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Benefit-Cost Analysis of the Slow the Spread Program: An Update Through 2045

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Cover photo: A recently emerged male spongy moth from an outbreak in central Wisconsin. Courtesy photo by Tom W. Coleman.

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ABSTRACT

Spongy moth or *Lymantria dispar* (L.) (Lepidoptera: Erebidæ), formerly known as gypsy moth, is a nonnative invasive defoliator pest to the United States. Introduced accidentally to the United States in the 1860s by an amateur entomologist, spongy moth spread quickly and large-scale efforts began soon thereafter to eradicate and limit its population and distribution. The National Slow the Spread (STS) Program, piloted in 1992 and fully implemented in 2000, currently operates in 11 States and monitors a buffer zone that stretches about 100 kilometers from North Carolina to Minnesota. Current management of spongy moth populations consists of large-scale suppression treatments and monitoring along the buffer zone. In this report, we build on previous economic assessments to aggregate the costs of the STS Program from 2007 to 2023 and quantify potential programmatic costs from 2024 to 2045. In addition, we compute the costs and costs avoided to human health, tourism and recreation, and willingness to pay for a public management program with and without the STS Program. We found that from 2007 to 2023, the benefit-cost ratio was between 1.60 and 2.31, and from 2024 to 2045, we expect a return of between 3.81 and 5.58. Findings suggest that continuation of the program under business-as-usual scenarios would result in net positive public benefits.

Keywords: Defoliator pest; economic efficiency; exotic insect; gypsy moth; net present value

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INTRODUCTION

Spongy moth or *Lymantria dispar* (L.) (Lepidoptera: Erebidæ), formerly known as gypsy moth, is a nonnative invasive defoliator pest in North America. Native to Eurasia, the Middle East, and Northern Africa (Pogue and Schaefer 2007), spongy moth was accidentally introduced to North America in Medford, Massachusetts by Étienne Léopold Trouvelot in the late 1860s (Forbush et al. 1896). The first large-scale eradication attempt began about a decade after the moth was initially released (Coleman 2023). Since 1967, the United States Department of Agriculture (USDA), in partnership with State Governments, has successfully coordinated eradication efforts and restricted the distribution of the primary population to 20 Eastern States in the United States (Coleman 2023).

Defoliation events can result in direct economic effects and externalities.¹ We (the researchers and authors of this report) quantified the benefits and costs of managing the spread and outbreaking events of the spongy moth in the Eastern United States via the National Slow the Spread (STS) Program. This study intends to design a replicable methodology for future analyses assessing the STS Program and update benefit and cost (B:C) estimates of the STS Program ex-post (2007 to 2023) and ex-ante (2024 to 2045).

The spongy moth is polyphagous, meaning it can feed on numerous host species. Trees highly favored by the spongy moth include various species of oak (*Quercus* spp.), birch (*Betula nigra*, *B. papyrifera*, and *B. populifolia*), poplar/aspen (*Populus balsamifera*, *P. grandidentata*, and *P. tremuloides*) and basswood (*Tilia americana*). For this reason, forest stands with higher proportions of oak species tend to sustain greater acreages

of defoliation compared to stands without oak dominance (Coleman 2023).

In contrast, maples (*Acer negundo*, *A. rubrum*, and *A. saccharum*) and some pines (*Pinus strobus* L.) are resistant to defoliation (Liebhold et al. 1995). While conifers are not preferred hosts, they are potentially more vulnerable to mortality since they are not adapted to rapid leaf turnover (Davidson et al. 1999). Trees weakened by drought, late spring frost, and secondary pests and diseases are also more susceptible to mortality (Gansner and Herrick 1984, Campbell and Valentine 1972, Campbell and Sloan 1977, Gottschalk and MacFarlane 1994, Davidson et al. 2001, Coleman 2023), as well as understory trees with suppressed crowns or poor crown conditions (Campbell and Valentine 1972). In general, Davidson et al. (1999) found that tree species; intensity, duration, and frequency of defoliation; tree physiological condition at the time of defoliation; and the presence of secondary organisms such as *Armillaria* spp. and *Agrilus bilineatus*,² are factors that significantly determine whether a tree dies or only experiences a short-term reduction in radial growth. For example, research suggests that forest stands whose original basal area contained approximately 98 percent oak experienced mortality rates three times greater than stands that contained 29 percent oak (Brown et al. 1979), suggesting that mortality could be localized.

Widespread mortality events from spongy moth are relatively infrequent (every 8–12 years regionally) as compared to persistent tree injury and mortality from other exotic forest pests such as emerald ash borer (*Agrilus planipennis*) and hemlock woolly adelgid (*Adelges tsugae*) (Johnson et al. 2006) (See appendix 2, Forest Health Protection Detection Survey, R9 2024 Download).

¹ A clear definition of “externality” is found in Harris and Roach (2016): “An effect of a market transaction that impacts individuals or firms not involved in the transaction.” The potential costs of spongy moth, in large part, are accounted for in the transactions in timber markets or recreation markets that facilitate spread, even though the impacts felt by individuals result in real costs. Thus, the impacts of spongy moth can be thought of as externalities of these market transactions.

² *Armillaria* spp. is a genus of about 35 species of parasitic fungi. *Agrilus bilineatus*, or the two-lined chestnut borer, is a species of wood-boring beetle.

According to Sills (2008), mortality events can thin forest stands—freeing densely stocked stands or stands in poor health, resulting in zero change to timber value. However, if left unchecked, changes to forest species composition can occur, which we discuss at length in another section of this report. Negative externalities of spongy moth defoliation include nuisance from falling frass, rash, allergic reaction and other health impacts, decreased aesthetics from defoliated trees, and tree removal and replacement costs.

In this report, we quantified the costs to human health, tourism, and recreation, as well as the willingness to pay (WTP) for a public management program with and without the STS Program from 2007 to 2023 and from 2024 to 2045. Similar to Sills (2008), we did not quantify impacts on timber value. In addition, we provided information on the number of wood mills that would fall within the generally infested and the STS Program areas. However, we did not quantify costs imposed on wood mills or trade, since movement of products from one facility to another is often unknown and difficult to measure, and the cost burden is generally placed on facilities outside of the infested area.

For this analysis, we devised scenarios similar to those of Sills (2008), who estimated ex-post (2000 to 2006) and ex-ante (2007 to 2026) costs and benefits of the STS Program, as well as counterfactuals without the program. In the counterfactual,³ more households across the Eastern and Midwestern United States were impacted by spongy moth defoliation events. Thus, the STS Program measures costs avoided. In ex-post scenarios, we found that the benefit-cost ratio was between 1.6 and 2.31, while in ex-ante scenarios the ratio was between 3.81 and 5.58. These results are similar to previous analyses and suggest that continued public management of spongy moth spread and outbreaking events may result in net positive benefits to society.

In the following sections, we provide a brief background of the STS Program and describe the

two previous benefit-cost analyses. We then detail the methods used for this analysis, including the Geographic Information System (GIS) work used to devise the data frame for county-level impacts. We also describe the externality estimations for human health and tourism impacts, as well as household WTP for a public management program. In addition, we detail other externalities not directly quantified in this analysis. Finally, we provide the results as well as a detailed discussion and conclusion.

Brief History of the Slow the Spread Program

The National STS Program was piloted in 1992 and fully implemented in 2000 (Coleman 2023). The program is managed by State and Federal agencies in collaboration with the [Slow the Spread Foundation](https://www.slowthespread.org/pages/foundation) (<https://www.slowthespread.org/pages/foundation>), a nonprofit foundation funded by the U.S. Department of Agriculture (USDA), Forest Service, Forest Health Protection (FHP) and the Animal and Plant Health Inspection Service (APHIS). Current management of spongy moth populations consists of monitoring spongy moth populations at the edge of its STS suppression zone (fig. 1) to detect movement into new, uninfested counties. Subsequent large-scale suppression treatments then may be applied via aircraft. STS coordinates the monitoring and suppression of established populations within the program boundaries with cooperators and currently operates in 11 States. The STS buffer is approximately 100 kilometers (km) wide from North Carolina to Minnesota.

Slow the Spread Zones

The area in which STS operates is divided into two separate zones: the action zone and the monitoring zone (figs. 1 and 2). The spongy moth's population dynamics, shaped by Allee effects and the fact that only males can fly, make small spongy moth populations (colonies) susceptible to suppression through trapping, larvicide, mating disruption, and other treatments within the action zone.

³ The term “counterfactual” in reference to a program effect is the difference between what happened after the program was implemented and what would have happened if the program had not been implemented, but everything else had been the same (Reichardt 2022).

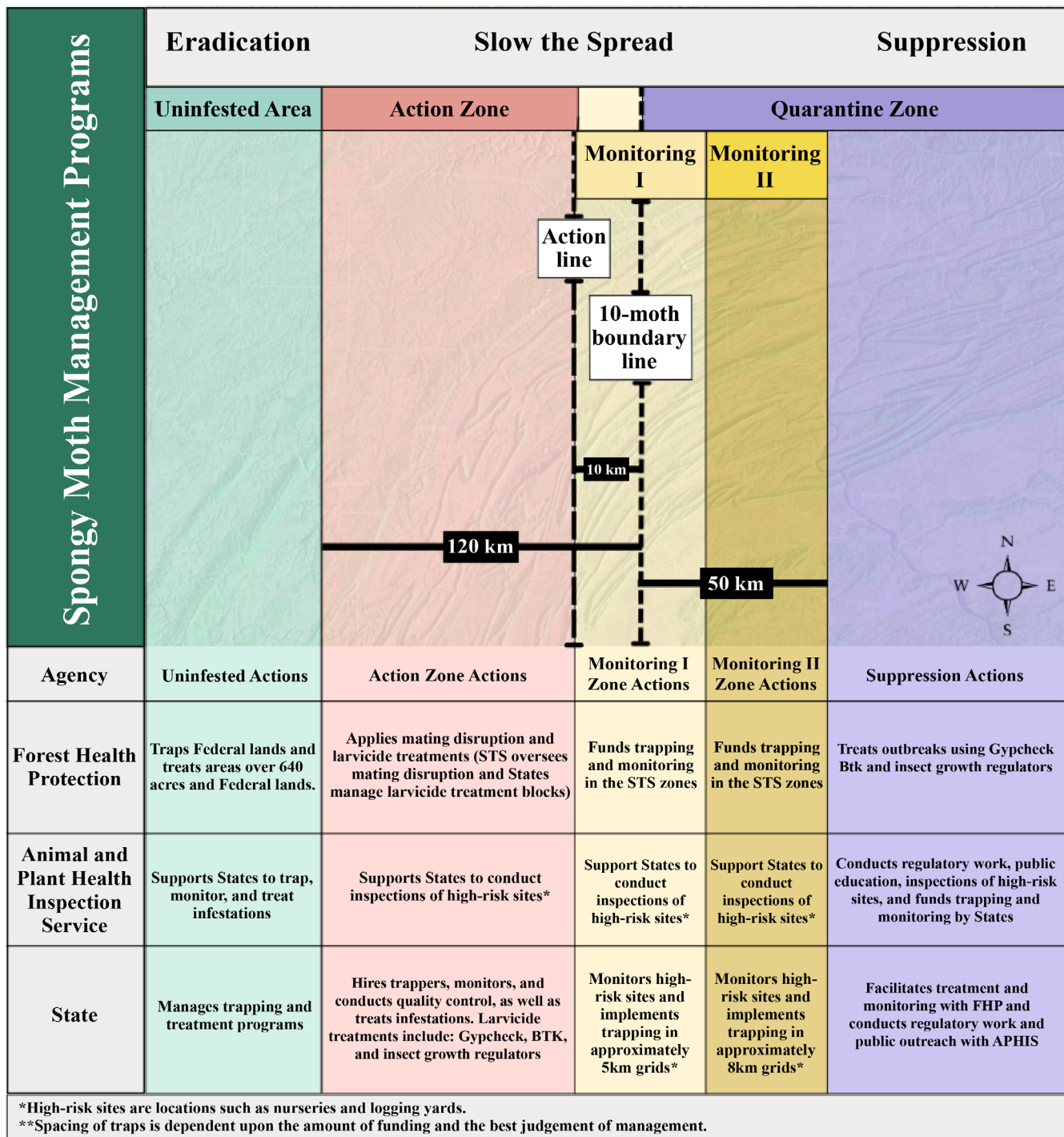


Figure 1—Coordination of agencies and structure of spongy moth management programs (eradication, Slow the Spread, and suppression) in the United States (Bruck et al. 2024). FHP = Forest Health Protection; APHIS = Animal and Plant Health Inspection Service. Equivalent units: 1 km = 0.621 mi; 1 square km = 247.105 acres.

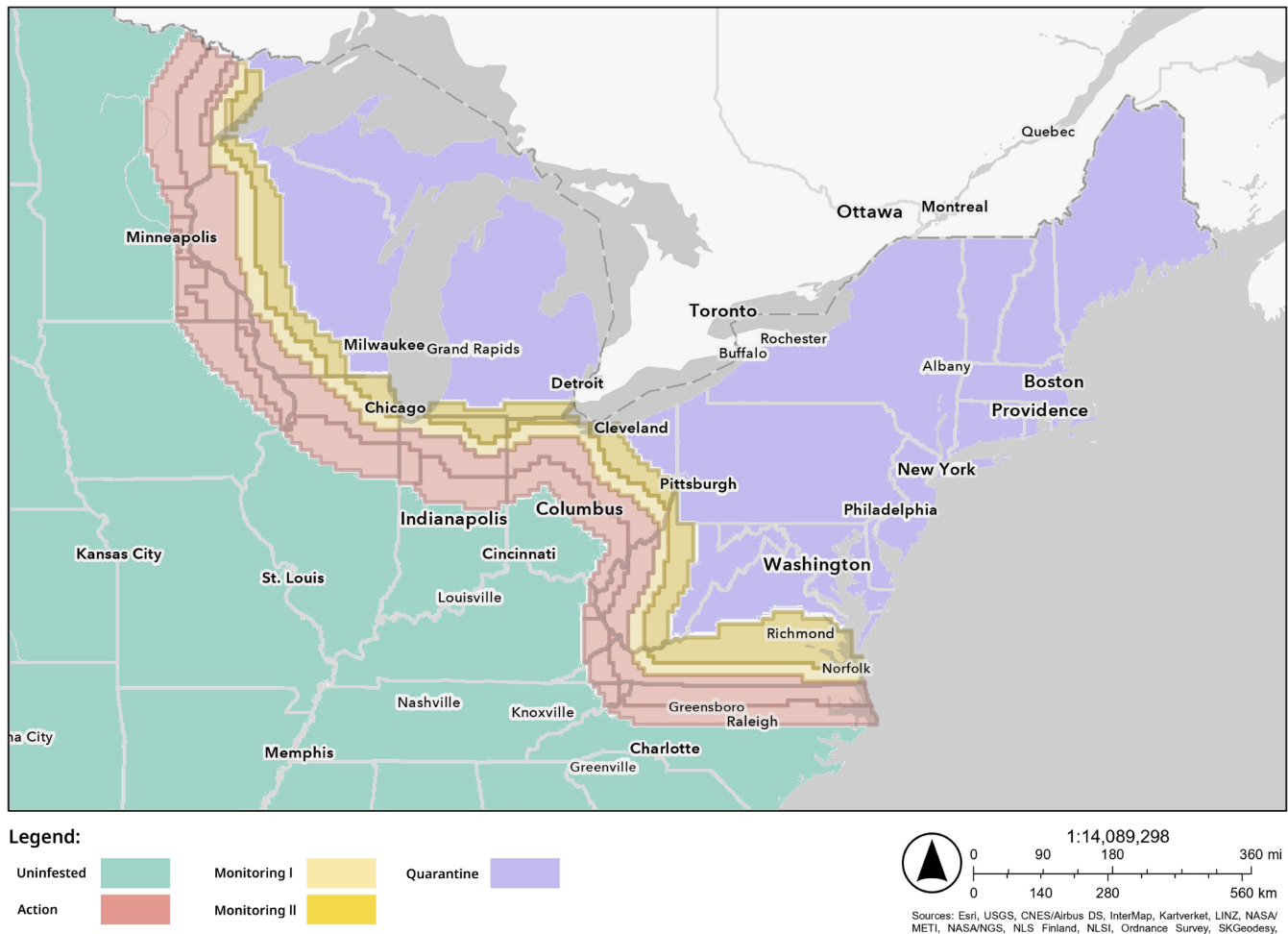


Figure 2—Map of figure 1 transposed across the Northeastern and Midwestern United States (boundaries from 10/29/2025).

The action zone is where intensive monitoring and management strategies are applied, whereas the monitoring zone is the area where moths are trapped to provide data on moth population growth and spread, estimate zone boundaries, and update data used in the STS decision algorithm.⁴ Control measures are rarely performed in the monitoring zone. Trapping is critical to detecting and mapping the boundaries of new colonies, known as delimiting. Two monitoring boundaries exist: the area directly adjacent to the action zone contains traps at a 5-km spacing, and a second monitoring zone farther away from the action zone contains traps at a lower density (8 km) (Tobin and Blackburn 2007).

Previous Benefit-Cost Analyses

Two prior studies (Leuschner et al. 1996, Sills 2008) estimated the benefits and costs associated with slowing the spread of spongy moth in the United States (table 1). Both analyses estimated the difference between damages to society both with and without the STS Program, using a comparison of simulated scenarios. Leuschner et al. (1996) considered pest management activities, including the average cost per acre to treat infestation. The authors estimated this through personal communication with an individual from Pennsylvania for the years 1988–1989 of \$0.182/acre (\$0.47/acre in 2023 dollars). The authors estimated the likely amount of infested timber and assumed a timber yield loss (i.e.: 10-year loss in harvestable timber if infested).

⁴ The STS decision algorithm uses catch data from traps to provide management recommendations (Tobin and Sharov 2007).

Table 1—Assumptions of the previous benefit cost analyses of the STS Program, as well as the assumptions of this analysis, which are discussed in detail in the methods section

Scenarios	Leuschner et al. 1996 (includes ex-ante analysis of the STS Program)	Sills 2008 (includes ex-ante and ex-post analysis of the STS Program)	This analysis (includes ex-ante and ex-post analysis of the STS Program)
Base year (projected year)	1990/ 2015	2007/2026	2007/2045
Rates of spread	Six rates of spread: 2.5 to 15 miles per year/ 4.02–24.14 kilometers per year	Five spread scenarios: 1.78–28.86 miles per year/ 2.87–46.45 kilometers per year	Both flat rate of spread of 12.18 miles per year/ 19.6 km per year, and variable rates of spread based on historical trap counts
Rates of spread	Six rates of spread: 2.5 to 15 miles per year/ 4.02–24.14 kilometers per year	Five spread scenarios: 1.78–28.86 miles per year/ 2.87–46.45 kilometers per year	Both flat rate of spread of 12.18 miles per year/ 19.6 km per year, and variable rates of spread based on historical trap counts
Economic impacts considered	Moth management activities, timber production, high density recreation, and residential infestations	Moth management, residential management, willingness to pay for residential avoided moth infestation, human health and tourism impacts	Moth management activities, willingness to pay for residential avoided moth infestation, human health and tourism impacts
Discount rate(s)	4% (real)	4% and 7% (real)	4% (nominal, including high and low estimates for economic impacts considered)

Recreation impacts were estimated by assuming that the proportion of visitor days during a year when impacts were possible was 0.71. The authors used the Leuschner and Young (1978) southern pine beetle study to determine the proportion of people who may substitute for other uninfested recreation areas (0.39) and the proportion of people who would stop recreating (0.17). Furthermore, they used Forest Service (1984) estimates (inflated to 1990 price levels) of participants' WTP for a visitor day of camping and picnicking in the Forest Service Southern Region (damages per visitor day of stopped recreation = \$13.58 in 1990 dollars; damages per visitor day of substituted recreation = \$0.19 in 1990 dollars). Finally, residential impacts were estimated as willingness to avoid damages via the 1988 contingent valuation study from University of Maryland (\$41.07 per household to avoid damages in 1990 dollars). A real discount rate of 4 percent was used. Different spread projection scenarios were estimated with and without the STS Program (10 miles per year without STS and 7.5 miles with STS; 12.5 and 5 miles per year; and 15 and 2.5 miles per year, respectively). Potential program benefit estimates ranged from \$800 million to \$3.8 billion in 1990 dollars over a 25-year period.

In contrast to Leuschner et al. (1996), Sills (2008) estimated both ex-post and ex-ante scenarios. The

ex-post analysis considered the operational phase of the program from 2000 to 2006, while ex-ante analysis considered costs and benefits from 2007 through 2026. For both the ex-post and ex-ante scenarios, Sills (2008) compared outcomes in which STS was implemented against outcomes in which it was not. This was done both for constant rates of spongy moth spread and for dynamic rates of spongy moth spread. Both constant annual rates of spread and dynamic differentiated rates were used. Sills (2008) implemented the dynamic models after the suggestion that Allee effects and higher wind speeds may increase the rate of spread, where dynamic differentiated rates assumed a gradual increase in time over Wisconsin and Minnesota toward the northern prairies.

Sills (2008) considered two ex-post and three ex-ante spread scenarios:

Ex-Post

1. Actual observed spread with STS compared to spread without STS at 20.78 km/year.
2. Actual observed spread with STS compared to spread without STS at dynamic differentiated rates increasing over 7 years: Wisconsin initiated at 19.56 km/year and increased to 46.45 km/year, while spread in the rest of

the range was initiated at 3 km/year and increased to 20.78 km/year.

Ex-Ante

3. STS spread at 6 km/year compared to spread without STS at 20.78 km/year.
4. STS spread at 6 km/year compared to spread without STS at dynamic differentiated rates increasing over 7 years: spread in Wisconsin and continuing into Minnesota began at 11.5km/year and increased to 46.45 km/year until it slowed to 20.78 km/year once it reached the prairies, while spread in the rest of the range began at 2.87 km/year and increased to 20.78 km/year.
5. STS spread at 10 km/year compared to spread without STS at dynamic differentiated rates increasing over 20 years to a maximum: spread in Wisconsin and continuing into Minnesota was initiated at 11.5km/year and increased to 46.45 km/year until it slowed to 20.78km/year once the population reached the prairies. Spread in the rest of the region was initiated at 2.87 km/year and increased to 20.78 km/year.

Sills described that there is weak justification for assuming differentiated rates of spread because there is little evidence for deciding how far west faster rates of spread will continue (2008):

Evidence that a single cycle of increased spread does not necessarily mean the faster rate of spread over [Wisconsin] and [Minnesota] is constant over time. Thus, a dynamic spread rate over the lake-State region may not be suitable for scenario analysis, assuming that once a county is in the generally infested zone (GIZ) that county will remain the GIZ. Tobin, Liebhold, and Roberts (2007), conducted a study comparing two methods for estimating spread of spongy moth. They found that there was general congruence in the overall mean rate of spread in most regions, particularly when the data spans several decades. Conflicting estimates were only found in Upper Michigan and Wisconsin, likely due to the fact that the moth was spreading from both east and west in the region (i.e.: upwards).

For an analysis of the first 7 years of the STS Program, Sills (2008) included an estimate of defoliation for projected scenarios, a long run average of 6 percent of susceptible forest, as well as the number of additional campsites, total number of households, and number of households occupying single family homes that would be affected by defoliation. Two estimates of residential costs were included: (1) direct costs of suppression and mitigation, and (2) WTP to reduce the presence of the moth. The WTP estimates came from a contingent valuation survey from 1991 which was disseminated to households in Pennsylvania and Maryland. Neither Sills nor this analysis includes net impact on timber value. Sills assumed that rates of defoliation were relatively low, especially repeat defoliation events. Furthermore, there may be some benefits from the moth “thinning the forest” (i.e., culling some smaller, weaker, or sickly trees amongst dense forest stands) to counterbalance loss in forest products.

For projected years 2007–2026, Sills (2008) assumed that trapping and treatment costs remained constant per unit area. Quarantines occurred when the 10-moth trap line crossed 50 percent of the county. Defoliation was assumed to be a long-run average of 6 percent defoliation of susceptible forest. Average annual estimates were reported, but the author stressed that there would be “better and worse” outbreak years. For example, when *Entomophaga maimaiga*, a fungus that proliferates in cool, wet springs and exclusively kills spongy moth caterpillars, is highly abundant, the moth population will be lower, and vice versa. Thus, the benefits estimated are actually lower bounds, since suppression is only undertaken when there is an infestation and it costs less than the expected impacts in the absence of management.

METHODS

The STS Program has consistent and well-maintained data on monitoring and treatment of a nonnative invasive species (see www.slowthespread.org, Virginia Tech 2025), which made this analysis possible. Appendix 1 provides the data sources necessary to reproduce this analysis. To estimate the benefit-cost ratio of the STS Program, we began by creating ex-ante and ex-post scenarios, similar to those devised by Sills (2008). For the reasons described above, we chose to estimate flat rate of spread for counterfactual scenarios and then used preferred host species by county to assess costs and costs avoided. Ex-ante scenarios included the actual spread of the spongy moth through time and an estimated counterfactual without the program. For ex-post scenarios, historical trap counts were used to estimate the spread of the moth with the STS Program compared to an associated counterfactual. Counterfactuals and future spread were based on the literature and significant input from experts. Full explanations for scenario estimations are provided in the sections below.

Many costs to society arise from spongy moth infestations. Because these costs are not directly associated with any market transaction, they are considered externalities. Externalities are costs that are borne by individuals or groups from a transaction that are not involved in the transaction (Harris and Roach 2016). In this case, these are individuals not involved in market decisions involving the potential spread of spongy moth. Because we are concerned with estimating the impacts of these externalities for potential spread scenarios, we further define these costs as potential externalities. We quantified potential externalities of the spongy moth on human health, tourism and recreation, and the WTP of households for a public management spongy moth program. The WTP refers to homeowner's value

for preventing defoliation in urban canopy cover. Thus, the associated benefit-cost ratio (B:C) is:

$$B:C = \frac{(E_0 - E_1)}{C}$$

Where E_0 are the discounted externalities without the STS Program, E_1 are the discounted externalities with the program, and C are the discounted STS Program costs. Therefore, if:

$B:C > 1$, then the program yields **higher** discounted benefits than costs

$B:C < 1$, then the program yields **lower** discounted benefits than costs

To estimate the net present value (NPV), the following formula was applied:

$$NPV = C * (B:C - 1) = (E_0 - E_1) - C$$

A positive NPV indicates that the program benefits outweigh the costs. NPV indicates the total net value of the STS Program and B:C is the estimation of efficiency of cost per unit. In this analysis, a nominal discount rate of 4 percent was used, as suggested by the White House Office of Management and Budget (OMB 2026). We compared this method to Sills (2008), who used the CPI deflator index for the base year, and applied a real discount rate of 4 percent. The results were not significantly different.

We varied assumptions about externalities to estimate the bounds of benefits and costs. ArcGIS Pro 3.3.4, R 4.5.0, and STATA 18 were used to merge and clean data as well as conduct analyses. Final scenarios were put in Microsoft Excel to estimate the benefit-cost ratios.

Ex-Post (2007–2023) and Ex-Ante (2023–2045) Scenario Assessments

Scenario A: Ex-Post Scenario

Scenario A (fig. 3) is the observed spread with the STS Program from 2007 to 2023. We downloaded observed STS action and monitoring zones from slowthespread.org and plotted by zone by year. Thus, the action lines were the actual historical boundaries (i.e., the back of the actual action zone). Counties that were at least 50 percent within the action zone at the frontier were included in the action zone, and any counties that touched the back of the action line were included in the action zone. Counties included in the monitoring zone began directly adjacent to the action counties (at the front of the monitoring frontier) and were included in monitoring if the back of the monitoring line touched any area of the county. This method favored the highest treatment intensity, and thus the highest potential cost of the STS Program. From 2007 to 2023, the STS action line moved backward over Ohio, reducing the STS area by approximately 30,000 square kilometers (11,000 square miles). During the same period, the STS action line moved forward over the Great Lake States and Appalachian Mountains, accounting for an increase of about 66,000 square kilometers (25,000 square miles). On net, the STS action line moved forward about 36,000 square kilometers (14,000 square miles).

Scenario B: Ex-Post Scenario

Scenario B (fig. 4) is the spread that would have occurred had the STS Program not been in place between 2007 and 2023 (i.e., the counterfactual to scenario A). We took the 2007 action line and allowed a flat rate of spread of 19.6 km per year (Liebhold et al. 1992), then estimated the action and monitoring zones based on the typical widths of each zone: 100 km for the action zone, 20 km for monitoring I, and 40 km for monitoring II. Counties included in each of the zones were estimated in the same way as scenario A. Had the STS Program not occurred, spongy moth would

likely have spread southward toward South Carolina and westward into Iowa. The STS zone area may have extended about 783,000 square kilometers (302,000 square miles) from the 2007 action line.

Scenario C: Ex-Ante Scenario

Scenario C (fig. 5) is the expected spread of the spongy moth with the STS Program from 2023 to 2045. This scenario was estimated using historical trap counts, and thus incorporates management intensity, policy, and environmental factors (Tobin et al. 2014). Trap counts were lower in locations where management intensity was higher, or perhaps where environmental factors were inhospitable. Therefore, we expect there to be very little movement over Ohio and little backward movement from central North Carolina toward Virginia, *ceteris paribus*. It is likely that the spread will increase over the Appalachian Mountain range as well as toward Iowa and Minnesota. The expected spread may increase by almost 193,000 square kilometers (75,000 square miles) and decrease approximately 19,000 square kilometers (7,300 square miles). This would result in a net increase of about 174,000 square kilometers (67,000 square miles). The action and monitoring zones were estimated using the same method in Scenario B.

Scenario D: Ex-Ante Scenario

Scenario D (fig. 6) is the expected spread that will occur if the STS program ended in 2023 and moth spread continues through 2045. We estimated this scenario by allowing the progression of infestation to occur at a flat rate of spread of 19.6 kilometers. The action and monitoring zones were estimated the same way as scenario B. Between 2023 and 2045, the expected increase in infestation area may be over 1 million square kilometers (386,000 square miles). It is likely that the moth will spread west toward North and South Dakota and extend over northern Georgia to Tennessee in the South. In the following sections, we describe how we account for environmental factors, and thus where the spongy moth may not establish outbreaking populations.

Scenario Maps

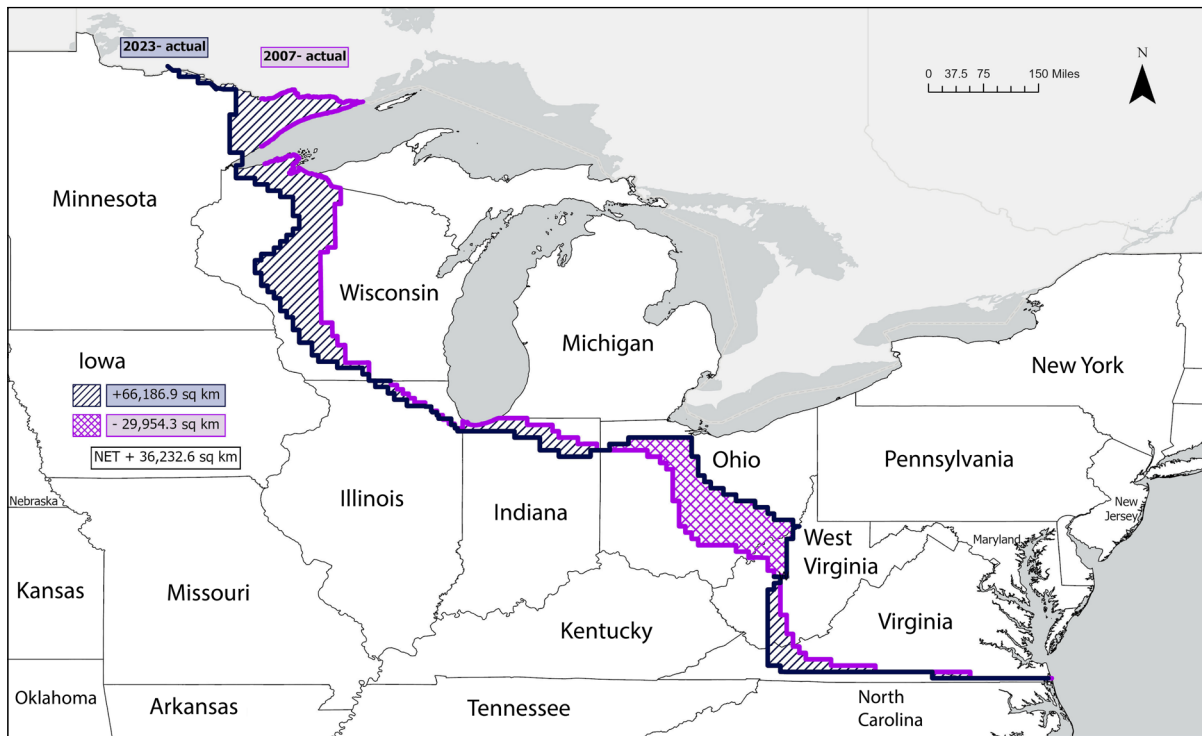


Figure 3—Scenario A, the observed spread with Slow the Spread Program from 2007–2023, where the observed action lines move backward in areas where trapping and policies are more successful and forward over regions with significant amounts of preferred host and/or less robust management practices.

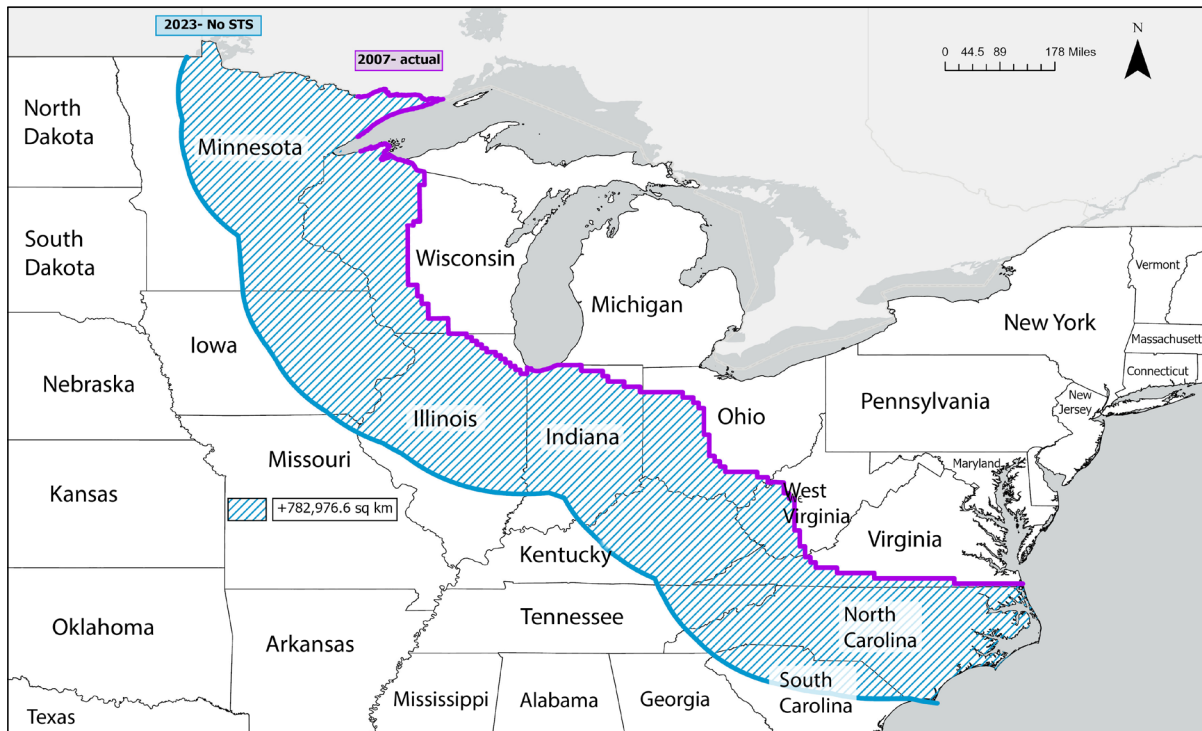


Figure 4—Scenario B, the counterfactual spread without Slow the Spread Program from 2007–2023 using a flat rate of spread of 19.6 km per year and factoring in host tree species when estimating externalities and associated costs of the STS Program.

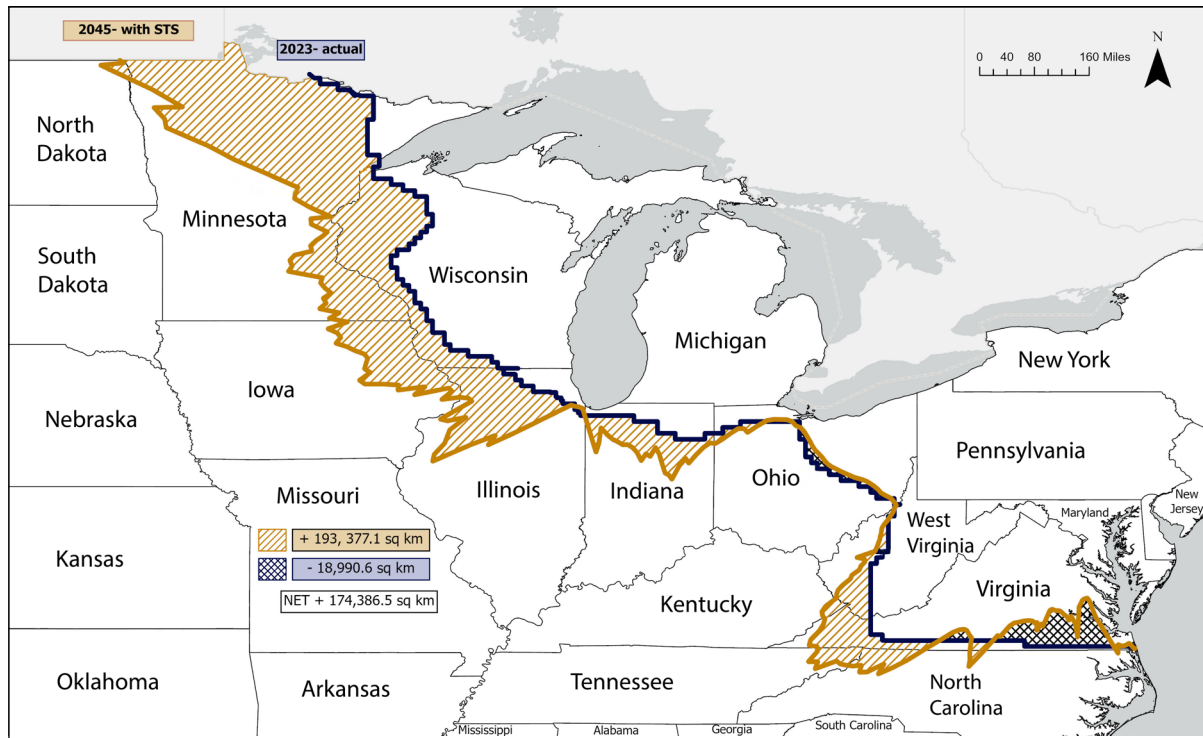


Figure 5—Scenario C, the expected spread with the Slow the Spread Program from 2023–2045 using a variable rate of spread based on historical trap count. This method assumes that policies, management, and environmental factors that have influenced trap counts over regions with effectively zero spread will be consistent in the future.



Figure 6—Scenario D, the expected spread without the Slow the Spread Program from 2023–2045 using a 19.6 km spread until 2045. Externality and cost estimations factor in host tree species; for example, counties in North and South Dakota are excluded from analysis.

Treatment and Monitoring Costs for Scenario A

For Scenario A, we used chemical treatment costs provided by the STS Program from 2007 to 2020. Often, multiple chemical treatments were applied during the same year to address varying population densities and environmental considerations. To calculate the average per-acre cost of each treatment, we utilized a linear regression. When run without the intercept, the coefficients of the regression can be interpreted as the average per-acre cost for a particular chemical treatment. In some instances, the chemical treatment is applied twice to the same treatment block to ensure the population is suppressed. First, we ran a regression where all acres are pooled, such that a double-treated acre is counted as 2 acres. This estimation is found in the equation below.

$$C = B_1 BTK + B_2 DFB + B_3 Gypchek + B_4 Mimic + e$$

There may be economies of scale in chemical treatments such that a double treatment, on a per-acre basis, is cheaper than a single treatment. To test this, we ran the model below in which the costs of double treatments are estimated separately, where d indicates the second treatment.

$$C = B_1 BTK + B_2 DFB + B_3 Gypchek + B_4 Mimic + B_5 dBTK + B_6 dDFB + B_7 dGypcheck + B_8 dMimic + e$$

Using the results from the first regression, we estimated the average per-acre cost of all chemical treatments. We then adjusted to 2020 dollars (approximately \$97.00 prior to inflation adjustment and \$57.98 post adjustment).

Once the average cost of chemical treatment was calculated, we estimated exact chemical treatment costs by multiplying the cost by the reported acres of treatment in each year. However, since we only had chemical treatment block costs through 2020, we estimated the last 3 years using the Lymantria Dispar Treatment Archive (appendix 1). In addition, the COVID-19 pandemic disrupted STS activities in 2020, resulting in an anomalously low chemical treatment cost. We totaled acres treated

and multiplied by the average chemical treatment cost. This alternative estimation (*Alt. Chemical*, table 2) was only necessary for 2021 to 2023. The resulting price trend was similar to the prior 3 years of actual chemical treatment costs (table 2). Prior to 2018, the price of chemical treatment was on average \$1.5 million with substantial variation.

Average mating disruption and monitoring costs were provided by the STS Program. After inflation adjustment, mating disruption was \$8.35 per acre and monitoring was \$57.98 per acre, both in 2020 dollars (table 3). To estimate mating disruption costs, the STS program manager provided us with actual costs from 2007 to 2023, including cost of racemic disparlure (i.e., mating disruption pheromone), treatment costs, treated acres, and cost per acre. To estimate monitoring costs, we used the trap catch archive from slowthespread.org (appendix 1) to estimate the number of traps placed from 2007 to 2023 and then used the average trap cost to calculate total monitoring cost.

Table 2—Chemical treatment estimation for Scenario A

Year	Actual Chemical Cost	Alternative Chemical Cost
2015	\$1,007,057.00	
2016	\$2,448,821.00	
2017	\$1,102,456.00	
2018	\$565,726.00	
2019	\$198,428.00	
2020	\$20,000.00	
2021		\$577,575.63
2022		\$717,471.55
2023		\$401,322.39

Table 3—Average cost for chemical treatment, mating disruption, and monitoring

Category	Costs	Unit
Chemical treatment	\$33.95	U.S. dollars, per acre (2020 adjustment)
Mating disruption	\$8.35	U.S. dollars, per acre (2020 adjustment)
Monitoring	\$57.98	U.S. dollars, per trap (2020 adjustment)

In brief, we summed chemical treatment, alternative chemical treatment, mating disruption, and monitoring estimates to get the total cost for the STS Program for the actual ex-post scenario. We estimated costs for the last 3 years of chemical treatment and monitoring costs and were provided with actual price data for chemical treatments from 2007 to 2020 and mating disruption from 2007 to 2023.

Treatment and Monitoring Costs for Scenario C

For Scenario C, we made assumptions based on historical treatment and monitoring of the STS Program as well as the environmental preferences of the spongy moth to estimate likely program costs. Spread has occurred with greater intensity where preferred host tree species are more abundant. We accounted for this by gathering Forest Inventory and Analysis Data (FIA) data from EVALIDator on percent of county in “white oak/red oak/hickory forest type” to align with the

preferred host species. The low sample size of FIA plots within counties results in a high variance at smaller scales; however, when aggregated, the estimates are more robust. For context, FIA defines forest land as land that has at least 10-percent canopy cover of trees of any size or land that has had at least 10-percent canopy cover of trees in the past, based on the presence of stumps, snags, or other evidence, and that will be naturally or artificially regenerated. The minimum area for classification of forest land is 1 acre in size and 120 feet wide, measured stem-to-stem from the outermost edge.

To determine the typical amount of preferred host that is treated in any year, we overlaid National Land Cover Database (NLCD) data from the U.S. Geological Survey. An example from 2023 is provided (fig. 7) over the STS treatment areas and deciduous forest, as well as the amount of deciduous forest treated in the STS action zone (fig. 8). We identified the highest 3 treatment years and the lowest 3 treatment years in acres to estimate



Figure 7—An example of all Slow the Spread (STS) treatment areas in 2023. Kentucky is in the STS Program but has never conducted treatments due to its location away from the infestation front.

the percentage of deciduous forest treated (fig. 9). Findings suggested that the highest treatment years were 2011, 2012, and 2015, and the lowest were 2019, 2020, and 2023. In addition, using the spatial overlay analysis, we found that 0.5 percent to 1.64 percent of areas have been treated with a combination of mating disruption and chemical

treatment (“all treatment”), and chemical treatment ranged between 0.02 percent and 0.15 percent of deciduous forest treated. This provides a range of preferred host species that are treated in any year in the STS action zone.



Figure 8—Deciduous forest cover overlaid with 2023 Slow the Spread (STS) treatment areas. Kentucky is in the STS Program but has never conducted treatments due to its location away from the infestation front.

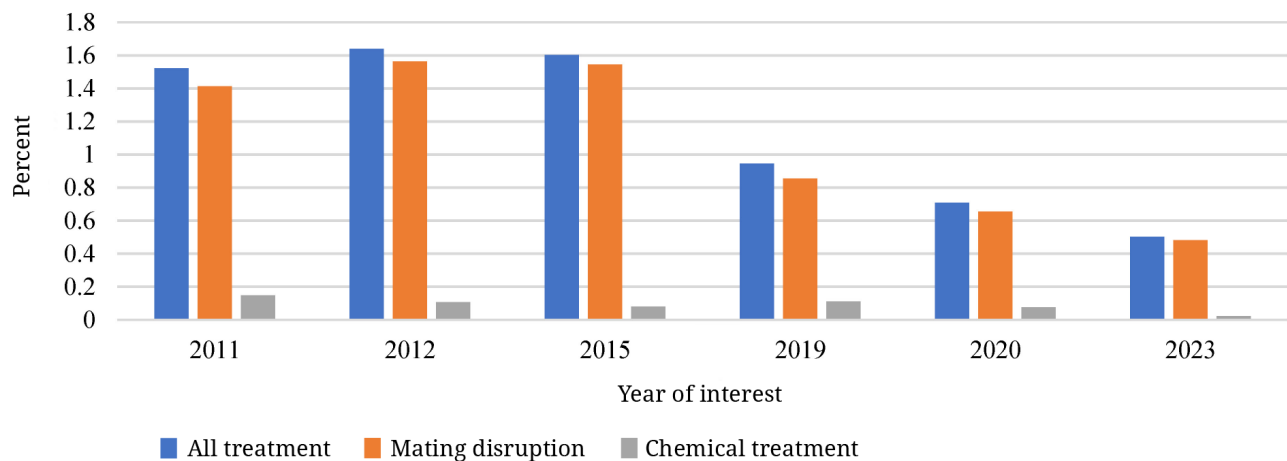


Figure 9—The percent of deciduous forest treated from the 3 highest and 3 lowest years of treated area in the Slow the Spread Action Zone.

We estimated that between 1 percent and 3 percent of the white oak/red oak/hickory forest type would be treated in future years in the STS action zone, since treatments do not solely occur on deciduous forests or preferred host species (table 4). Acres treated were then multiplied by the associated average chemical treatment cost per acre, since chemical treatment was the upper bound cost (\$33.95 per acre).

To estimate monitoring costs, we assumed that traps were placed in 5-km grids in the action and monitoring I zones and 8-km grids in the monitoring II zone. We then multiplied the number of traps by the average trap cost (\$92.53 per trap). No assumptions were made about delimits, and there were no treatment or monitoring costs associated with the counterfactual scenarios (since the program does not exist in the counterfactual). The STS Program aims to have traps set at 5-km grids in monitoring

Table 4—Estimated STS program cost for Scenario C

Year	Action Monit Cost	Monit I and II Zones	1% treated oak	3% treated oak	1% Total	3% Total
2024	1,437,598.34	2,071,336.00	2,098,440.99	6,295,322.97	5,607,375.33	9,804,257.30
2025	1,533,685.21	2,036,619.46	2,142,241.80	6,426,725.39	5,712,546.46	9,997,030.05
2026	1,520,236.54	2,034,661.68	2,078,004.70	6,234,014.09	5,632,902.91	9,788,912.30
2027	1,540,107.59	2,024,579.07	2,051,338.08	6,154,014.25	5,616,024.74	9,718,700.91
2028	1,598,957.01	2,059,993.35	2,097,639.17	6,292,917.52	5,756,589.53	9,951,867.88
2029	1,658,957.43	2,046,003.18	2,130,912.31	6,392,736.93	5,835,872.92	10,097,697.54
2030	1,596,579.18	2,292,339.13	2,120,344.72	6,361,034.15	6,009,263.03	10,249,952.46
2031	1,628,414.12	2,384,845.18	2,135,471.98	6,406,415.93	6,148,731.28	10,419,675.23
2032	1,638,910.96	2,423,219.72	2,109,633.06	6,328,899.19	6,171,763.74	10,391,029.87
2033	1,673,067.16	2,403,434.20	2,094,778.30	6,284,334.91	6,171,279.66	10,360,836.26
2034	1,634,212.54	2,628,408.06	2,014,485.44	6,043,456.33	6,277,106.04	10,306,076.92
2035	1,681,430.23	2,546,363.16	2,099,518.28	6,298,554.84	6,327,311.67	10,526,348.23
2036	1,709,969.09	2,577,038.21	2,100,768.71	6,302,306.14	6,387,776.02	10,589,313.44
2037	1,742,313.91	2,607,079.44	2,135,907.17	6,407,721.51	6,485,300.52	10,757,114.86
2038	1,737,982.74	2,723,537.67	2,197,447.84	6,592,343.52	6,658,968.24	11,053,863.92
2039	1,741,977.25	2,656,671.46	2,193,454.97	6,580,364.90	6,592,103.67	10,979,013.61
2040	1,774,193.90	2,674,797.47	2,211,517.11	6,634,551.33	6,660,508.48	11,083,542.70
2041	1,804,262.70	2,731,209.38	2,248,148.36	6,744,445.07	6,783,620.43	11,279,917.15
2042	1,841,432.47	2,815,080.42	2,246,554.63	6,739,663.89	6,903,067.52	11,396,176.79
2043	1,880,712.90	2,842,415.91	2,257,449.55	6,772,348.65	6,980,578.37	11,495,477.47
2044	1,935,412.13	2,729,203.66	2,329,887.89	6,989,663.66	6,994,503.68	11,654,279.46
2045	1,974,781.33	2,703,045.27	2,338,872.98	7,016,618.95	7,016,699.59	11,694,445.56

I and 2-km grids in action zones, but began setting action zone traps in 3-km grids due to a decreasing budget in the late 2000s. In 2013, STS found that 3-km grids were not sufficient to pick up emerging populations. Currently, the grid is 2 km close to the action zone boundary and spreads to 3 km with movement toward the west. We estimated 5-km grids across both monitoring I and action zones, because the costs can significantly vary per trap. In areas that are easy to access, such as near a road, the cost to set the trap is lower (as low as \$18.00 per trap) compared to mountainous terrain or heavily forested areas. In addition, States contribute an additional 30 percent to the Federal share, which is not a part of the STS budget, and makes up for the shortfall in monitoring and other costs. For context, traps in the action zone set at 2-km grid spacing for Scenario C would cost \$9 million in 2024 and \$12.3 million in 2045 at \$92.53 per trap. Action monitoring cost is high since the boundary line of predicted spread is much larger than historical scenarios. This cost may be justifiable under a mid-2000s budget allocation; however, over the last decade, the budget allocation has been declining. This means the STS Program may have to continue to space out traps closer to the action boundary, assign treatment dollars to monitoring dollars, require more State matching funds, or potentially improve future trapping or monitoring technology. Assuming management, policies, and funding continue business as usual, the “1 percent total” column most accurately reflects future programmatic costs.

EXTERNALITIES OF SPONGY MOTH

Human Health Impacts Data and Methods

The spongy moth caterpillar has tiny urticating hairs (setae) that can trigger an immune response. These hairs can become lodged in the skin when caterpillars are touched and/or travel through the air. Typical symptoms include mild to moderate stinging or pain followed by welts, vesicles (fluid-filled sacs), and/or patches of red scaly skin (Coleman 2023). Children may accidentally put caterpillars in their mouth or near mucous membranes, which can cause more serious reactions such as shortness of breath, conjunctivitis, difficulty swallowing, and hay fever. Treatment for typical symptoms includes removing visible setae and taking over-the-counter pain relievers such as ibuprofen or acetaminophen, as well as allergy medication such as Benadryl (Reliant Medical Group 2022). More serious reactions may require additional medical treatment.

To begin exploring the impact of spongy moth caterpillar reactions on human health, we partnered with data scientists at the Agency for Healthcare Research and Quality (AHRQ 2026). We hypothesized that there may be an increase in emergency room (ER) visits in generally infested and STS zone States compared to States without infestation during the second and/or third quarter (Q2/Q3) of the calendar year (when caterpillars typically emerge). We pulled diagnosis codes related to allergic reaction and irritation (ICD-10-CM) for Connecticut, District of Columbia, Illinois, Indiana, Maine, Maryland, Massachusetts, Minnesota, New Jersey, New York, North Carolina, Ohio, Rhode Island, Vermont, and Wisconsin ($n = 15$). Some generally infested States, such as Pennsylvania, were not included in the analysis because they do not make ER visit data publicly available. We compared impacted States to non-impacted States ($n = 20$). We found no discernable difference between impacted and non-impacted States, likely because allergic reactions included

ER visits not related to spongy moth. In general, we did see a trend of increasing ER visits during Q2 and Q3 of the calendar year, which may have been related to spongy moth reactions and other likely allergens that emerge during the spring and summer months.

In addition, it is possible that individuals impacted by spongy moth do not visit an ER and opt for urgent care or family medical clinic. However, data on treatment for these facilities is not available to the public. Since we were unable to discern between spongy moth related reactions and other allergic reactions, a different approach was taken. Literature has shown that Google Trends can predict outbreaking health events (such as influenza and H1N1 influenza) (Ginsberg et al. 2009, Doornik 2009, Cook et al. 2011, Eysenbach 2006). We assumed that individuals impacted by a typical allergic reaction look up causes and symptoms in search of treatment. We used Google Glimpse to gather insights into the absolute number of searches for 10 keyword combinations that may indicate an individual having an allergic reaction from spongy moth:

1. *Moth rash*
2. *Caterpillar allergy*
3. *Caterpillar rash*
4. *Spongy moth caterpillar rash*
5. *Gypsy moth caterpillar rash*
6. *Gypsy moth rash*
7. *Spongy moth rash*
8. *Spongy moth allergy*
9. *Gypsy moth allergy*
10. *Gypsy moth allergic reaction*

The “moth rash” search provided sufficient count data information. The top States where individuals searched this phrase were Maine, New Hampshire, Vermont, and Massachusetts, followed by Connecticut, Rhode Island, New York, and Pennsylvania. Data were gathered for each week of the year from Q1 2020 to Q1 2025 (fig. 10). The maximum number of searches was 21,004 in 2021 (an outlier compared to the other years), and minimum was 5,874 in 2024. The average, excluding the outlier, was 7,165 searches. Including the outlier, the average was 9,932 searches.

Defoliation and treated acres data obtained from the *Lymantria Dispar* Digest were used to determine outbreak years (USDA Forest Service 2025, fig. 11). Nine years (2007, 2008, 2010, 2015, 2016, 2017, 2021, 2022, and 2023) had over 1 million defoliated acres and were associated with a lagged increase in treated acres. Assuming that outbreak years had a higher level of negative health impacts than non-outbreak years, 7,165 individuals had health impacts in outbreak years and 5,874 individuals in non-outbreak years for the ex-ante with STS (2007 to 2023 with STS). For the counterfactual (2007 to 2023 no STS), a higher number of health impacts in outbreak years

(9,932 individuals) and the same level of impacted individuals in the non-outbreak years (5,874 individuals) was used for the generally infested and STS zones. We then multiplied the number of impacted individuals by \$8.00 and \$11.50, the typical high and low cost of the allergy treatment Benadryl according to a Google search in spring 2025.

Similar methods were applied to model the ex-post scenarios, where we assumed a typical rotation of 4 years of non-outbreak years followed by 2 years of outbreak years. Thus, 2028, 2029, 2034, 2035, 2040, and 2041 were assumed to be outbreak years. Assumptions used 9,932 impacted individuals for outbreak years, 7,239 impacted individuals with continuation of the STS Program, and 9,932 impacted individuals in outbreak years without STS. Findings suggest that in ex-ante scenarios from 2007–2023 with the STS Program, there may have been about \$660,000 in associated health impacts, and without STS approximately \$800,000 in associated health impacts across the Northeast—a difference of \$140,000. In future ex-post scenarios, \$740,000 in health impacts are expected with the STS Program and about \$830,000 in health impacts will occur without STS—a difference of approximately \$90,000 (fig. 12).

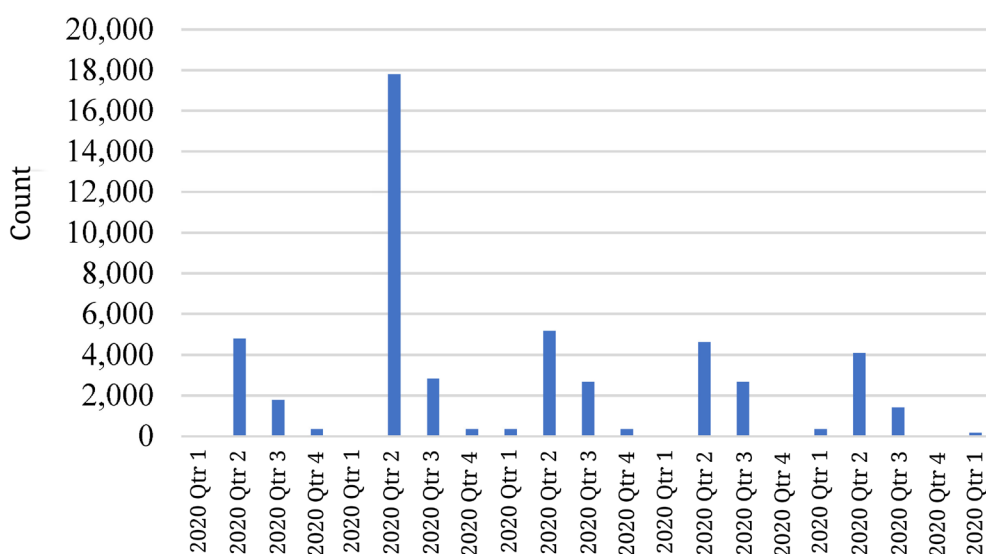


Figure 10—Count of Google searches for the key word “moth rash” from the first quarter of 2020 to the first quarter of 2025.

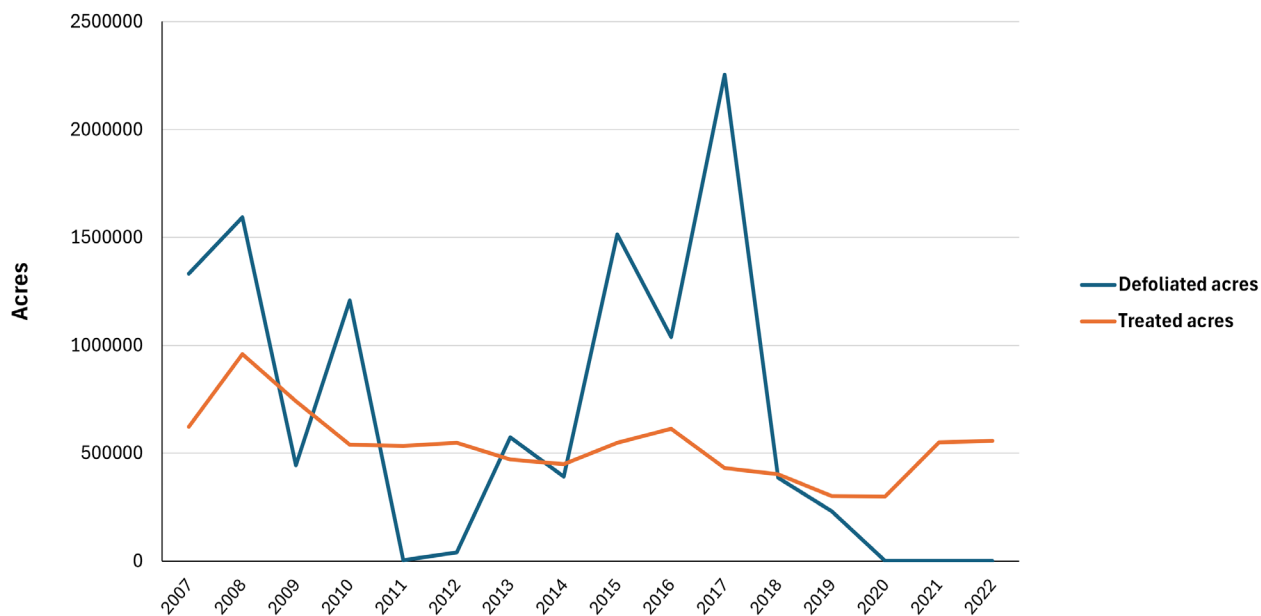


Figure 11—Defoliated and treated acres by year. Data from the Lymantria Dispar Digest. Data were unavailable for defoliated acres for the years 2020, 2021, and 2022 (shown as zeros). The increase in treated acres can likely be associated with outbreaking events.

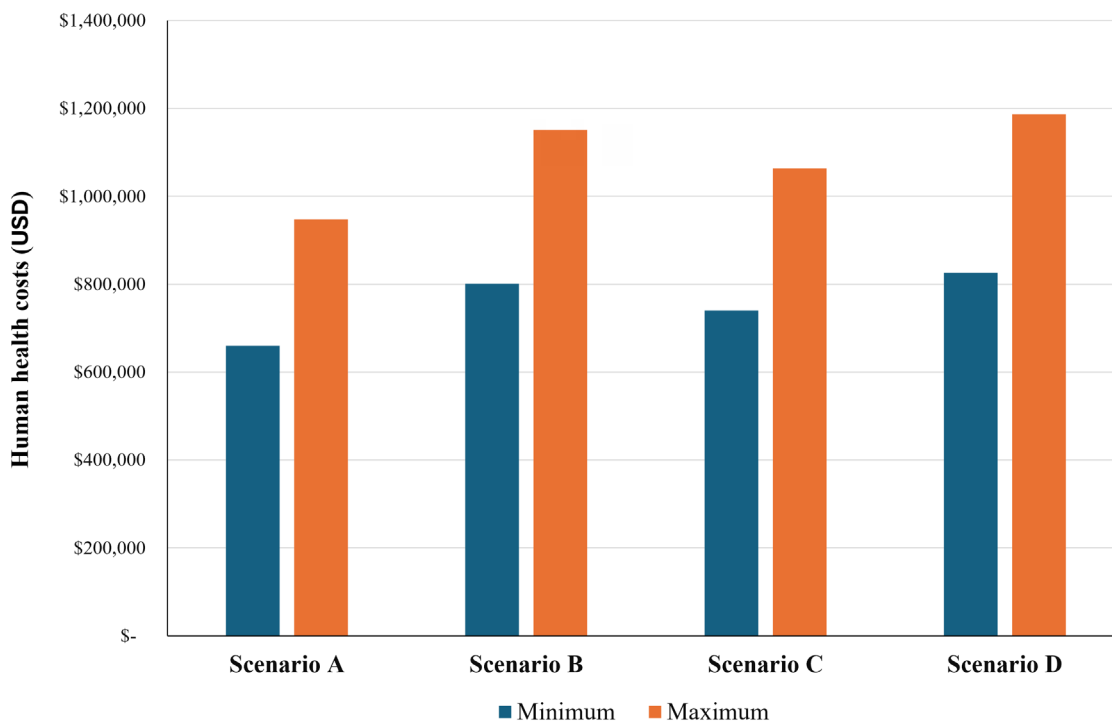


Figure 12—Human health costs discounted at a 4 percent nominal discount rate where the \$8.00 allergy treatment (minimum) is shown in blue and the \$11.50 allergy treatment(maximum) in orange. Scenario A: 2007–2023 with Slow the Spread (STS); Scenario B: 2007–2023 without STS; Scenario C: 2024–2045 with STS; and Scenario D: 2024–2045 without STS.

This was the first analysis to use Google Glimpse data to assess human health impacts from spongy moth allergic reactions, but not the first to predict outbreaking public health events (Ginsberg et al. 2009, Doornik 2009, Cook et al. 2011, Eysenbach 2006). We quantified the cost of ailment related to spongy moth, which is likely a lower-bound estimate since people are willing to pay significantly more to avoid ill health (Hanley and Roberts 2019). For example, Machado and Maurato (2002) evaluated the benefits of marine water quality improvement in Portugal. Results from a contingent valuation survey showed that respondents were willing to avoid gastroenteritis (inflammation of the stomach) by paying an average of \$44.39 per person. A similar survey could be conducted during an outbreaking event to quantify the WTP to avoid an immune response from caterpillar contact.

In this analysis, many assumptions were made and thus there are many limitations. First, not all individuals who searched “moth rash” actually had a rash from spongy moth. For example, the exotic browntail moth caterpillar (*Euproctis chrysorrhoea* L. (*Lepidoptera: Erebidiae*)) has barbed hairs that can cause allergic reaction and overlaps with area infested with spongy moth (specifically Maine). On the other hand, those who had a rash caused by spongy moth may not have known to search the term “moth rash,” and unknowingly suffered from a spongy moth caterpillar reaction. In addition, not all those who had a spongy moth rash and searched for the treatment purchased the medication. However, we can assume that because they searched for the cause of their symptoms, they were experiencing some discomfort, which we may assume was equal to or less than the cost of treatment. Finally, we assumed an interval of 4 non-outbreak years followed by 2 outbreak years across the Northeast. This pattern may be more dynamic in the future. Yet this is a conservative approach, since outbreaks generally last 3–4 years, sometimes longer. In addition, the number of impacted individuals could be more dynamic, as observed in the Google Glimpse data. We aimed to make sensible assumptions about the average number of searches and potentially impacted individuals.

Tourism Impacts Data and Methods

Bruck et al. (2026) examined the impact of spongy moth defoliation events on tourism and recreation to 94 national park units in the Northeastern United States from 1993 to 2019. In this period, approximately 840,000 recreationists visited each national park unit in an average year. Of those parks examined, an average of 0.075 percent of each park was defoliated in the year of the event. The authors associated this with an average of 299 defoliated acres. Findings from this study suggest that national park units could expect a decrease in recreation visitors in the year of the defoliation event, with a lagged effect up to 5 years after the event due to partial park closures (to manage infestations), repeated infestation events, and the effect on park aesthetics. With average defoliation levels, Bruck et al. (2026) found that national park units could expect a decrease of 4.55 percent of recreation visits in the year of the defoliation event. Most national park units do not charge an entrance fee, but those that do require a \$10.00 per-person fee. The average national park unit that charges a per-person fee could expect about 38,000 fewer visitors in the year of the defoliation event, or an annual loss of \$383,000. Notably, the average number of recreation visitors is skewed; there are a few large parks with millions of recreation visitors and many smaller parks with visitors in the thousands or tens of thousands.

Using the available data compiled by Bruck et al. (2026) from 2007 to 2022, we assessed the number of potential defoliation events that occur in parks. Over this period, 10 defoliation events occurred (2007, 2008, 2009, 2015, and 2016). In general, between one and three national park units were affected by defoliation in any year, with 5- to 6-year intervals between the first impact and the last impact event. This equated to between 0.769 percent to 2.308 percent of parks in the Northeast region impacted in event years. Data were gathered from a USA Parks GIS polygon layer, which represents parks, gardens, and forests at national, State, county, regional, and local levels (TomTom 2024). We filtered out “State park or forest” and “national park or forest,” since Bruck

et al. (2026) most closely measured the impact on public lands used for recreation. GIS park data were merged to the scenario data⁵ by county to estimate the number of parks in the STS and generally infested zones for ex-post and ex-ante scenarios.

There were between 223 and 288 parks in the STS and generally infested zones between 2007 and 2023 with STS management, and between 229 and 338 impacted parks in the counterfactual scenario (fig. 13). We estimated a high (2.3 percent) and low (0.77 percent) number of parks that would likely have a defoliation event in any year using observed years of defoliation, resulting in a maximum between 1.78 (low) and 6.25 (high) parks defoliated in event years. Using Bruck et al. (2026), we estimated an annual visitor decrease of 465 annual per park in the year of the defoliation event with an average defoliation (0.075 percent), assuming that the park has on average approximately 10,200 recreation visitors per year. We multiplied the decrease in recreation visits by \$10.00—the per-person entrance fee. While not all parks had an entrance fee, we assumed that this amount proxies for the utility lost to the recreationist who did not get to visit their preferred park. We discounted costs using a 4 percent nominal discount rate and found that from 2007 to 2023, with the STS program, approximately \$40,000 (low) to \$119,000 (high) were lost in both utility and income to parks;

the counterfactual would have resulted in an estimated \$42,000 (low) to \$126,000 (high) loss (fig. 15).

Similar methods were used to estimate the impacts on tourism and recreation for the ex-post scenarios. In general, we found that there were 6 years between defoliation events on national park units, which persisted between 2 and 3 years. We took the lower bound and assumed that parks will be impacted in 2026, 2027, 2034, 2035, 2042, and 2043. Between 2024 and 2045, we found that there may be between 226 and 314 parks in spongy moth impacted zones with STS and between 266 and 524 parks in impacted zones without STS (fig. 14). With STS, we would expect a total loss of between \$51,000 (low) and \$152,000 (high), and without STS, an expected loss between \$61,000 (low) and \$183,000 (high) (fig. 15). We compared our estimate to Neher et al. (2013), who estimated a travel cost model of national park unit visitors to estimate WTP for recreation. They found the average WTP was \$102 systemwide, ranging from \$67 to \$288 across park units in 2011. This suggests that the observed entry fee amount (\$10), is perhaps significantly lower than the WTP of park visitors. Future analyses could incorporate WTP for recreation to national park units, or site-substitution effects (either to other national park units that do not have a defoliation event or within-park substitution).

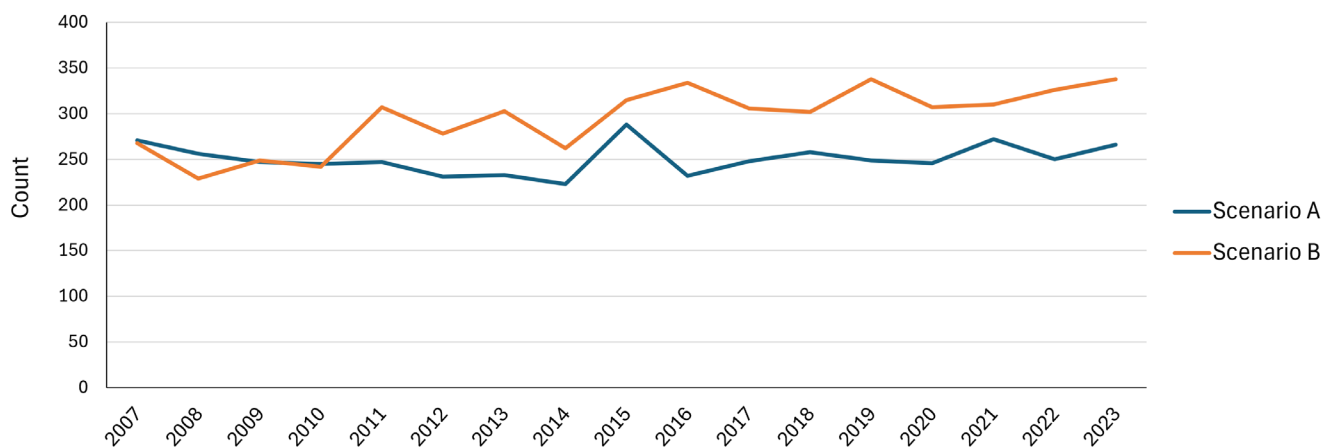


Figure 13—National park units in spongy moth zones between 2007 and 2023. The blue line represents actual data while the orange line represents the counterfactual.

⁵ We use the term “scenario data” to describe the dataset compiled by county by year for each of the associated STS zones and generally infested zone.

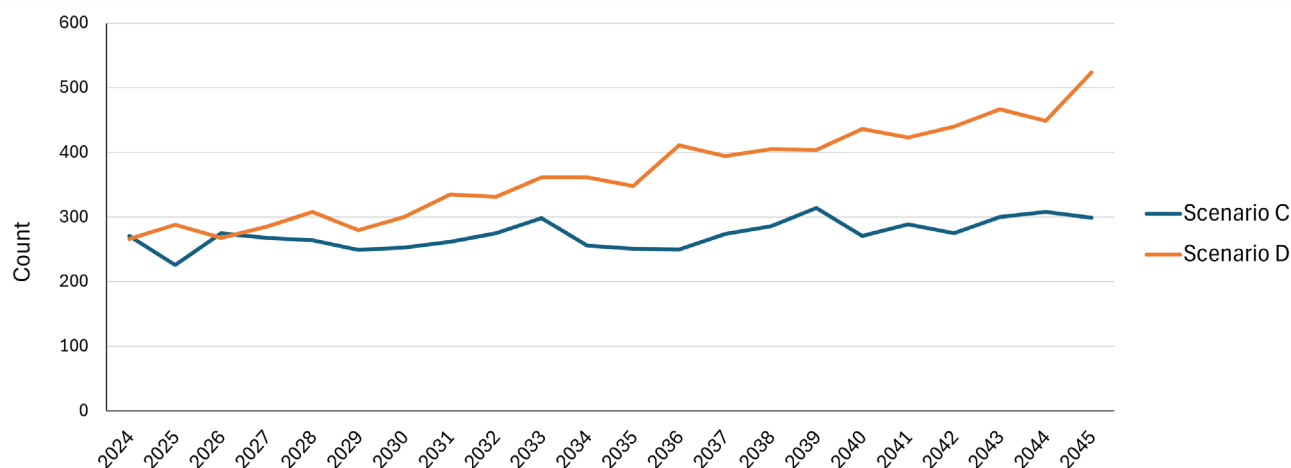


Figure 14—National park units in spongy moth zones between 2024 and 2045. The blue line represents the count with the Slow the Spread (STS) Program, while the orange represents the count without STS.

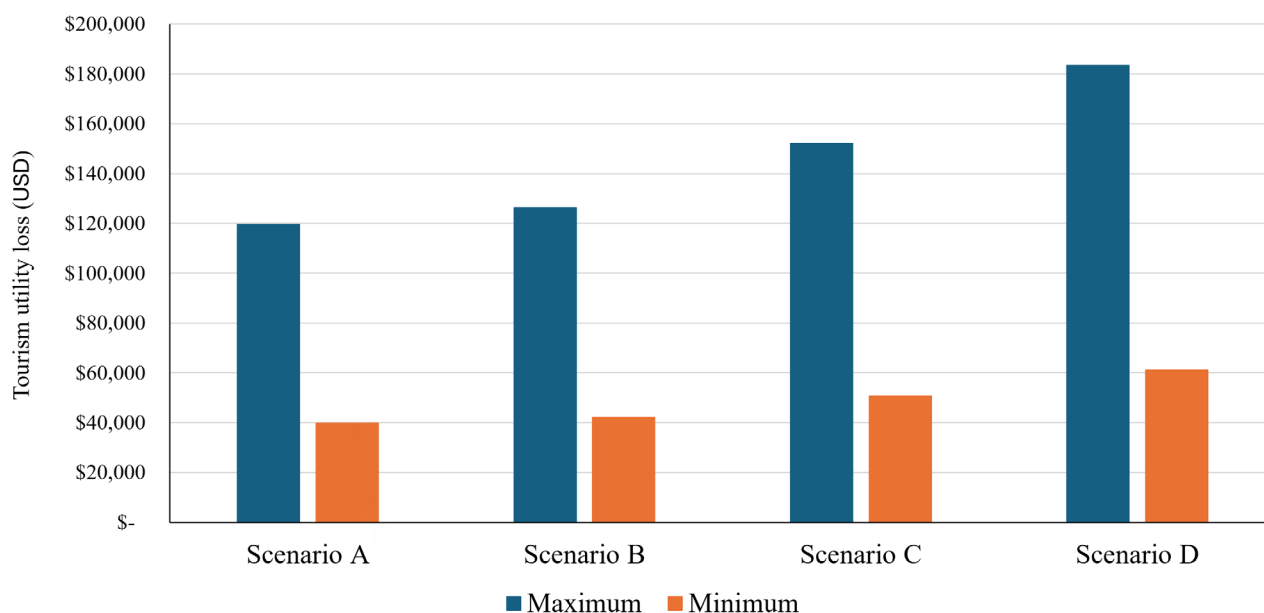


Figure 15—Maximum and minimum tourism utility loss using a 4 percent nominal discount rate for the four scenarios. Scenario A: 2007–2023 with the Slow the Spread (STS) Program; Scenario B: 2007–2023 without STS; Scenario C: 2024–2045 with STS; and Scenario D: 2024–2045 without STS.

There are some limitations to this analysis. First, we only considered the effect in the year of the defoliation event, not the lagged effect (as found in Bruck et al., 2026), which we believe results in a lower-bound estimate on recreation impacts in this analysis. Further, the percentage of parks defoliated in Bruck et al. (2026) was found to range from 0.000023 percent to a maximum of 0.356 percent of any national park

unit. Thus, using the average defoliation (0.075 percent) may not be completely representative. In addition, the counterfactual scenarios (without the STS Program), would presumably not have management efforts, and thus no partial park closures. However, we were unable to differentiate the lagged decrease due to partial park closures, and from that due to other effects (such as decreased willingness to recreate in future years

from human health impacts, impacts to park aesthetics, and falling frass). Furthermore, we used the average effect of defoliation on recreation visitation, so the impact on parks may be larger or smaller depending on the actual size of the defoliation event relative to park size. Lastly, we had to make reasonable assumptions about the number of parks defoliated in any one year. Using data collected from Bruck et al. (2026), we were able to observe actual defoliation events on national park units for ex-post scenarios and then assumed a similar percentage of defoliation events for both national and State parks and forests for ex-post and ex-ante scenarios. For ex-post scenarios, we observed an approximate 5-to-6-year interval between impact events on parks. Hence, we assumed a 6-year interval between defoliation events. This differs from the cyclical pattern we see across the Northeast, which had outbreaks approximately every 4 years. Accordingly, the number of parks and extent of defoliation over time could be more dynamic.

Household Willingness to Pay for Spongy Moth Management Data and Methods

Invasive defoliator pests can cause significant injury to trees, sometimes resulting in dieback and mortality, which imposes market and non-market costs to society. Costs associated with damage caused by forest pests are primarily the burden of local governments and landowners (Miller and Lindsay 1993, Adams et al. 2020). Homeowners, landowners, and business owners may bear the burden of pesticide application as well as tree removal and replacement costs. Tree mortality can result in replacement costs, increased fire hazard, reduced stormwater mitigation, increased energy usage from lack of shading, and harm to businesses and property values via reduced aesthetics (Adams et al. 2020). Studies have correlated urban trees with positive impacts on physical, mental, and social well-being such as longevity (Pataki et al. 2021), recuperation after stress and illness (Ulrich et al. 1991, Li and Sullivan 2016), and lower mental fatigue

(Houlden et al. 2018). The STS Program is unique in its purpose to reduce the number of impacted households by suppressing or eradicating spongy moth populations and slowing its spread from quarantined counties, thus reducing the likelihood that outbreaking events occur on private property.

Studies on economic valuation of preventing the spread of invasive species overwhelmingly focus on calculating willingness to pay (WTP), which is the amount of money an individual would be willing to pay for a certain good or service on average. In the current context, WTP is the maximum amount an individual would pay for a spongy moth management program rather than do without. Several studies have quantified the WTP of private homeowners to surveil and control the spread of invasive species. The collection of studies calculating WTP for invasive species control makes it possible to utilize the benefit transfer method to estimate the WTP for STS. The benefit transfer method involves using preexisting research results from similar sites or contexts to predict estimates (Johnston et al. 2015) and saves time and resources in comparison to conducting primary research (Griffiths and Wheeler 2005, Iovanna and Griffiths 2006, Johnston and Rosenberger 2010).

We gathered literature that assessed the WTP of homeowners to manage nonnative invasive species, focusing on tree defoliators: nine studies met these criteria (Payne et al. 1973, Moeller 1977, Jakus and Smith 1992, Miller and Lindsay 1993, Leuschner et al. 1996, MacDonald et al. 1997, Jetter and Paine 2004, Chang Wei-Yew 2010, Adams et al. 2020). However, only three of these studies were comparable in methods and estimates.⁶ Miller and Lindsay (1993) disseminated a dichotomous choice questionnaire to three towns in New Hampshire in 1991. They posed questions about a hypothetical “yearly service fee” at different price points for a program that would treat spongy moth infestations with minimal risk to human health or the environment. The lowest WTP was \$53.94 per household per year on average (\$120.68 per year

⁶ Sills used Miller and Lindsay (1993) to estimate WTP.

in 2023 dollars), with 39.1 percent of the survey population willing to participate.

Adams et al. (2020) disseminated a survey in Florida asking participants to indicate their WTP for a monitoring program that would allow for early detection and eradication of nonnative invasive forest pests. The hypothetical program would be implemented via a utility fee that would protect urban forests. Approximately 68 percent of the participants voted in favor of the initiative, with a mean WTP of a \$5.44 monthly fee (\$82.88 per year in 2023 dollars). The findings also suggested that the more effective the program, the more the household is willing to pay (up to \$8.00 on average per month).

Chang (2010) assessed the social benefits of controlling forest insect outbreaks, specifically the forest tent caterpillar [*Malacosoma disstria* Hübner (Lepidoptera: Lasiocampidae)] and eastern spruce budworm [*Choristoneura fumiferana* (Clemens) (Lepidoptera: Tortricidae)]. Eastern spruce budworm typically results in tree mortality, while forest tent caterpillar results in defoliation events that cause personal nuisance. A survey disseminated among households in Saskatchewan and New Brunswick asked participants about their WTP for control of future outbreaks of the invasive pests via increased income taxes. Approximately 80 percent of respondents supported the control of future outbreaks. In general, households were willing to pay more for control of eastern spruce budworm than forest tent caterpillar. The lowest WTP was \$60.13 (\$88.36 in 2023 dollars) and the highest was \$104.48 (\$153.54 in 2023 dollars) per year, depending on the insect outbreak.

We used the low and high estimates of household WTP for spongy moth control (i.e., a public program) for counties in the STS and generally infested zones. The minimum WTP was \$82.88 per year for 68 percent of households (Adams et al. 2020), and maximum was \$120.68 per year for 39 percent of households (Miller and Lindsay 1993).⁷ Using the scenario data, we estimated the proportion of occupied households who

were in counties with host tree species (i.e., white oak, red oak, and hickory forest type) and potentially susceptible to impacts from spongy moth caterpillars and/or defoliation. Counties in preferred host tree species were estimated using FIA data, including counties that were partially in the STS action zone. We then multiplied the proportion of households that could be potentially impacted by an outbreaking event by the willingness to pay for management (68 percent and 39 percent) and then multiplied by respective prices.

We assumed 6 percent of occupied households were susceptible to impacts from spongy moth in counties with the host tree species based on Sills (2008), who found the long-run average defoliation rate was 6 percent of susceptible forest. This differed from our assessment of the treated area. However, we also considered that households who do not have defoliation on their property may find outbreaks to be a nuisance on public or adjacent properties. Therefore, we considered 6 percent to be a lower bound of households susceptible. Note that the WTP estimate is 39 percent and 68 percent, respectively, of 6 percent of households susceptible. Therefore, 2.34 percent and 4.1 percent of all households in any county with preferred host trees are willing to pay for management. Because we only included counties with preferred host tree species from FIA data, we excluded urban counties such as Kings County, NY where green urban spaces are still susceptible to spongy moth infestation. Households might be willing to pay a premium to protect green spaces in urban areas, but we did not consider that in this analysis.

Using a nominal discount rate of 4 percent, we found that ex-ante the actual WTP of those who lived in the STS and generally infested zones was at a minimum \$1.8 billion and maximum of \$2.7 billion. Without the STS Program, the total WTP would have been a minimum of \$2.1 billion and maximum of \$3 billion. Ex-post the WTP ranged from \$2.6 billion to \$3.9 billion in sum with STS, and from \$3.1 billion to \$4.6 billion without the STS Program (fig. 16).

⁷ Amounts are all in 2023 dollars.

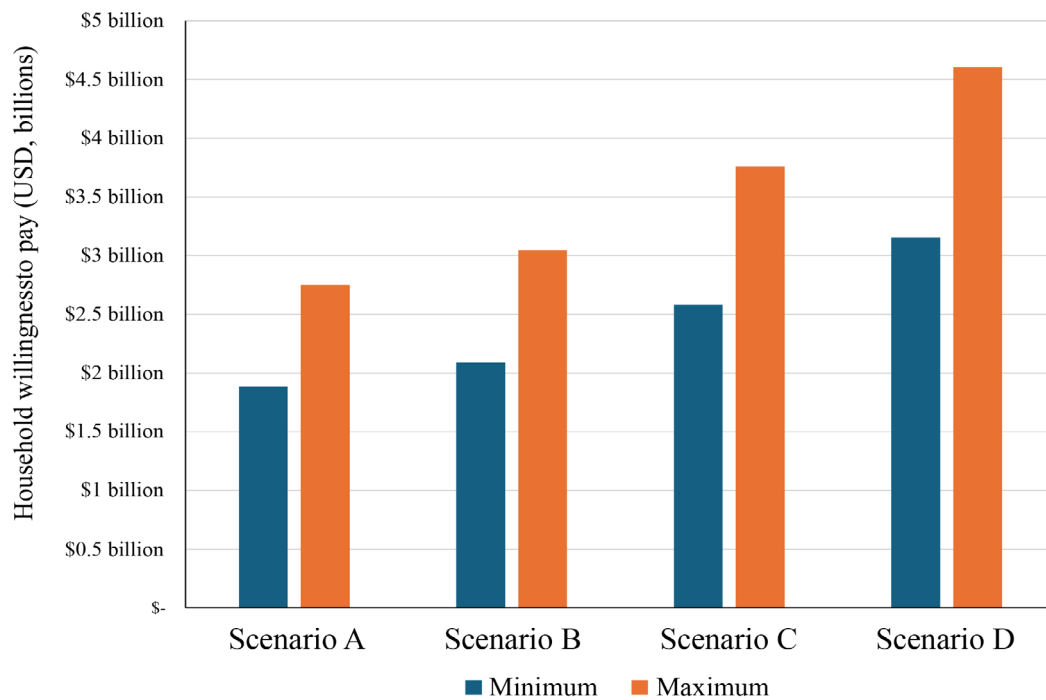


Figure 16—Private household willingness to pay for public spongy moth control programs discounted at a 4 percent discount rate. Scenario A: 2007–2023 with Slow the Spread (STS) Program; Scenario B: 2007–2023 without STS; Scenario C: 2024–2045 with STS; and Scenario D: 2024–2045 without STS.

In 2023, the WTP calculated by our study would have been \$112 million across 22 States. In contrast, Miller and Lindsay (1993) found that the WTP for a town in New Hampshire would conservatively be WTP \$94,041 (\$210,397 in 2023 dollars). Aggregated up to the State of New Hampshire, the authors found that households would be willing to pay a minimum of \$13.13 million per year (\$29 million in 2023 dollars), and an upper bound of \$27.9 million per year (\$62 million in 2023 dollars). In addition, Adams et al. (2020) found that Floridians would be willing to pay \$550 million dollars per year (\$698 million in 2023 dollars) to reduce forest pest invasions. Thus, our findings are rather conservative considering the spatial extent. We restricted our analysis to only those households potentially impacted (with preferred host trees), since these other studies assume that all benefits and costs are dispersed equally across the State populations, which may not be true.

There are quite a few limitations to our analysis. First, we held occupied households constant across space and time. However, we aggregated to a regional level, so unless the region substantially changes in population, the assumptions seem practical. We excluded large urban populations in our estimation (i.e., Philadelphia, New York City, and Washington, DC). While these cities do have large urban parks that are at risk, the WTP of city dwellers may be substantially different than suburban homeowners, which was not factored in this analysis. A study on the WTP of those impacted in larger cities could be conducted in the future. A third limitation is that we included estimates for WTP metrics that were not specifically for spongy moth. However, since these studies focused on defoliators and were not markedly different than estimates found for spongy moth, we included them in this analysis.

ADDITIONAL EXTERNALITIES

Wood Mill Impacts

The USDA Animal and Plant Health Inspection Service (APHIS) enforces regulations meant to prevent the movement of the federally regulated spongy moth across States. Wood mills in infested areas may face more constraints, such as regular inspections of facilities and potential fines if out of compliance. Although fines are extremely irregular, a larger burden is often placed on mills who receive product from the infested zone to the uninfested zone to ensure sanitation. For this reason, we did not assign a cost to mills in infested zones since data on the movement of wood products from one facility to another is limited. However, we highlight that 114 more wood mills would have been in the infested zone without the STS Program ex-ante, and 289 more mills would

be impacted ex-post without the STS Program (figs. 17 and 18). This may place a higher burden on facilities that rely on exporting to uninfested areas domestically and internationally.

Prestemon et al. (2008) examined the potential impacts of Asian spongy (*L. dispar asiatica* Vnukovskij) and/or nun (*L. monacha* L.) moths in the United States. They found that moth infestations could potentially disrupt international supply chains, which would affect potential profitability as lumber producers may not be able to sell to as many international buyers. Future benefit-cost analyses could explore exact costs imposed on wood mills in infested and uninfested zones and impacts on international trade via a managerial survey.

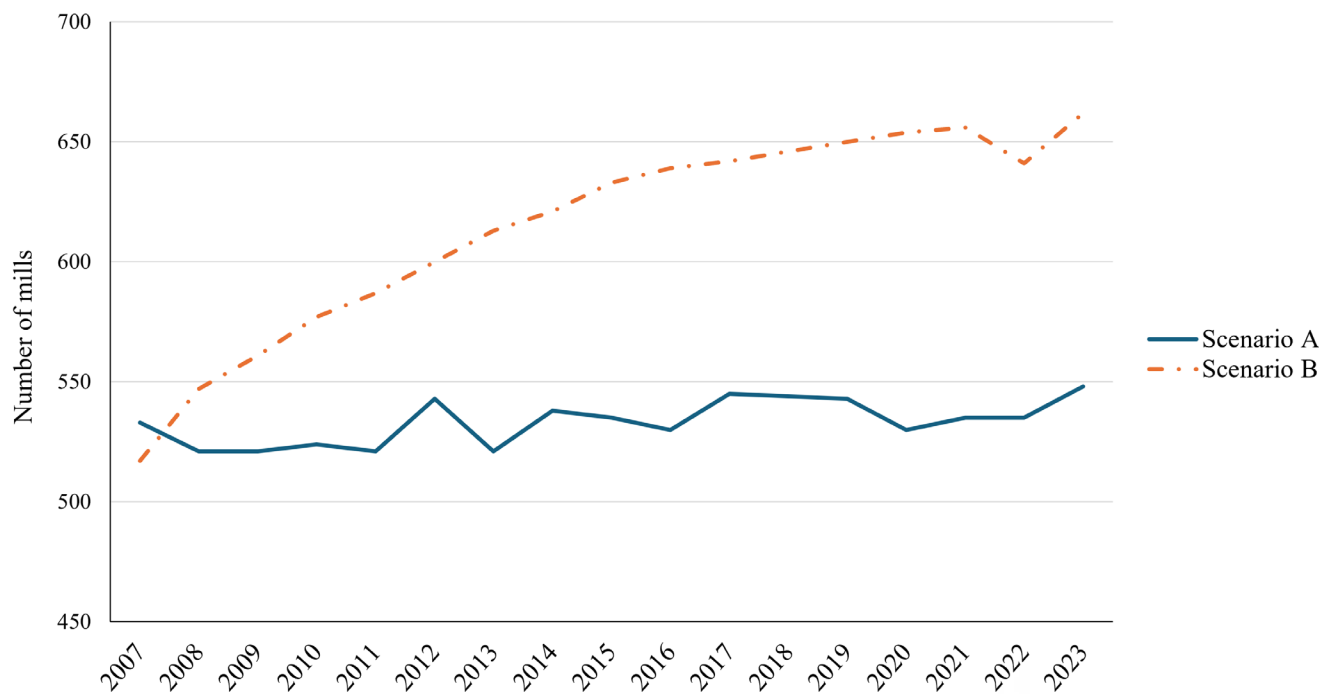


Figure 17—Number of wood mills that would have been in the STS or infested zones ex-post. The blue line represents the 2007–2023 scenario with the Slow the Spread (STS) Program and the orange line represents data from the same period (Forisk 2008).

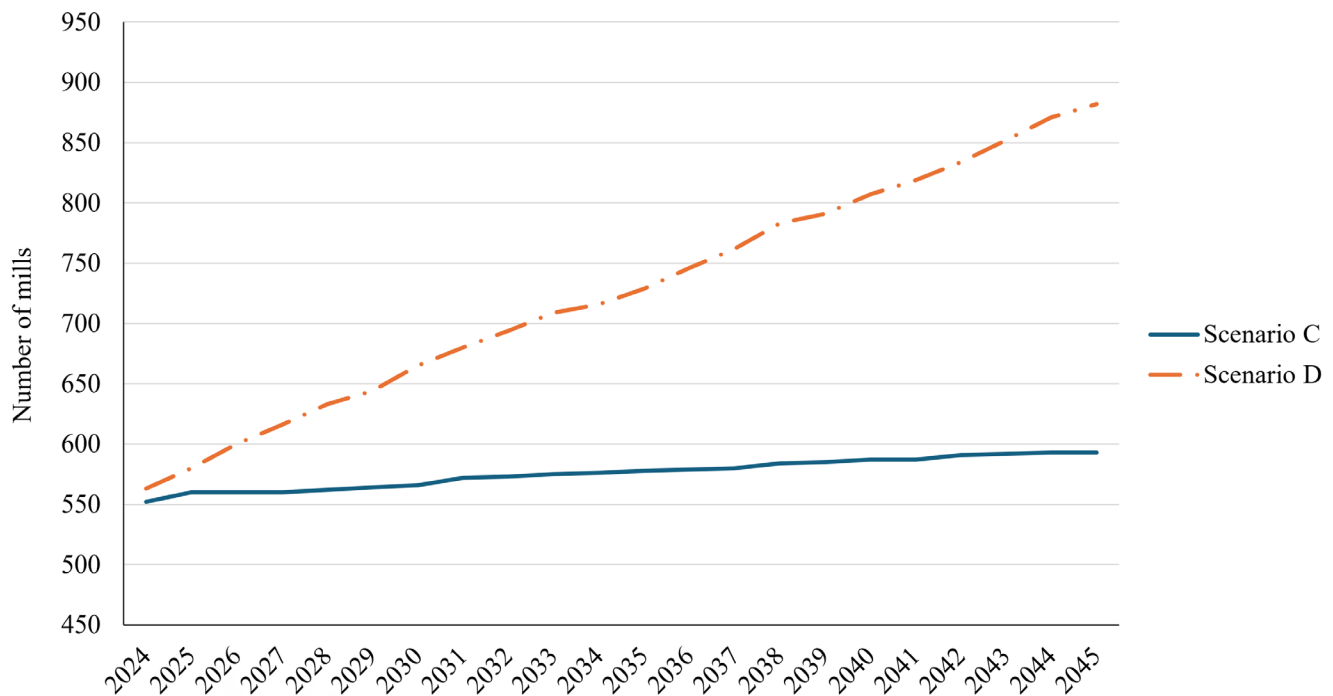


Figure 18—Number of wood mills that would have been in the Slow the Spread (STS) Program or infested zones ex-ante. The blue line represents the 2024–2045 scenario with STS; the orange line represents the 2024–2045 scenario without STS (Forisk 2008).

Ecological Change and Timber Price

The impacts of large-scale disturbance events on supply of stumpage and timber prices are well known and documented in literature (Cohen et al. 2016). For instance, Abbott et al. (2009) found that mountain pine beetle [*Dendroctonus ponderosae* Hopkins (Coleoptera: Curculionidae)] die-back increased lumber prices in British Columbia, Canada. Prestemon et al. (2006) found that tree mortality from wildfires can also cause shocks to lumber markets. In this analysis, we followed the approach of Sills et al. (2008) and did not quantify impacts on timber value, based on those authors' assumption that periodic defoliation and associated mortality may thin forest stands but leave timber value undiminished in the short run.

Nevertheless, research suggests that changes in forest species composition can occur under ongoing defoliation (Morin and Liebhold 2015), though the pace of expected change is uncertain. Here, we discuss recent research and modeling studies that can inform how tree

species composition may change, and at what pace, after the spongy moth becomes established and starts causing outbreaks in host-dominated landscapes. In the long run, this ecological change could impact the supply of certain product types, including hardwood pulpwood and sawtimber as well as nontimber forest products such as white oak basketry or white oak whiskey barrels.

Spongy moth outbreaks cause defoliation that can persist on trees and stands for multiple years. This recurring defoliation has been shown to reduce wood growth (Baker 1941, Wargo 1981, Rubtsov 1996, Colbert and Fekedulegn 2001) and increase mortality in host tree species (Baker 1941, Campbell and Valentine 1972, Herrick and Gansner 1987, Feicht et al. 1993) at rates that vary depending on the length of an outbreak or a tree species' susceptibility (Foster 2017, Fei et al. 2019). These changes in growth and mortality affect competition among species, and thus, trajectories of species dominance that emerge as defoliated stands develop over time, though long-term studies of forest change are rare.

Once established, spongy moth outbreaks tend to be episodic with a periodicity that can vary from one outbreak on average every 4–5 years in dry oak-pine forests to once every 8–10 years in oak-hickory forests (Johnson et al. 2006, Medvigy et al. 2012). Longer intervals between outbreaks have also been observed in the Northeastern United States, where spongy moth populations have been established the longest and no large-scale outbreaks occurred for more than 30 years prior to the 2015 outbreak (Pasquarella et al. 2018). This long delay has been attributed to larval mortality caused by a fungus (*Entomophaga maimaga*) and other agents that may have been rendered less effective during a 3-year drought that started in 2014. The extensiveness of the 2015–2017 outbreak suggests that infrequent outbreaks may be more widespread and severe. During spongy moth outbreaks, defoliation tends to be geographically patchy with high local defoliation where spongy moth populations are highest; this variation in larval density and thus defoliation levels has been shown to depend on many factors, such as local host abundance and defoliation treatment history (Foster et al. 2013a, Foster et al. 2013b).

To synthesize current knowledge of spongy moth outbreak dynamics and project outbreak effects on forest composition and productivity over time, Foster et al. (in review) developed a defoliation landscape simulation model and applied it to predict forest change in oak-hickory forests in the central hardwoods region of the Eastern United States (similar to south-central areas in counterfactuals B and D). These simulations tested potential disturbance scenarios that included probabilistic rates of active forest management and harvests as well as wind damage, and then added defoliation from spongy moth outbreaks and/or a native defoliator for a State forest in western Maryland. Because trees and forests age and develop slowly, the authors ran simulations for a 400-year period. They compared the resulting forest biomass and species composition for scenarios with and without spongy moth defoliation at points in time.

These simulations of forest development demonstrated that invasive spongy moth significantly reduced the amount of aboveground forest biomass stored in wood but did not change the overall rate of net wood accumulation in comparison to rates under alternative disturbance scenarios. This suggests that wood accumulation rates are driven more by long-term successional processes from the legacy of large-scale logging and forest clearing between the 1880s and 1930s—a land use legacy that tends to overwhelm the short-term effects of introduced spongy moth defoliation when averaged to landscape scales (Loudermilk et al. 2013, Nowacki and Abrams 2014). Surprisingly, forest composition changed less when spongy moth defoliation was introduced to the forest than when defoliation was caused by outbreaks of a native defoliator alone, or when no defoliation outbreaks occurred. The relative abundance of nonhost tree species did increase over time. However, changes in forest species composition were small through 2070, which is beyond the time frame considered in this publication. Combined, these results indicate that the new disturbance regime that develops once spongy moth invades a forest in the Eastern United States likely represents a regime weaker than the one with past disturbances that formed the forest composition and structure observed today (Nowacki and Abrams 2014, Robbins et al. 2024).

Other studies from empirical data or simulation models report similar findings: Eastern forests in the generally infested zone and along the invasion front are often composed of mature and older forest age classes, and growth of these forests is likely to continue to exceed mortality and losses to disturbance or harvest until 2050–2070 (Loudermilk et al. 2013, Wang et al. 2015). In the Eastern United States, 40 percent or more of oak-hickory forests can be described as mature or older based on age class or forest structure metrics, similar to maple-beech-birch hardwood forests that are more common along the northern invasion front (Barnett et al. 2023, Woodall et al. 2023). This mature age structure reflects the land use history of the Eastern United

States, where most forests experienced periods of forest clearing, agricultural use, agricultural abandonment, and subsequent regeneration and forest regrowth between the 1850s and 1930s (Thompson et al. 2013, Nowacki and Abrams 2014). Today's mature forests arose from this "catastrophic disturbance era" and subsequent fire suppression (Nowacki and Abrams 2014). That land use history and its effects often overwhelm changes expected to arise from less intense disturbances or environmental trends, including periodic spongy moth outbreaks. The net effect is that forest composition in the central hardwoods region may continue to be dominated by oak-hickory species through 2100 (Robbins et al. 2024) despite spongy moth outbreaks or predicted increases in fire frequency. This suggests that spongy moth would not have a large impact on hardwood prices, perhaps even in the long run.

Impacts on Private Property Value

Several publications have shown how outbreaks of nonnative invasive species can impact residential property values by defoliating canopy cover using hedonic pricing and other causal inference methods. Individual trees and forest cover on and adjacent to residential properties generally increase property values. Loss of amenity value from defoliation and tree mortality has been measured from invasions of hemlock woolly adelgid (*Adelges tsugae*) (Holmes et al. 2010), sudden oak death (*Phytophthora ramorum*) (Kovacs et al. 2011a, Kovacs et al. 2011b), emerald ash borer (*Agrilus planipennis*) (Kovacs et al. 2010, Sydnor et al. 2011), and oak wilt (*Bretziella fagacearum*) (Haight et al. 2011).

Hemlock woolly adelgid was introduced to Virginia from Japan in the 1950s. Eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliniana*) show no resistance once moderately to severely infested, which results in tree mortality. Hemlocks have little commercial value and are mostly valued for aesthetics or scenic beauty. Holmes et al. (2010) found that dead hemlocks consistently had a negative impact on property transactions in West Milford, NJ. Using a fixed effects estimator, the authors found

the average property loss between \$2,231 and \$3,352 at final sale—between 1.05 percent and 1.6 percent of the sale price. In addition, hemlock decline on neighboring properties (within 0.1 km from the parcel centroid) resulted in economic losses that ranged from approximately \$1.2 million to \$1.9 million from 1992 to 2002 in the county studied.

Kovacs et al. (2011a, 2011b) estimated the effects of sudden oak death on property values in California and Oregon. Sudden oak death was discovered in Marin and Santa Cruz, California in the mid-1990s. Similar to management of spongy moth, quarantines restrict the movement of nursery and forest plants and surveys are conducted to detect new infestations of *P. ramorum* (Peronosporales: Peronosporaceae). Using a stochastic epidemiological model, Kovacs et al. (2011a) predicted the numbers of trees affected in response to infestation in California and southern Oregon and then assigned potential manager actions based on tree size (e.g., remove smaller trees and/or use fungicide on larger trees). Over a 10-year period, they estimated costs of \$7.5 million in treatment, removal, and replacement of oak in developed communities, and a median loss of \$135 million in property value. Further, Kovacs et al. (2011b) estimated the loss of residential property values in response to sudden oak death in Marin County, CA. The analysis covered 30,000 property transactions from 1983 to 2008. Findings suggested that properties within a three-tenths mile from infested oak woodlands experienced a 3–6 percent decrease in sale price.

Other studies have quantified the removal and replacement costs of trees that have died from damages due to invasive species. Kovacs et al. (2010) found that damage from emerald ash borer would lead to the removal and replacement of more than 17 million ash trees across the Midwest and Northeast, resulting in a mean discounted cost of \$10.7 billion from 2009 to 2019. In addition, in a study of the Minneapolis-Saint Paul metropolitan area, Haight et al. (2011) found that the discounted removal cost of 76,000–266,000 trees affected by oak wilt in the region would result in discounted costs between \$18 million and \$60 million from 2007 to 2016.

To our knowledge, there have not been any hedonic models investigating the effect of spongy moth in the Northeastern United States on private property values. It is difficult to conduct a hedonic model over large geographic areas due to data limitations and the challenge of adequately controlling confounding factors. In general, studies that estimated loss to property values have been case studies at the county level. The largest area study that we came across was Kovacs et al. (2010), who estimated removal and replacement costs of ash trees across 25 States, which did not necessitate private property value transactions. We believe that spongy moth may impact private property values, which is why homeowners are willing to pay for a public management program. Future studies could focus on key spongy moth impacted counties in the Northeast, concentrating on tree mortality, repeated defoliation events, or properties with high likelihood of repeated defoliation, since the effect on property values has been shown to be transitory (Kovacs et al. 2011b). These estimates could improve future benefit-cost analyses.

RESULTS

We compared our results to Sills (2008), who estimated the associated benefit-cost ratio of the STS Program from 2000 to 2006 and projected forward until 2026. Findings from the Sills analysis suggested that the benefit-cost ratio for the program was at least 2. Under similar assumptions, we evaluated the benefits and costs associated with the STS Program ex-post from 2007 to 2023 and ex-ante from 2024 to 2045.

The ex-post STS Program nominal costs ranged from \$11 million to \$24 million between 2007 and 2010 (table 5). Beginning in 2011, programmatic costs dramatically decreased to an average annual cost of \$6.9 million. In recent years (2019–2023), the average program cost was \$5.3 million. This suggests that STS Program managers and cooperative partners have received a smaller budget over the last 16 years yet have continued to manage the spread of spongy moth. Further analyses may be necessary to assess the optimal program budget and the impact on the ex-post program from receiving less funding over time.

Ex-ante, if associated management costs and funding continue business as usual, we expect that future STS Program costs will linearly increase from approximately \$5.6 million in the present to \$7 million by 2045, which is 49 percent lower than the \$11 million budget of the early 2000s. In summary, since the program budget was larger in early ex-post years, the resulting benefit-cost ratio was lower compared to ex-ante scenarios. We found that ex-post, the benefit-cost ratio was between 1.6 and 2.31, and ex-ante was between 3.81 and 5.58. For every dollar invested between 2007 and 2023 (ex-post), the return was between \$1.60 and \$2.31. For future investments (until 2045), we expect a return between \$3.81 and \$5.58 for each dollar spent on the STS Program. These estimates are consistent with previous analyses and rather conservative, considering the constraints on each assumption made. In addition, we estimated the net present value (NPV) of the STS Program. Ex-post, the NPV ranged from \$64

million to \$139 million, and ex-ante we estimated the NPV to be between \$233 million and \$385 million. An example of the exact calculation is provided in appendix 3. See tables 5, 6, 7, and 8 for dollar values for each scenario.

Benefit-Cost Ratios

Ex-post 2007–2023 (16 years)

- *High benefit-cost ratio* 2.31
- *Low benefit-cost ratio* 1.60

Ex-ante 2024–2045 (22 years)

- *High benefit-cost ratio* 5.58
- *Low benefit-cost ratio* 3.81

Table 5—Scenario A quantifies the actual costs and costs avoided of the Slow the Spread (STS) Program from 2007 to 2023^{a,b}

Year	STS Program Actual Costs	Health (Max)	Health (Min)	Tourism (Max)	Tourism (Min)	WTP (Max)	WTP (Min)	Total Externalities (Max)	Total Externalities (Min)	Discounted STS Program Costs	Discounted Externalities (Max)	Discounted Externalities (Min)
2007	11,113,598	83,249	57,912	29,084	9,693	163,000,000	112,000,000	163,112,333	112,067,605	5,933,641	87,087,008	59,833,811
2008	12,529,141	83,249	57,912	27,474	9,157	159,000,000	109,000,000	159,110,723	109,067,069	6,956,987	88,348,536	60,561,072
2009	24,012,548	67,551	46,992	26,509	8,835	158,000,000	109,000,000	158,094,060	109,055,827	13,866,648	91,295,380	62,977,023
2010	16,662,587	83,249	57,912	-	-	160,000,000	110,000,000	160,083,249	110,057,912	10,007,118	96,141,851	66,097,930
2011	8,870,173	67,551	46,992	-	-	159,000,000	109,000,000	159,067,551	109,046,992	5,540,284	99,353,123	68,110,429
2012	8,178,875	67,551	46,992	-	-	163,000,000	112,000,000	163,067,551	112,046,992	5,312,841	105,925,572	72,783,589
2013	7,954,732	67,551	46,992	-	-	158,000,000	108,000,000	158,067,551	108,046,992	5,373,932	106,784,774	72,992,676
2014	7,959,414	67,551	46,992	-	-	162,000,000	111,000,000	162,067,551	111,046,992	5,592,178	113,866,512	78,020,144
2015	8,450,003	83,249	57,912	30,909	10,302	162,000,000	111,000,000	162,114,157	111,068,214	6,174,334	118,455,227	81,156,456
2016	8,812,148	83,249	57,912	24,899	8,298	162,000,000	111,000,000	162,108,147	111,066,210	6,696,508	123,188,869	84,401,192
2017	7,217,716	83,249	57,912	-	-	164,000,000	113,000,000	164,083,249	113,057,912	5,704,266	129,677,375	89,351,310
2018	6,173,631	67,551	46,992	-	-	164,000,000	112,000,000	164,067,551	112,046,992	5,074,275	134,851,568	92,094,460
2019	5,316,821	67,551	46,992	-	-	163,000,000	112,000,000	163,067,551	112,046,992	4,544,841	139,390,826	95,778,238
2020	5,283,700	67,551	46,992	-	-	162,000,000	111,000,000	162,067,551	111,046,992	4,697,190	144,077,463	98,720,372
2021	5,648,990	83,249	57,912	-	-	164,000,000	113,000,000	164,083,249	113,057,912	5,222,809	151,704,187	104,528,395
2022	5,208,169	83,249	57,912	-	-	164,000,000	112,000,000	164,083,249	112,057,912	5,007,855	157,772,354	107,747,992
2023	5,006,871	83,249	57,912	-	-	164,000,000	112,000,000	164,083,249	112,057,912	5,006,871	164,083,249	112,057,912
Sum	154,399,118	1,289,645	897,144	138,875	46,285	2,751,000,000	1,887,000,000	2,752,428,519	1,887,943,429	106,712,579	2,052,003,871	1,407,213,001

- = no tourism impacts estimated.

^aFindings suggest that the STS Program costs totaled approximately \$154 million over this time period. The budget allocated to the program was higher from 2007 to 2010, or an average of \$16 million. Beginning in 2011 the budget decreased from approximately \$9 million to \$5 million in 2023. The human health impact costs during this time ranged from \$897,000 to \$1.3 million, tourism ranged from \$46,000 thousand to \$139,000 (we assumed tourism impacts did not occur in any recreation area in some years, incurring zero cost), and household willingness to pay (WTP) ranged from \$1.8 billion to \$2.8 billion. Total externalities imposed by the spillover during this time ranged from \$1.9 billion to \$2.8 billion. Discounted at a 4 percent discount rate, the total program was approximately \$106 million and discounted externalities ranged from \$1.4 million to \$2.1 million.^a

Table 6—Scenario B quantifies the counterfactual costs and costs avoided without the STS Program from 2007 to 2023^a

Year	Health (Max)	Health (Min)	Tourism (Max)	Tourism (Min)	WTP (Max)	WTP (Min)	Total Externalities (Max)	Total Externalities (Min)	Discounted Externalities (Max)	Discounted Externalities (Min)
2007	114,218	79,456	28,762	9,586	150,000,000	103,000,000	150,142,880	103,089,042	80,162,565	55,040,082
2008	114,218	79,456	24,577	8,191	160,000,000	110,000,000	160,138,795	110,087,647	88,919,388	61,127,763
2009	67,551	46,992	26,723	8,907	163,000,000	112,000,000	163,094,274	112,055,899	94,182,879	64,709,489
2010	114,218	79,456	-	-	166,000,000	114,000,000	166,114,218	114,079,456	99,763,895	68,513,165
2011	67,551	46,992	-	-	170,000,000	117,000,000	170,067,551	117,046,992	106,223,691	73,107,206
2012	67,551	46,992	-	-	175,000,000	120,000,000	175,067,551	120,046,992	113,720,543	77,980,237
2013	67,551	46,992	-	-	178,000,000	122,000,000	178,067,551	122,046,992	120,296,057	82,450,575
2014	67,551	46,992	-	-	182,000,000	125,000,000	182,067,551	125,046,992	127,918,246	87,856,358
2015	114,218	79,456	33,806	11,267	184,000,000	126,000,000	184,148,024	126,090,723	134,555,158	92,133,256
2016	114,218	79,456	35,846	11,947	186,000,000	127,000,000	186,150,064	127,091,403	141,458,749	96,573,021
2017	114,218	79,456	-	-	188,000,000	129,000,000	188,114,218	129,079,456	148,669,399	102,013,369
2018	67,551	46,992	-	-	189,000,000	130,000,000	189,067,551	130,046,992	155,399,745	106,889,148
2019	67,551	46,992	-	-	190,000,000	131,000,000	190,067,551	131,046,992	162,470,539	112,019,518
2020	67,551	46,992	-	-	192,000,000	132,000,000	192,067,551	132,046,992	170,747,353	117,389,295
2021	114,218	79,456	-	-	192,000,000	132,000,000	192,114,218	132,079,456	177,620,394	122,114,882
2022	114,218	79,456	-	-	189,000,000	130,000,000	189,114,218	130,079,456	181,840,594	125,076,400
2023	114,218	79,456	-	-	194,000,000	133,000,000	194,114,218	133,079,456	194,114,218	133,079,456
Sum	1,568,370	1,091,040	149,714	49,898	3,048,000,000	2,093,000,000	3,049,718,084	2,094,140,938	2,298,063,414	1,578,079,220

^a - = no tourism impacts estimated.

^a Findings suggest that health costs would have ranged from \$1.1 million to 1.6 million, tourism costs would have ranged from \$49,000 to \$150,000, and WTP would have been between \$2.1 billion and \$3 billion dollars. Discounted at a 4 percent discount rate, the total externality cost without the STS Program from 2007 to 2023 would have been between \$1.6 billion and \$2.3 billion.

Table 7—Scenario C estimates the future programmatic cost from 2024–2045^a

Year	STS Program Future Costs	Health (Max)	Health (Min)	Tourism (Max)	Tourism (Min)	WTP (Max)	WTP (Min)	Total Externalities (Max)	Total Externalities (Min)	Discounted STS Program Costs	Discounted Externalities (Max)	Discounted Externalities (Min)
2024	5,607,375	67,551	46,992	29,084	9,693	160,000,000	110,000,000	160,096,635	110,056,685	5,607,375	160,096,635	110,056,685
2025	5,712,546	67,551	46,992	24,255	8,084	163,000,000	112,000,000	163,091,806	112,055,076	5,492,833	156,819,044	107,745,265
2026	5,632,903	67,551	46,992	29,514	9,837	163,000,000	112,000,000	163,097,065	112,056,829	5,207,935	150,792,404	103,602,837
2027	5,616,025	67,551	46,992	-	-	164,000,000	113,000,000	164,067,551	113,046,992	4,992,626	145,855,455	100,498,364
2028	5,756,590	83,249	57,912	-	-	165,000,000	113,000,000	165,083,249	113,057,912	4,920,757	141,113,853	96,642,377
2029	5,835,873	83,249	57,912	-	-	168,000,000	115,000,000	168,083,249	115,057,912	4,796,662	138,152,178	94,569,217
2030	6,009,263	67,551	46,992	-	-	168,000,000	116,000,000	168,067,551	116,046,992	4,749,208	132,826,227	91,713,623
2031	6,148,731	67,551	46,992	-	-	169,000,000	116,000,000	169,067,551	116,046,992	4,672,530	128,477,444	88,186,176
2032	6,171,764	67,551	46,992	29,514	9,837	170,000,000	117,000,000	170,097,065	117,056,829	4,509,647	124,288,259	85,532,278
2033	6,171,280	67,551	46,992	31,982	10,659	171,000,000	117,000,000	171,099,533	117,057,651	4,335,859	120,212,262	82,243,153
2034	6,277,106	83,249	57,912	-	-	172,000,000	118,000,000	172,083,249	118,057,912	4,240,588	116,233,277	79,755,695
2035	6,327,312	83,249	57,912	-	-	173,000,000	119,000,000	173,083,249	119,057,912	4,110,101	112,431,578	77,337,749
2036	6,387,776	67,551	46,992	-	-	173,000,000	119,000,000	173,067,551	119,046,992	3,989,786	108,097,482	74,356,400
2037	6,485,301	67,551	46,992	-	-	174,000,000	119,000,000	174,067,551	119,046,992	3,894,903	104,540,460	71,486,538
2038	6,658,968	67,551	46,992	-	-	174,000,000	119,000,000	174,067,551	119,046,992	3,845,388	100,519,673	68,746,672
2039	6,592,104	67,551	46,992	-	-	175,000,000	120,000,000	175,067,551	120,046,992	3,660,361	97,208,797	66,657,833
2040	6,660,508	83,249	57,912	-	-	175,000,000	120,000,000	175,083,249	120,057,912	3,556,100	93,478,378	64,099,901
2041	6,783,620	83,249	57,912	-	-	175,000,000	121,000,000	175,083,249	121,057,912	3,482,529	89,883,056	62,147,893
2042	6,903,068	67,551	46,992	29,514	9,837	176,000,000	121,000,000	176,097,065	121,056,829	3,407,548	86,926,463	59,757,055
2043	6,980,578	67,551	46,992	32,197	10,731	176,000,000	121,000,000	176,099,748	121,057,723	3,313,279	83,584,411	57,459,131
2044	6,994,504	67,551	46,992	-	-	178,000,000	122,000,000	178,067,551	122,046,992	3,192,200	81,267,706	55,700,654
2045	7,016,700	67,551	46,992	-	-	178,000,000	122,000,000	178,067,551	122,046,992	3,079,164	78,142,025	53,538,321
Sum	138,729,894	1,580,307	1,099,344	206,058	68,677	3,760,000,000	2,582,000,000	3,761,786,365	2,583,168,021	93,057,381	2,550,967,067	1,751,863,819

- = no tourism impacts estimated..

^aWe found that in sum, the total STS cost over this period will equal \$139 million, increasing from \$5.6 million in 2024 to \$7.0 million in 2045. These assumptions are predicted by an increasing spread rate and a business-as-usual budget scenario. Costs for total human health impacts may be between \$1.1 million and \$1.6 million, tourism utility loss may be between \$69,000 and \$206,000, and WTP may range from \$2.6 billion to \$3.8 billion. The discounted STS program costs will be \$93 million and discounted externalities may range from \$1.8 billion and \$2.5 billion.

Table 8—Scenario D estimates the future with no STS Program, assuming the program ceased to exist in 2024^a

Year	Health (Max)	Health (Min)	Tourism (Max)	Tourism (Min)	WTP (Max)	WTP (Min)	Total Externalities (Max)	Total Externalities (Min)	Discounted Externalities (Max)	Discounted Externalities (Min)
2024	67,551	46,992	28,548	9,515	168,000,000	115,000,000	168,096,099	115,056,507	168,096,099	115,056,507
2025	67,551	46,992	30,909	10,302	176,000,000	121,000,000	176,098,460	121,057,294	169,325,442	116,401,244
2026	67,551	46,992	28,762	9,586	183,000,000	125,000,000	183,096,313	125,056,578	169,282,834	115,621,836
2027	67,551	46,992	-	-	186,000,000	127,000,000	186,067,551	127,046,992	165,413,375	112,944,313
2028	114,218	79,456	-	-	190,000,000	131,000,000	190,114,218	131,079,456	162,510,430	112,047,268
2029	114,218	79,456	-	-	193,000,000	132,000,000	193,114,218	132,079,456	158,725,810	108,559,685
2030	67,551	46,992	-	-	197,000,000	135,000,000	197,067,551	135,046,992	155,745,348	106,729,599
2031	67,551	46,992	-	-	199,000,000	137,000,000	199,067,551	137,046,992	151,274,978	104,144,450
2032	67,551	46,992	35,524	11,840	201,000,000	138,000,000	201,103,075	138,058,832	146,944,047	100,878,236
2033	67,551	46,992	38,743	12,913	205,000,000	141,000,000	205,106,294	141,059,905	144,104,962	99,106,818
2034	114,218	79,456	-	-	209,000,000	143,000,000	209,114,218	143,079,456	141,270,073	96,659,354
2035	114,218	79,456	-	-	210,000,000	144,000,000	210,114,218	144,079,456	136,486,189	93,591,267
2036	67,551	46,992	-	-	212,000,000	146,000,000	212,067,551	146,046,992	132,456,767	91,220,520
2037	67,551	46,992	-	-	216,000,000	148,000,000	216,067,551	148,046,992	129,764,572	88,913,167
2038	67,551	46,992	-	-	222,000,000	152,000,000	222,067,551	152,046,992	128,238,477	87,803,349
2039	67,551	46,992	-	-	223,000,000	153,000,000	223,067,551	153,046,992	123,861,493	84,981,562
2040	114,218	79,456	-	-	229,000,000	157,000,000	229,114,218	157,079,456	122,325,954	83,866,006
2041	114,218	79,456	-	-	233,000,000	160,000,000	233,114,218	160,079,456	119,674,603	82,180,510
2042	67,551	46,992	50,119	16,704	235,000,000	162,000,000	235,117,670	162,063,696	116,060,694	79,999,198
2043	67,551	46,992	48,188	16,060	237,000,000	163,000,000	237,115,739	163,063,052	112,545,189	77,396,642
2044	67,551	46,992	-	-	240,000,000	165,000,000	240,067,551	165,046,992	109,563,696	75,325,293
2045	67,551	46,992	-	-	242,000,000	166,000,000	242,067,551	166,046,992	106,227,375	72,867,000
Sum	1,766,124	1,228,608	260,792	86,919	4,606,000,000	3,161,000,000	4,608,026,916	3,162,315,527	3,069,896,408	2,106,293,845

- = no tourism impacts estimated.

^a The costs to human health would range from \$1.2 million to \$1.7 million, tourism utility loss would range from \$87,000 to \$261,000, and WTP would range from \$3.2 billion to \$4.6 billion. Discounted at a 4 percent discount rate, total externalities would range from \$2.1 billion to \$3.1 billion.

DISCUSSION AND CONCLUSION

Spongy moth was introduced to the Northeastern United States more than 150 years ago. Since then, the moth has been effectively managed by USDA and public collaborators. Spongy moth causes widespread defoliation and mortality of trees, which can result in negative human health impacts, reduced tourism and recreation, industry quarantines, and potential changes to forest tree species composition over the long term. From existing literature, we found that households are willing to pay for public programs that would reduce negative externalities. Findings suggest that the estimated efficiency of the STS Program is similar to that found in Sills (2008), and that continuation of the program under business-as-usual scenarios would result in net positive public benefits.

The purpose of this publication is to provide replicable instructions on how to assess the associated benefits and costs of the STS Program as well as suggestions for future research. The previous two analyses (Leuschner 1996, Sills 2008) bestowed the basic framework for determining scenarios and externalities. In this manuscript, we provided all assumptions, data sources, and instructions for data handling. We also provided some information on the considerations that went into how assumptions were ultimately determined.

The last assessment, conducted by Sills (2008) for the STS Program projected benefits and costs until the year 2026, suggested that the benefit-cost ratio of the STS Program was at least 2. Our updated analysis retrospectively assesses the assumptions and findings from Sills. We found, ex-post, that the benefit-cost ratio of the STS Program was between 1.6 and 2.31, and ex-ante may be between 3.81 and 5.58. The ratio is lower ex-post, since the STS Program budget was significantly higher in earlier years of the program. If a business-as-usual budget is allocated to the STS Program until 2045, we would expect a higher benefit-cost ratio ex-ante. For further comparison, Leuschner (1996)

estimated that the STS Program would provide between \$800 million and \$3.8 billion (in 1990 dollars) in benefits. We estimated a modest ex-post NPV ranging from \$64 million to \$139 million in 2007 dollars, and an ex-ante NPV between \$233 million and \$385 million in 2024 dollars.

The STS Program has been effective at treating recently established spongy moth populations—for example, pushing the area of infestation backward to the northeast over Ohio and North Carolina since 2007. This suggests that the program may be successful in pushing back the population frontier over regions where preferred host species were lacking, where weather was less hospitable, and/or where treatments were more intensive. Findings from Sills (2008) as well as this study suggest that spread is more likely over the Great Lake States and Appalachian regions due to an abundance of preferred host species and weather (Sills 2008), which can be directly observed in Scenario A. Without the STS Program, we would have expected an average flat rate of spread of 19.6 km per year, pushing the infested area in Minnesota to the north and in North Carolina to the south. Thus, while the frontier increased marginally over the last 16 years over the expected regions, the spread would have been significantly greater in the counterfactual.

Similar to Sills (2008), we restricted WTP to those locations with preferred host species. Using the FIA definition of forest land, we excluded urban counties without significant white oak, red oak, or hickory forest composition. Some homeowners or businesses in counties without FIA-defined preferred host species may have planted trees that would be susceptible to spongy moth impacts. This is especially true in urban settings. However, we excluded these counties for two reasons. First, current literature uses survey methods in suburban settings, but those methods do not accurately estimate WTP for urban areas. For example, fewer households in urban settings may be willing to pay for a public program. Perhaps

only those individuals that live closer to urban green space would be willing to pay (i.e., a smaller percentage of total households in the county), but those households may be willing to pay a higher price than previous studies that have focused on suburban settings. More research is necessary on this topic. Second, the restrictions placed on WTP resulted in a reasonable lower-bound estimate for the counterfactual scenarios. More counties were included in the estimation of STS programmatic costs, yet zero value was placed on WTP in counties with low levels of host species or urban settings with WTP that was difficult to measure. This is notable since WTP was the driving factor when estimating benefits and costs in this assessment, as it also was in the Sills (2008) analysis.

Research using hedonic methods has assessed the effects of nonnative invasive defoliator pests on private property values. Holmes et al. (2010) found tree mortality events can result in average property loss between 1.05 percent and 1.6 percent at time of sale. According to the Federal Reserve Bank of St. Louis,⁸ the median sale price of houses sold in the Northeast Census Region of the United States in the first quarter of 2024 was \$835,200. An outbreaking event may result in a decrease of between \$8,769 and \$13,363 from the final sale price. In general, the average length of homeownership is 12 years, which would equate to about \$730 to \$1,113 per year to protect against the risk of an outbreaking event damaging property values. We assumed that 68 percent of homeowners would be willing to pay \$82.88 a year for protection and 39 percent of homeowners would be willing to pay \$120.68 a year in areas where impacts are most likely to occur. This is a significantly lower WTP value than hedonic findings suggest. As previously discussed, future analyses would carefully need to consider the spongy moth context more specifically, since mortality events from spongy moth are significantly lower in frequency than other nonnative invasive pests.

This study included only the externalities reasonably quantifiable. Other spongy moth impacts could be further assessed, including: pecuniary impacts to wood mills and wood markets trade, long-term monitoring of forest ecology changes and co-mortality of host-species from spongy moth defoliation, collection of localized health impact data, econometric analyses of tourism substitution effects, and hedonic pricing methods assessing impacts to private property owners. Further research on these topics could refine benefit-cost analyses in the future.

⁸ <https://fred.stlouisfed.org/series/MSPNE>

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APPENDIX 1

Table A1.1—Data sources and variables used to produce this analysis

Data	Variables used	Source
Ex-post action lines	Area estimations by county in each zone (Monit. 1, Monit. 2, Action)	https://www.slowthespread.org/search?tags=planning
Ex-post trap archive	Trap counts	https://www.slowthespread.org/search?tags=trapping
Ex-post STS costs	BtK, DFB, Gypchek, Mimic cost per acre, and cost per trap	The STS program manager must provide this information.
National Land Cover Database (NLCD)	Deciduous forest cover type	https://www.usgs.gov/centers/eros/science/national-land-cover-database
FIA EVALIDator	Forest type by county "white oak/red oak/hickory," estimated percent of county in preferred host.	https://apps.fs.usda.gov/fiadb-api/evalidator
Google Glimpse	Absolute number of searches, key words "moth rash"	https://meetglimpse.com/
National Park Service	Tourism and recreation visitor counts	https://www.nps.gov/subjects/socialscience/visitor-use-statistics-dashboard.htm
Wood mill locations	Point data for wood mill locations	Forisk Consulting, Wood Mill Database
Lymantria dispar Digest	Suppression and treatment summaries	https://www.fs.usda.gov/science-technology/forest-health-protection/protecting/invasive-species/spongy-moth/lymantria-dispar-digest#:~:text=The%20Lymantria%20dispar%20Digest%20is,treatments%20at%20the%20national%20level.
USA Parks	State park or forest and national park or forest	https://www.arcgis.com/home/item.html?id=e49e181ac82c46edac3ae601ebb3ef2d#overview
National Insect & Disease Risk and Hazard Mapping	Appendix B: other forest pest defoliation and mortality (emerald ash borer and hemlock wooly adelgid)	https://www.fs.usda.gov/science-technology/data-tools-products/fhp-mapping-reporting/national-insect-disease-risk-and-hazard-mapping

APPENDIX 2

Figure A2.1 depicts acres with tree mortality⁹ caused by forest pests in the Eastern United States (USDA Forest Service, Region 9). As shown, emerald ash borer has resulted in 12.5 million acres of Ash (*Fraxinus* spp.) mortality since 2007 (i.e., the first recorded mortality event in the time series). Hemlock woolly adelgid has resulted in 2.1 million acres of tree mortality since 1999, and spongy moth has resulted in approximately 1 million acres of tree mortality since 1997 (Forest Health Protection Aerial Detection Surveys, Region 9).

Spongy moth has damaged (i.e., tree mortality, crown dieback and discoloration, and defoliation) almost 27 million acres since 1997, as compared to emerald ash borer at 15.9 million acres since 2007 and hemlock woolly adelgid at 2.2 million acres since 1999.

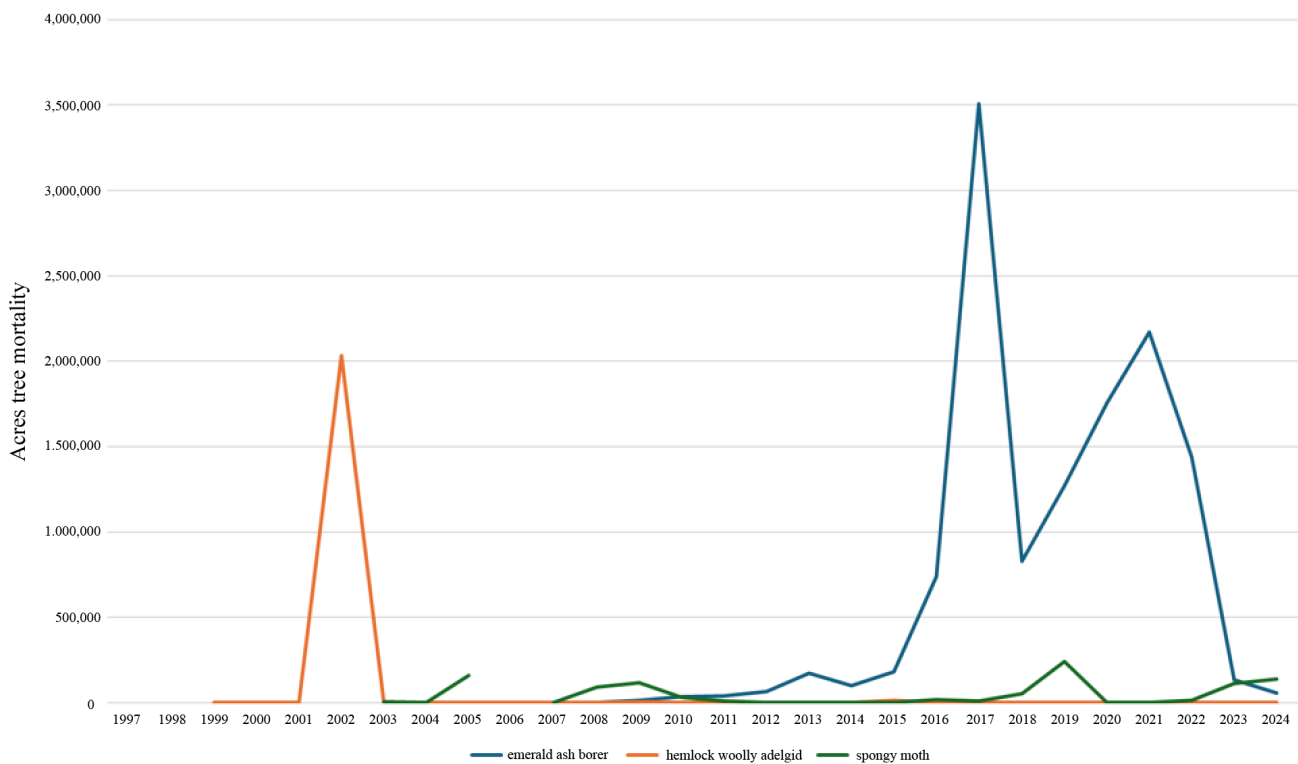


Figure A2.1—The sum of acres with tree mortality from emerald ash borer, hemlock woolly adelgid, and spongy moth from 1997 to 2024. Data via the National Insect and Disease Risk Hazard Mapping, Forest Service.

⁹ Not every tree in an insect and disease survey (IDS) polygon or point is dead, both because forest mortality is rarely uniform and because suitable host trees are usually mixed in with non-host trees, especially in the East. In other words, the IDS data are helpful in showing general geographic footprints of pest activity but less useful for characterizing the degree of impact within those footprints. This becomes even more complicated when the agent is a defoliator like spongy moth with heterogeneous impacts.

APPENDIX 3

Below are the exact calculations for the benefit-cost (B:C) ratio and net present value (NPV). The example provided uses high estimate data from 2007 to 2023. The B:C ratio can be calculated as:

Where:

$$B:C = \frac{(E_0 - E_1)}{C}$$

E_0 = Discounted externalities without the STS Program = \$2,298,063,413.75

E_1 = Discounted externalities with the program = \$2,052,003,871.42

C = Discounted STS Program costs = \$106,712,578.88

$$2.31 = \frac{(2,298,063,413.75 - 2,052,003,871.42)}{106,712,578.88}$$

And the NPV can be calculated as:

$$NPV = C * (B:C - 1) = (E_0 - E_1) - C$$

We already know the B:C ratio, thus:

$$\$139,346,963 = 106,712,578.88 * (2.31 - 1)$$

Or:

$$\$139,346,963 = (2,298,063,413.75 - 2,052,003,871.42) - 106,712,578.88$$

Bruck, S.R.; Sloggy, M.R.; Foster J.R. [et al.]. 2026. Benefit-Cost Analysis of the Slow the Spread Program: An Update Through 2045 Gen. Tech. Rep. SRS–289. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 44 p. <https://doi.org/10.2737/SRS-GTR-289>.

Spongy moth or *Lymantria dispar* (L.) (Lepidoptera: Erebidæ), formerly known as gypsy moth, is a nonnative invasive defoliator pest to the United States. Introduced accidentally to the United States in the 1860s by an amateur entomologist, spongy moth spread quickly and large-scale efforts began soon thereafter to eradicate and limit its population and distribution. The National Slow the Spread (STS) Program, piloted in 1992 and fully implemented in 2000, currently operates in 11 States and monitors a buffer zone that stretches about 100 kilometers from North Carolina to Minnesota. Current management of spongy moth populations consists of large-scale suppression treatments and monitoring along the buffer zone. In this report, we build on previous economic assessments to aggregate the costs of the STS Program from 2007 to 2023 and quantify potential programmatic costs from 2024 to 2045. In addition, we compute the costs and costs avoided to human health, tourism and recreation, and willingness to pay for a public management program with and without the STS Program. We found that from 2007 to 2023, the benefit-cost ratio was between 1.60 and 2.31, and from 2024 to 2045, we expect a return of between 3.81 and 5.58. Findings suggest that continuation of the program under business-as-usual scenarios would result in net positive public benefits.

Keywords: Defoliator pest; economic efficiency; exotic insect; gypsy moth; net present value.



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