to map and monitor how landscapes change over time. Her recent work includes near-real-time and historic assessment of gypsy moth defoliation and improved mapping of tree species distributions across Southern New England.