Chapter 3

A 20-Year Synthesis of the *Lymantria dispar* Slow the Spread Program

Tom W. Coleman, Christopher J. Foelker, and Travis Perkins

Abstract

For 20 years, the National Slow the Spread (STS) Program has successfully slowed the rate of spread of the non-native spongy moth, *Lymantria dispar* L. (Lepidoptera: Erebidae, formerly known as the "gypsy moth"), to a mean rate of 2.6 km/yr, an 87 percent reduction from its historical rate of spread and surpassing the program's goal of a 60 percent reduction. Because the program has been so successful and the location of the population front has remained in the same general area, state partners have remained fairly consistent during the course of the program. Much of the program focuses on the use of pheromone-baited traps to locate isolated populations along the invasion front, to measure spread, and to adjust program boundaries annually. From 2000 to 2021, a total of >9 million male moths were captured. Annually, a mean of 730 new, low-density, isolated *L. dispar* populations (i.e., "potential problem areas") were detected in the transition area, but only 13 percent were recommended for treatment. The STS Program has treated >3.76 million hectares with mating disruption and larvicides. Ohio, Virginia, and Wisconsin represent the states with the greatest treatments. Mating disruption treatments accounted for 88 percent of the total treatment hectares. Treatment blocks intersected with federal lands and urban areas on 10 and 9 percent of the total hectares, respectively.

Keywords: *Bacillus thuringiensis* var. *kurstaki*, gypsy moth, integrated pest management, mating disruption, pheromone-baited trap, spongy moth

Authors

Tom W. Coleman is an entomologist and the Slow the Spread Program Manager, USDA Forest Service, Forest Health Protection, 200 W.T. Weaver, Asheville, NC 28804, 828-257-4399, tom.coleman@usda.gov.

Christopher J. Foelker is a Forest Pest Survey Unit Supervisor, Wisconsin Department of Agriculture, Trade and Consumer Protection, Madison, WI.

Travis Perkins is an information technology professional, Department of Entomology, Michigan State University, East Lansing, MI.

Citation

Coleman, Tom W.; Foelker, Christopher J.; Perkins, Travis. 2023. **A 20-year synthesis to the *Lymantria dispar* slow the spread program.** In: Coleman, T.W.; Liebhold, A.M., eds. Slow the spread: a 20-year reflection on the national *Lymantria dispar* integrated pest management program. Gen. Tech. Rep. NRS-212. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station: 45–69. Chapter 3. https://doi.org/10.2737/NRS-GTR-212-chapter3.

INTRODUCTION

Since 2000, a broad network of collaborators has implemented the National Slow the Spread (STS) Program to reduce the rate of spread of *Lymantria dispar* L. (Lepidoptera: Erebidae, or spongy moth, formerly known as the "gypsy moth") in the eastern United States (Fig. 1) (Sharov et al. 2002b). These collaborators include 12 state agencies, the U.S. Department of Agriculture, the USDA Forest Service (USDA FS) and Animal and Plant Health Inspection Service (USDA APHIS), university partners, and the Slow the Spread Foundation, a non-profit organization with a board of directors. The USDA National Spongy Moth Management Program incorporates four strategies to reduce to the impact of *L. dispar*; the STS Program is a key component of that national strategy. The 12 participating states comprise three regions [southern region: Kentucky (KY), North Carolina (NC), Tennessee (TN), Virginia (VA), and West Virginia (WV); central region: Illinois (IL), Indiana (IN), and Ohio (OH); and northern region: Iowa (IA), Michigan (MI), Minnesota (MN), and Wisconsin (WI)] to plan and implement STS trapping and treatment programs along the *L. dispar* transition zone (invasion front), which encompasses invaded and uninvaded areas. This paper synthesizes the history of the program boundaries, output from the STS decision algorithm (STS DA) that guides program boundaries and trapping and treatment activities, trapping and treatment accomplishments, and the rate of spread achieved by the STS Program. In instances where complete datasets were unavailable for the full duration of the program, summaries based on partial timelines are provided.

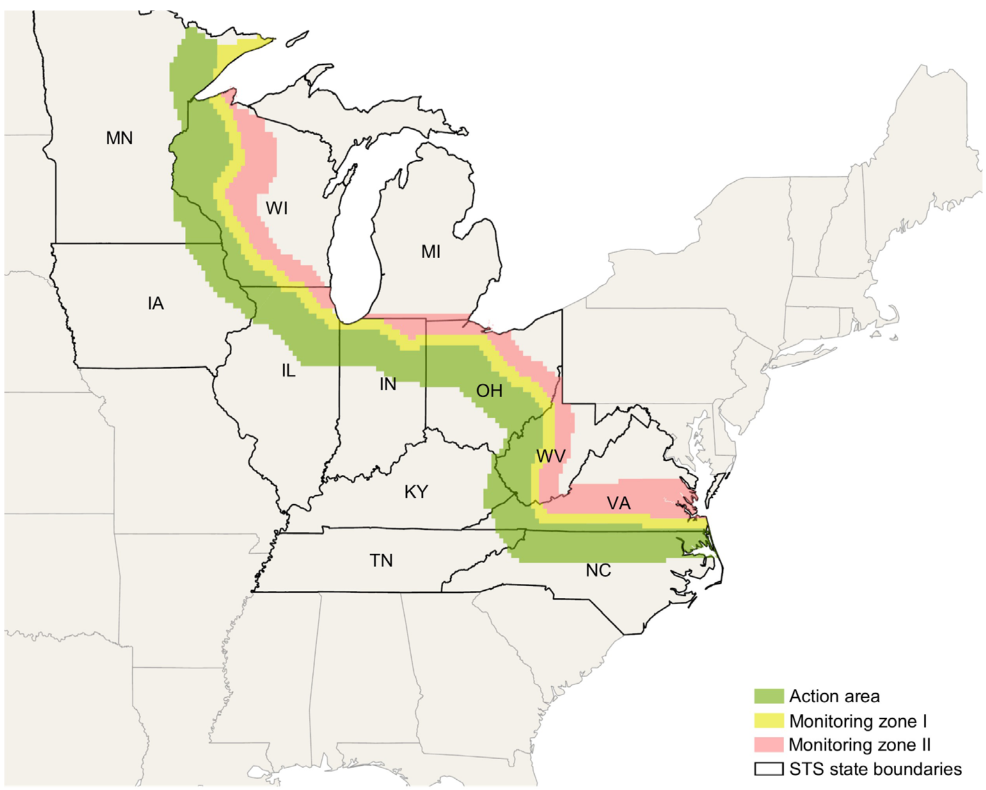


Figure 1.— State partners active in the National Slow the Spread Program in 2020 and the location of the program boundaries: the action area, monitoring zone I, and monitoring zone II.

PROJECT BOUNDARIES

Three distinct monitoring areas (action area, monitoring zone I, and monitoring zone II), each with a network of base trapping grids, comprise the STS project boundaries (Roberts and Ziegler 2007). The action area boundary shifts annually to stay approximately 10 km ahead of the 10-moth line (i.e., the boundary corresponding to where spatially interpolated values of trap capture equal 10 moths/trap) and along the leading edge of the uninvaded area (i.e., the transition zone). Both monitoring zones reside in quarantined, invaded areas. These base trapping grids are annually planned and implemented to detect new populations in the action area and to measure *L. dispar* population growth and spread in the monitoring zones. Additional trapping grids are monitored mostly in the action area to identify new populations, to delimit the extent of these new populations (for the purpose of planning for treatment boundaries), and to evaluate treatment efficacy. Slow the Spread trapping and treatment programs are concentrated in those states (IL, IN, OH, VA, WV, and WI) that reside in the proximal portion of the action area (80 to 100 km wide) (Fig. 2). These states also include a monitoring zone in the generally infested area, which is assessed at two base trapping grid densities: monitoring zone I (approximately 30 to 40 km wide with 5 km trap spacing) and monitoring zone II (approximately 40 to 50 km wide with 8 km trap spacing) (Fig. 2). The two monitoring zones are jointly referred to as the evaluation area. States in the distal portion of the action area (IA, KY, MN, NC, and TN) generally catch and treat fewer *L. dispar* populations because of the predominantly natural, short-distance spread [i.e., stratified dispersal model (Hengeveld 1989, Liebhold et al. 2007)] of *L. dispar* populations from generally infested areas. Due to the success of the program, the STS Program boundaries remain within most of the original state partners (IL, IN, NC, OH, VA, WV, and WI) (Fig. 2). The only state to exit the STS Program has been Michigan, which left when the transition area moved through the Upper Peninsula into northern Wisconsin. No new states have joined since Tennessee in 2013 (Coleman et al. 2023, this report page 28).

The National STS Program was initially implemented as optimized (Sharov and Liebhold 1998). At the start, implementation included a 100 km wide action area with a base trapping grid at 2 km spacing and a 70 km wide evaluation area with more widely spaced traps. In response to the first decline in federal funding of approximately $1.7 to $1.9 million (Coleman et al. 2023, this report page 28), the program responded by shifting the boundary between the action and evaluation areas to decrease the area included in the action area. The width of the action area was decreased to 90 km in 2007, 80 km in 2008, and back to 90 km in 2009, and the width of the evaluation zone was increased to reflect the lost width of the action area (Tobin 2008). These reductions reduced the total number of traps deployed and reduced overall costs (Table 1). In 2010, the action area width was expanded to the original 100 km because increased rates of spread were documented in the portions of the action area that had been excluded from treatment activities. From 2012 to 2013, when federal funding declined again, a different strategy was used. During that season, the base grid trap spacing in the action area was increased from a 2 km to a 3 km spacing (Table 1), but the wider trap spacing was ineffective for detecting newly established populations. As a result, in 2014 the base grid trap spacing was reverted to 2 km in the proximal 50 km of the action area and 3 km in the distal 50 km to facilitate detecting new populations and to address increasing monitoring costs. Ultimately, the 50:50 split of the base grid trap spacing has eliminated approximately 15,000 traps in the action area, saving the program approximately $1.17 million annually in monitoring

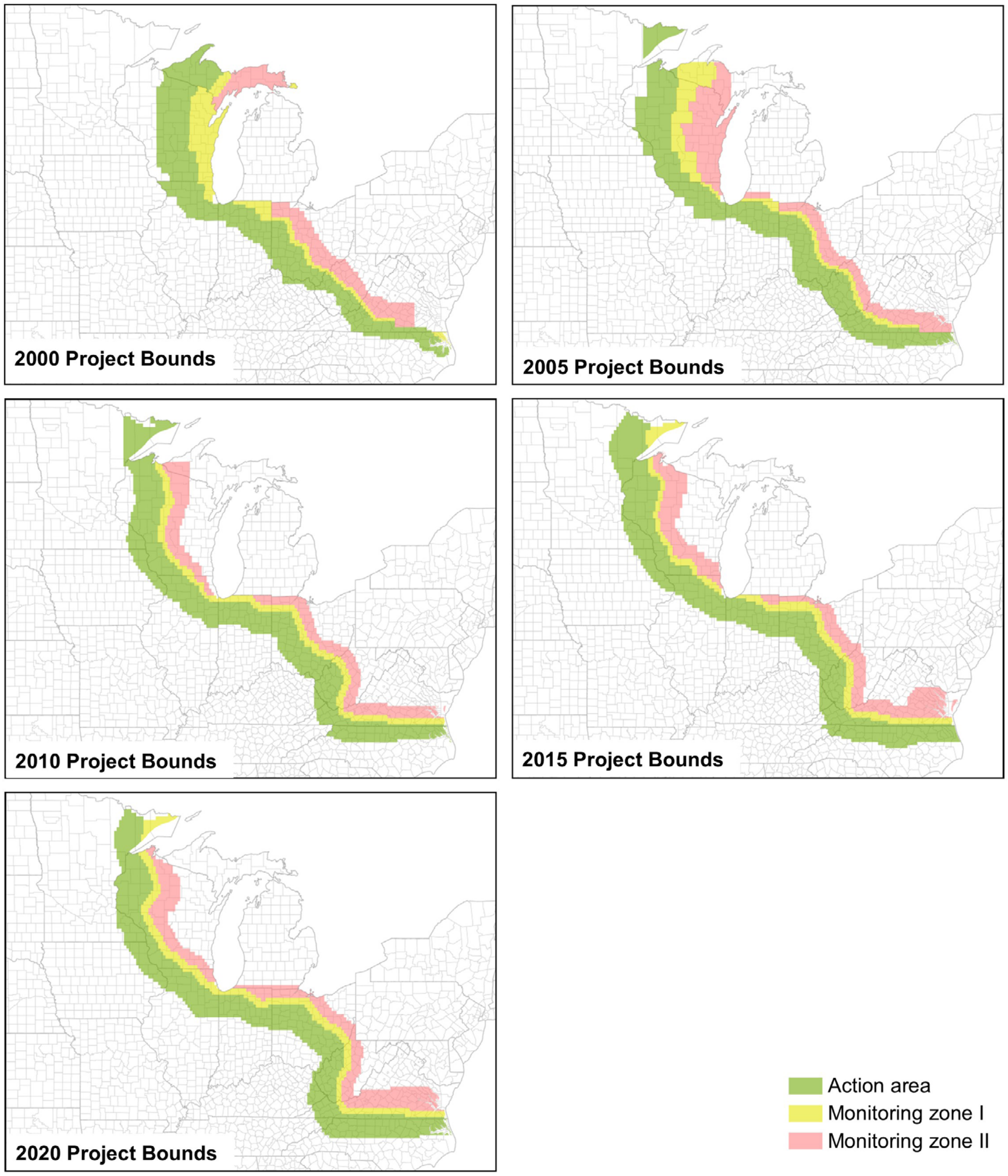


Figure 2.— Program boundaries: the action area, monitoring zone I, and monitoring zone II, of the National Slow the Spread Program in five-year increments from 2000 to 2020.

costs while not measurably impacting the efficacy of the program. The proximal edge of the action area increased in length from 2,157 km in 2000 to 2,771 km in 2020, representing a 27 percent change in advancements and retractions along the infested front (Fig. 2). The trap spacing grid of the evaluation zone (either 5 km or 8 km spacing) has not changed since the start of the program (Table 1). Some states use the equivalent English measurement in the action area, monitoring zones, and delimit-trapping grids to better align with roads for trap placement.

Table 1.—National Slow the Spread Program boundaries (action area, monitoring zone I, and monitoring zone II) planned from 2000 to 2020

Year	Action area width (km)	Action area trap spacing (km)[a]	Monitoring zones I and II width (km)	Monitoring zone I trap spacing (km)	Monitoring zone II trap spacing (km)
2000–2006	100	2	70	5	8
2007	90	2	80	5	8
2008	80	2	90	5	8
2009	90	2	80	5	8
2010	100	2	70	5	8
2011	100	2	70	5	8
2012	100	3	70	5	8
2013	100	3	70	5	8
2014–2020	100	2, 3[b]	70	5	8

[a] Equivalent English system used for trap spacing in Wisconsin, Minnesota, and Illinois. Some states have used narrower trap spacing in urban areas and as base trapping grids in the action area (i.e., 2 mile action area in Wisconsin and 1 km spacing in some Minnesota urban areas).

[b] The base trapping grid in the action area was split in half with traps in the proximal 50 km spaced at 2 km and traps in the distal 50 km spaced at 3 km in the second 50 km with the tighter trap spacing toward the quarantine area.

TRAPPING

Between 2000 and 2020, the STS Program has planned 1,487,460 traps (base trapping grids and delimits) across its boundaries and placed a total of 1,436,972 traps (97 percent). The program has monitored a mean (±s.e.) of 67,755 (±3,553) traps annually, with the highest number of traps monitored in 2005 (86,250) and the lowest in 2013 (46,403) (Fig. 3). The variations in these trap numbers correspond to periods of peak program funding and changes in the base trapping grid spacing, respectively (Table 1). In the evaluation zone (monitoring zones I and II), 5,386 (±531) traps were monitored annually. Total trap numbers since 2000 were 1,323,866 (2001–2020) for the action area and 113,106 (2001–2020) for the monitoring zones. Seven states (IA, IN, IL, OH, NC, KY, and VA) use the STS protocols and the centralized database to collect and monitor data from *L. dispar* detection traps deployed in the uninfested area for detection purposes. Positive trap catch data from the uninfested area were provided either to the USDA Forest Service or Animal and Plant Health Inspection Service for additional delimiting and potential eradication efforts. Although these data are displayed on the STS website, they are not included in this assessment because they are outside of the STS Program.

From 2000 to 2020, the mean annual number of pheromone-baited traps [(+)-disparlure, (7R,8S)-cis-7,8-epoxy-2-methyloctadecane, Scentry Biologicals Inc., Billings, MT)] monitored by the STS Program was similar among the three regions [southern: 22,153 (±1,369); central: 26,000 (±1,520); and northern: 25,737 (±1,411)]. The mean annual count of base grid traps monitored in the action area from 2001 to 2020 was also comparable across the three regions [mean southern: 15,198 (±1,404); central: 17,139 (±1,472); and northern: 17,115 (±1,297)], whereas the total count of base gird traps in the action area was comparable only in the central (342,784) and northern (342,317) regions and much

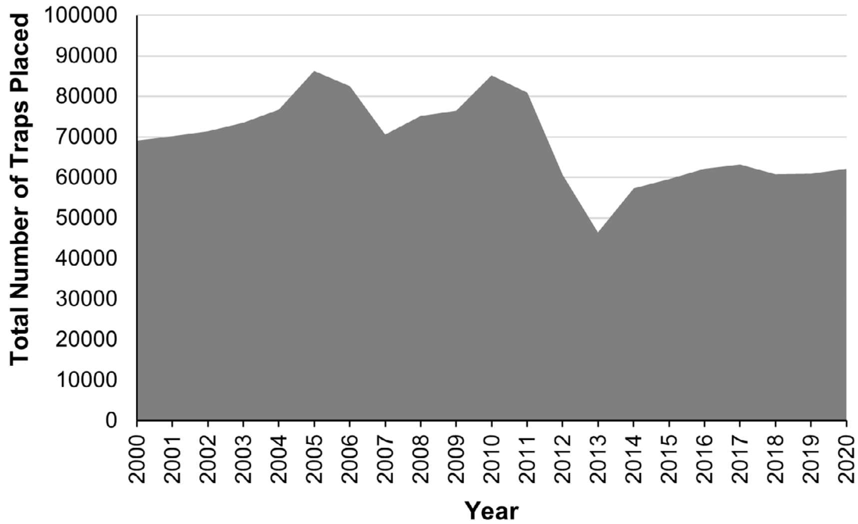


Figure 3.—Total number of traps placed annually from 2000 to 2020 in the National Slow the Spread Program.

lower in the southern region (303,974). The same trend was observed for the mean annual count of delimiting-traps monitored across the three regions [central: 3,768 (±253); northern: 5,001 (±337); and southern 1,712 (±214)]. These differences may be attributed to the fact that few potential problem areas (PPAs), that is, new, low density, isolated populations in the transition zone (Tobin et al. 2007), identified by the STS DA have been found in the southern region, and only a limited number of treatments have been conducted there (KY, NC, TN, and WV). However, Ohio and Wisconsin annually address numerous PPAs in the central and northern regions. To delimit newly detected, low-density, isolated populations, additional traps were placed in a 1 km grid spacing (185,956) or in a 500 m grid spacing (99,321) or in 250 m grid spacing (6,354). Evaluation area traps (monitoring zones I and II) were more prevalent in the southern [5,094 (±846)] and central regions [5,031 (±819)] than the northern region [3,351 (±528)]. This difference can likely be attributed to the larger geographical area covered by the central (three states with evaluation areas) and southern (two states with evaluation areas) regions when compared to the northern region (one state with an evaluation area).

From 2001 to 2020, a total of 9,746,980 male moths were captured in traps in the STS Program, with the majority of moths (92 percent) caught in milk carton traps and 8 percent obtained from delta traps (Scentry Biologicals Inc., Billings, MT). Milk carton traps are the standard in the evaluation area and certain delimit-trapping grids. Capable of catching hundreds of moths, these traps are used in areas with high trap catches. Because the efficiency of delta traps deteriorates in trap captures >12 males (Elkinton 1987), delta traps are generally used in areas where either low trap catches are expected (<12 moths) or <5 moths were caught the previous year. Delta traps are used primarily in the base trapping grids in the action area and most delimits. On average, from 2010 to 2020 a total of 60,771 (±15,017) moths were trapped annually in the action area, 95,535 (±18,020) moths were trapped annually in the monitoring zone I, and 123,086 (±10,926) moths were trapped annually in the monitoring zone II. During this period, a mean of 0.80 (±0.22) moths/trap/year were collected in the action area, 19.7 (±2.01) moths/trap/year were collected in the monitoring zone I, and 76.3 (±4.74) moths/trap/year collected in the monitoring zone II.

Counties in central Wisconsin, northeastern Illinois and Indiana, southcentral Ohio, southern West Virginia, and western Virginia had continually high *L. dispar* trap catches in either the action area or evaluation area (Fig. 4). Although counties with high trap catches contained areas with more contiguous forest canopy cover and a higher proportion of host composition, and forest composition was incorporated into the decision-making process for the Maryland Integrated Pest Management Project (MD-IPM) (Reardon et al. 1993), additional confirmation studies are needed. Counties with higher trap densities located in southcentral Ohio represent formerly *L. dispar*-invaded areas, where STS treatments have successfully eliminated the populations and caused the transition zone to retreat from this area (Fig. 4). Counties located within the action area since the start of the STS Program generally show lower levels of total trap catches (10 to 5,000). However, *L. dispar* has been trapped in all counties in the STS Program and in many adjacent counties (Fig. 4), highlighting its ability to disperse into diverse landscapes (e.g., agricultural, urban, and forested). The capture of males in some of these areas may not indicate the local presence of reproducing populations but rather dispersal of males into these regions (Tobin and Blackburn 2008).

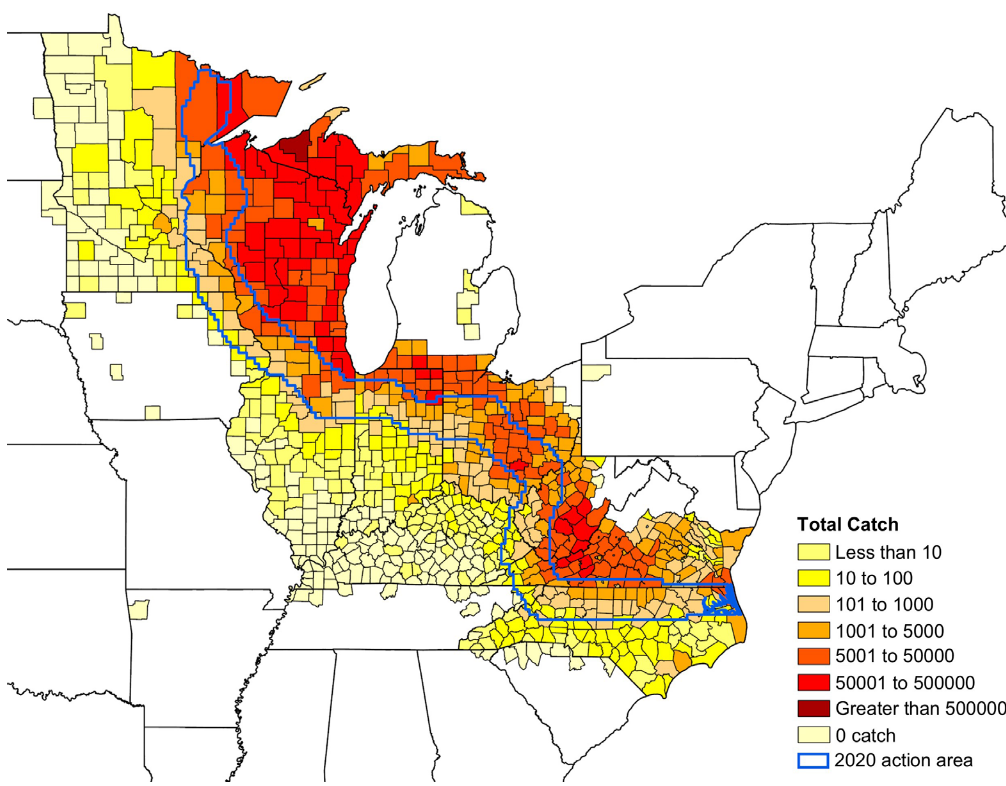
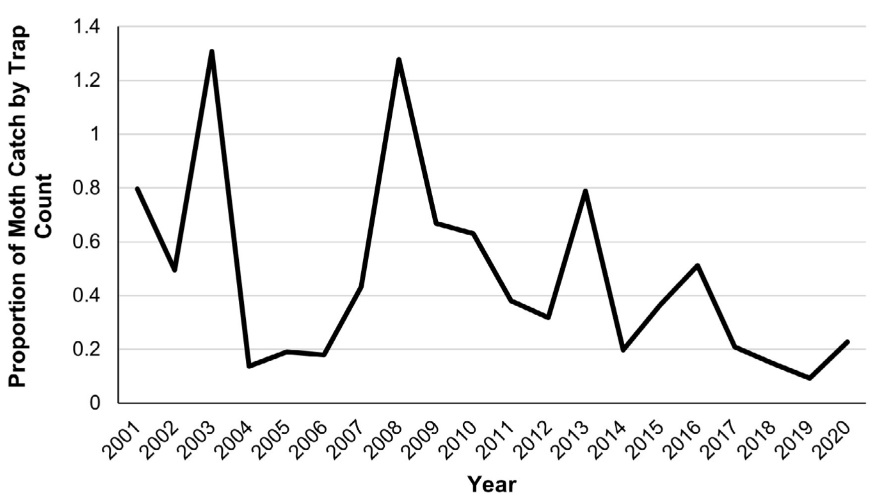


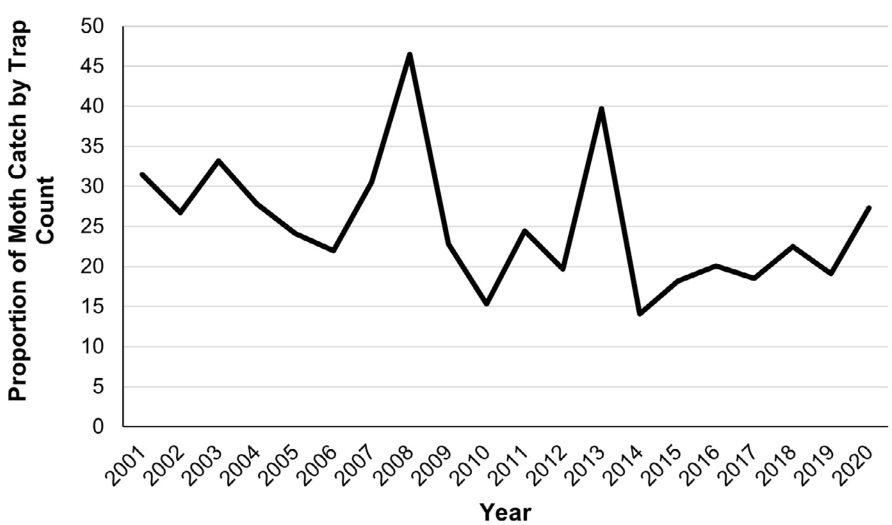
Figure 4.— Cumulative *Lymantria dispar* trap catch by county in the National Slow the Spread Program.

Across all monitoring areas, mean trap catch for milk carton traps was 32.1 (±3.51), and mean trap catch for delta traps was 0.45 (±0.08). The count of male moths caught per trap per year was variable from 2001 to 2020 for the action area and the evaluation area (Fig. 5A, B). The collection of male moths/trap/year peaked during three periods (2003, 2008, 2013) for both trap types, but these peak periods of trap catch do not correspond to extensive *L. dispar* outbreak years in infested areas (Fig. 5C) (USDA FS 2021). The number of male moths/trap has been in a general decline in the program from 2001 to 2020.

A



B



C

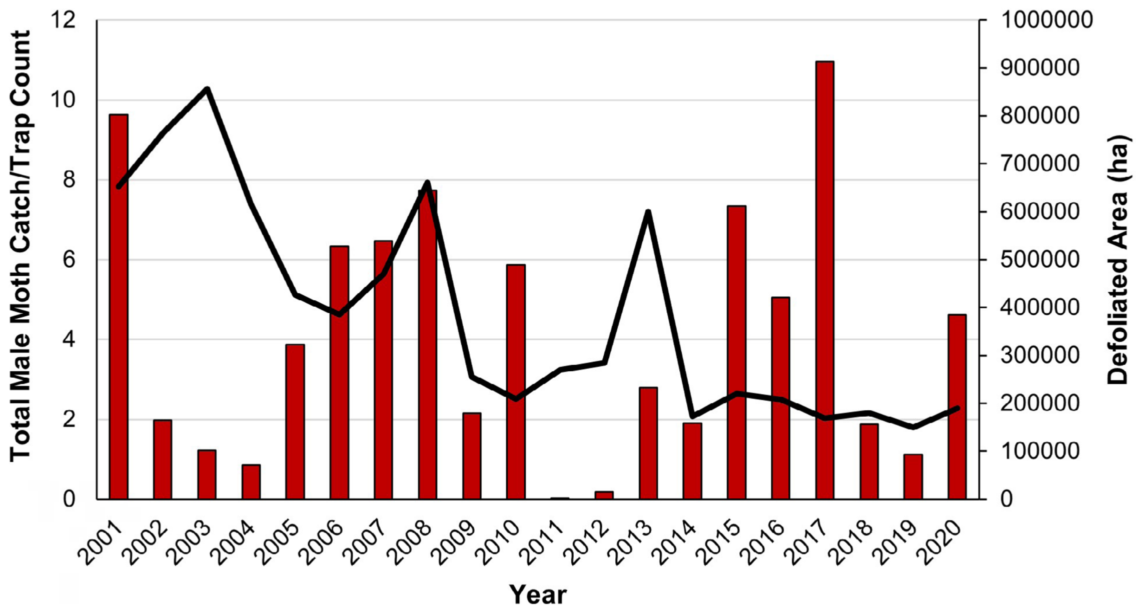


Figure 5.— Proportion of *Lymantria dispar* male moth catch by trap count from 2001 to 2020 for delta traps (A), milk carton traps (B), and both trap types (C). *Lymantria dispar* defoliation data (ha) recorded from aerial detection surveys was added for both trap types (USDA FS 2021).

The mean cost of setting a trap, potentially conducting a mid-season check on a trap, and retrieving a trap, including project overhead and costs associated with the centralized database, from 2000 to 2020 was $66.96 (±2.93). Trapping costs generally increased during the two decades of work, with the lowest trap cost occurring in 2001 ($47.00) and the highest trapping cost occurring in 2020 ($101.42). Annually, there are approximately 200 trap leaders and trappers to implement the program. Monitoring costs continue to account for nearly 60 percent of the annual budget (Coleman et al. 2023, this report page 28).

Trapping data are the foundation of the STS Program and guide management activities. As a result, quality assurance-quality control (QA-QC) standards for the trapping program were implemented and have been assessed annually since 2001 (Roberts and Ziegler 2007). Lead trappers and program managers conduct QA-QC checks on traps and use the STS trapping software to upload information into the centralized database (Coleman et al. 2023, this report page 28). An annual report is developed by the STS Information Systems Group and submitted to the board of directors.

The program strives to account for 100 percent of the planned trapping locations in the database as deleted, omitted, or placed. From 2001 to 2020, a mean of 0.03 (±0.01) percent traps were unaccounted for in the database. The number of unaddressed trapping nodes in a year ranged from 0 to 95 traps over the two decades of work. A mean of 2,506 (±291) traps were omitted annually, representing a 3.38 (±0.30) percent omission rate and surpassing the program goal of setting 95 percent of planned traps. The predominant reasons for omitting traps were the following: the site was too wet; an obstacle prohibited access to the site; rough, steep terrain; thick vegetation; no structure for a trap; or a landowner denied access. The program also strived to inspect at least 10 percent of the traps in a state, with QA-QC checks conducted by state and federal personnel. Annually, 8,869 (±357) traps or 12.9 (±0.50) percent of the traps were evaluated following QA-QC guidelines. Trap inspections had an exceptionally high passing rate [mean of 98.8 (±0.14) percent]. The primary reasons traps failed inspections were the following: the trap information was not recorded correctly on the trap; the trap was assembled incorrectly; the trap was too far from the node; directions to the trap location were wrong; the record was filled out, but no trap was set; or the trap was hung too low.

From 2009 to 2020, QA-QC assessments included an evaluation of traps placed within a defined distance of a trapping node, trap placement and removal dates, and compliance with the STS DA. Over 12 years, a mean of 91.7 (±1.17) percent of traps were placed within the target distance of a trapping node, falling short of the 95 percent goal. However, the goal of placing traps within a certain target circle was achieved from 2018 to 2020, surpassing 95 percent for traps in the target circle. Technological advances and adoption of trapping protocols (i.e., all states moved to a digital platform) across the entire program likely led to the improved trap set accuracy. Traps were placed outside the defined target circle in the greatest numbers in 2012 (15.5 percent were outside the target circle). Trap placement and removal aligned 97.2 percent (±1.62) of the time with the period of moth flight predicted by BioSIM, a *L. dispar* phenology model linked with raster climatic data (Régnière et al. 2017). BioSIM projections have been used to help plan trap deployment, trap retrieval, and treatment timing since 2008 (Fig. 6). Alignment between the STS DA recommendations and actual management action taken for treatments and delimits was 86.2 percent (±2.74) and 87.5 percent (±3.64), respectively, indicating the STS DA is a useful model in guiding and prioritizing decision-making processes.

DECISION ALGORITHM

The STS DA assists program managers in identifying new, isolated *L. dispar* populations (i.e., PPAs) located in the transition zone and providing a recommendation for a management action (e.g., do nothing, delimit, post-treat delimit, or treat) using a geospatial and trap catch based assessment process (Tobin and Sharov 2007). The total number of PPAs identified since 2000 was 15,348 with a mean annual number of 730 (±43.8). The northern region [mean 311 (±32.5), 6,541 total] had more PPAs than the central [mean 252 (±9.29), 5,299 total] and southern [mean 167 (±10.6), 3,508 total] regions. The mean number of PPAs across the three regions has been in a general decline since 2011, with the highest number of PPAs occurring from 2009 to 2011 (Fig. 7). The STS DA was altered in 2012 to address PPA geometry (i.e., smooth the action area along the transition zone), to end the creation of independent action PPAs, and to correct issues with priority indices, which may account for some of the reductions in PPA numbers.

The STS DA has detected PPAs across the entire STS Program (Fig. 8); however, certain areas have experienced *L. dispar* population growth that has been particularly intense. These include areas near central and southern Wisconsin; urban areas near Ft. Wayne, Indiana and Columbus, Ohio; southern Ohio; and western and southcentral Virginia. The intense population growth has often resulted in additional trapping and treatments that have reduced *L. dispar* population growth and also slowed moth spread. Recommendations of “do nothing” from the STS DA were higher (44 percent) when compared to other PPA recommendations [delimit (27 percent), independent (6 percent), post-treatment delimit (9 percent), and treat (13 percent)] (Table 2). In the early years of the program, managers added management actions into the database independent of the STS DA decision-making process. These independent recommendations are no longer used or tracked in the database.

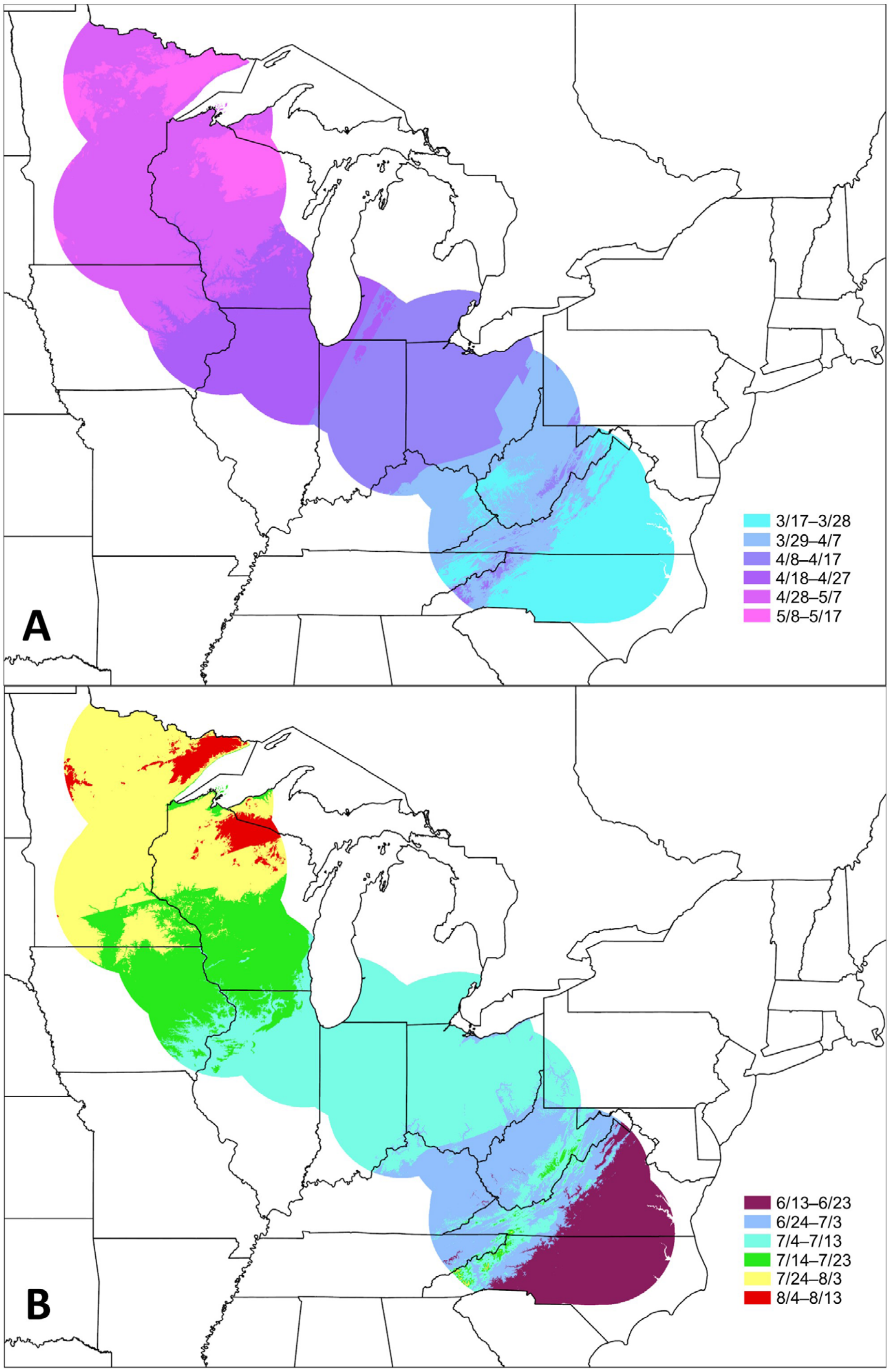


Figure 6.— BioSIM model projections (30-year average) for egg hatch (5 percent, A) and adult male moth flight (5 percent, B) for the National Slow the Spread Program (Régnière et al. 2017).

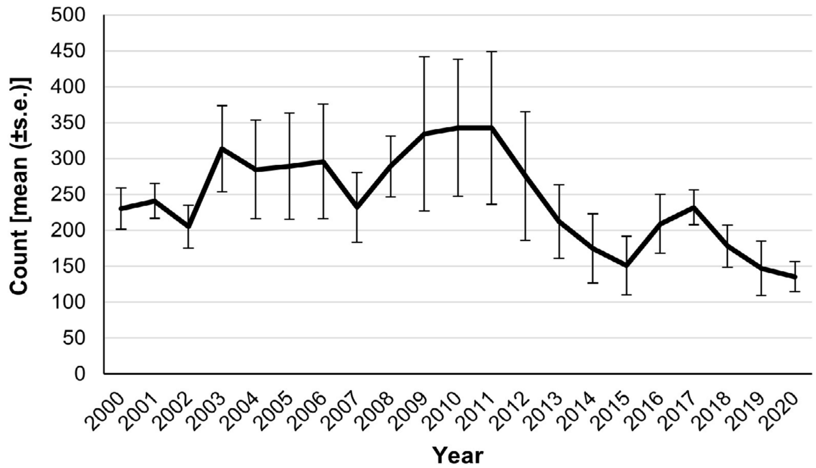


Figure 7.— Mean (±s.e.) count of potential problem areas (PPAs) from 2000 to 2020 across the three regions in the National Slow the Spread Program.

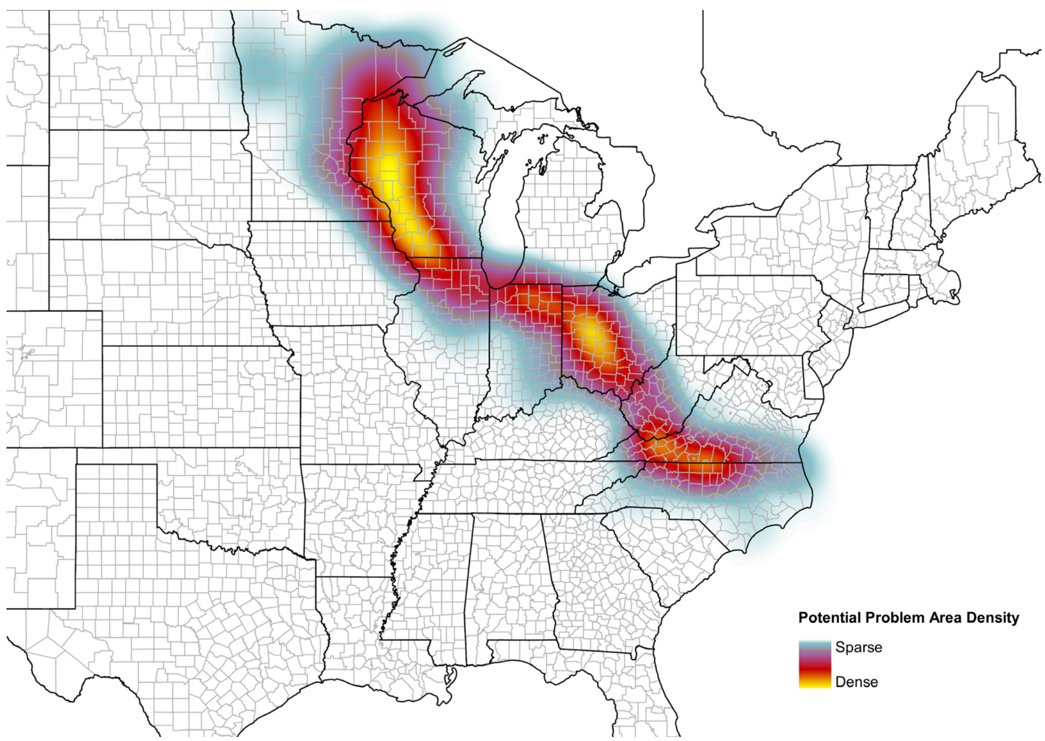


Figure 8.— Smoothed density of potential problem areas (PPAs) from 2000 to 2020 defined by the National Slow the Spread Program decision algorithm. These areas are identified by higher percentile of trap catches than the surrounding area and incorporate four indices. Potential problem areas represent isolated, low-density populations in the transition area.

Table 2.—Mean (±s.e.) count, distance from infested area, maximum previous year trap catch, and current year trap catch for recommended management actions from 2000 to 2020 by the National Slow the Spread Program decision algorithm

Management recommendation	Count	Distance from infested area (km)	Maximum previous trap catch	Maximum current trap catch
Delimit	147 (±10.6)	43.0 (±2.81)	28.2 (±3.81)	42.2 (±4.68)
Do nothing	362 (±31.6)	18.4 (±3.64)	16.6 (±2.01)	28.2 (±2.82)
Independent	179 (±26.4)	86.8 (±2.51)	4.36 (±0.58)	0.89 (±0.18)
Post-treatment delimit	62.6 (±11.7)	30.6 (±3.46)	6.01 (±4.59)	0 (±0)
Treat	66.2 (±3.53)	45.2 (±2.59)	48.0 (±6.28)	91.6 (±7.30)

Table 3.—Mean (±s.e.) count (A), maximum previous year trap catch (B), and maximum current year trap catch (C) for management recommendations from the decision algorithm in the three regions of the National Slow the Spread Program from 2005 to 2020; percentages represent proportion of management recommendations by region

Parameter	Management recommendation	Southern region	Central region	Northern region
A. Count	Delimit	36.2 (±3.43) 28%	56.3 (±2.35) 27%	54.8 (±6.86) 22%
	Do nothing	84.1 (±11.7) 42%	127 (±8.99) 45%	152 (±23.3) 42%
	Independent	16.9 (±5.14) 6%	34.3 (±5.57) 6%	131 (±34.8) 22%
	Post-treatment delimit	14.1 (±2.37) 7%	32.8 (±5.43) 9%	29.2 (±7.16) 6%
	Treat	20.3 (±2.24) 17%	27.9 (±1.61) 13%	18.0 (±2.05) 8%
B. Maximum previous trap catch	Delimit	40.1 (±8.17)	31.1 (±6.51)	21.3 (±8.12)
	Do nothing	24.3 (±6.48)	17.7 (±3.03)	13.5 (±2.02)
	Independent	7.64 (±6.29)	3.12 (±1.79)	4.37 (±0.43)
	Post-treatment delimit	10.8 (±8.45)	5.35 (±4.03)	1.77 (±1.17)
	Treat	54.8 (±12.4)	58.8 (±7.92)	25.4 (±6.96)
C. Maximum current trap catch	Delimit	47.7 (±9.22)	52.5 (±8.06)	31.0 (±8.43)
	Do nothing	39.1 (±5.53)	25.9 (±2.77)	26.8 (±4.33)
	Independent	0.65 (±0.22)	0.44 (±0.56)	1.09 (±0.06)
	Post-treatment delimit	0 (±0)	0 (±0)	0 (±0)
	Treat	83.9 (±16.3)	111 (±12.5)	79.2 (±22.2)

Across the three regions, the mean count of recommendations was greatest for "do nothing" in each region (Table 3A). Recommendations of "delimit" ranged from 22 to 28 percent across the three regions, and "treat" ranged from 8 to 17 percent. Delimit-trapping grids from 2000 to 2020 extended across the transition area, with lower numbers of delimit grids along the Illinois and Indiana border, eastern West Virginia, and eastern Virginia and

North Carolina (Fig. 9). The border of Illinois and Indiana is dominated by agriculture, and suitable hosts are sparse and highly fragmented. *Lymantria dispar* populations rarely establish and are comparatively easy to contain if detected in these highly fragmented landscapes. In eastern West Virginia, many hypotheses have been proposed for the lack of increasing populations (e.g., lack of preferred host type, increased summer temperatures, rolling topography), although none have been adequately tested. A higher number of delimit-trapping grids occurred in central and southern Wisconsin; the metropolitan areas of Duluth and Minneapolis, MN; Chicago, IL; Ft. Wayne, IN; southern Ohio, including Columbus; and western and southcentral Virginia. Although the southern region had the least number of PPAs compared to the central and northern regions, the distribution of the recommendations was comparable across the three regions (Table 3A). The northern region had generally lower maximum previous year and current year trap catches in PPAs when compared to the other regions (Table 3B, C). Program managers have often taken a more aggressive approach against populations in Wisconsin when compared to the other regions because low trap catches have a higher likelihood of persisting in subsequent years (Whitmire and Tobin 2006). The program continues to discuss adjusting the STS DA to address this issue, but changes have not yet been implemented.

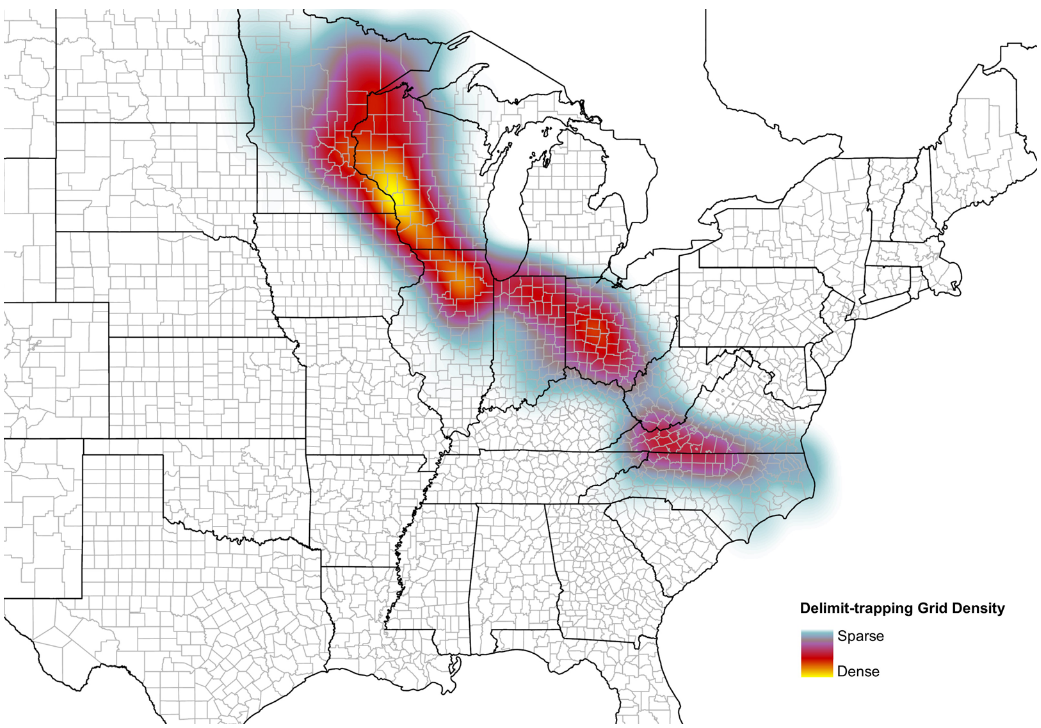


Figure 9.—Smoothed density of delimit-trapping grids monitored from 2000 to 2020 in the National Slow the Spread Program. Traps located to the west and south of the program area represent *Lymantria dispar* detection traps for eradication efforts.

TREATMENTS

The STS Program has treated 3,760,681 ha since 2000 (Table 4). An additional 90,194 ha were treated during the STS Pilot Project (Coleman 2023, this report), bringing the total to 3,850,793 ha for STS programs. Mean annual planned treatment hectares [163,018 (±8,475) from 2006 to 2020] was lower than the mean annual accomplished treatment hectares by 9 percent [178,818 (±10,778) from 2000 to 2020]. This increase in treatment area generally resulted from underestimating the treatable forested area in mating disruption blocks. The most treatment hectares were accomplished in 2004 (268,695) and the least in 2019 (120,201). The mean area covered by the STS action area from 2000 to 2020 was 23,206,212 (±536,837) ha. Each year, treatments targeted newly established populations in the transition area and covered only a mean 0.8 percent of the STS action area land area.

Table 4.—Area treated (ha), primarily by aerial applications, from 2000 to 2020 by the National Slow the Spread Program

	Biological pesticides		Insect growth regulator		Mating disruption			
Year	*Bacillus thuringiensis* var. *kurstaki (Btk)*	Nucleopolyhedrosis virus (Gypchek)	Diflubenzuron	Tebufenozide	Hercon® Disrupt® II[a]	SPLAT[b]	Hercon Bioflakes	Total
2000	34,082	0	0	0	37,890	0	0	71,972
2001	25,252	0	263	0	86,170	0	0	111,685
2002	11,617	0	1,594	0	219,587	0	0	232,798
2003	28,519	2,760	0	0	224,391	0	0	255,670
2004	53,129	3,331	0	0	212,241	0	0	268,701
2005	43,954	6,910	320	0	116,507	0	0	167,692
2006	38,794	2,834	4,975	0	172,456	0	0	219,058
2007	23,278	1,533	39	0	147,674	0	0	172,524
2008	18,311	45	0	0	140,703	8,288	0	167,348
2009	14,636	123	0	0	114,059	40,805	0	169,623
2010	23,880	1,884	0	0	140,328	49,267	0	215,359
2011	17,376	1,043	0	0	185,631	8,854	0	212,903
2012	12,646	1,152	0	0	202,189	4,346	0	220,333
2013	11,132	1,818	0	26	153,272	0	0	166,248
2014	8,531	1,945	0	0	157,952	9,756	0	178,184
2015	8,989	849	0	0	188,108	9,993	1,214	209,153
2016	9,521	413	0	7	150,744	18,187	4,128	183,000
2017	13,790	0	0	0	152	137,523	0	151,465
2018	11,072	151	0	0	0	135,431	0	146,655
2019	15,526	45	0	0	0	104,633	0	120,204
2020	9,636	409	0	0	0	110,061	0	120,106
Total	433,671	27,245	7,190	33	2,650,056	637,144	5,342	3,760,681

[a] Hercon® Disrupt® II and Bioflakes® (Hercon Environmental, Emigsville, PA)

[b] SPLAT (ISCA Technologies, Riverside, CA)

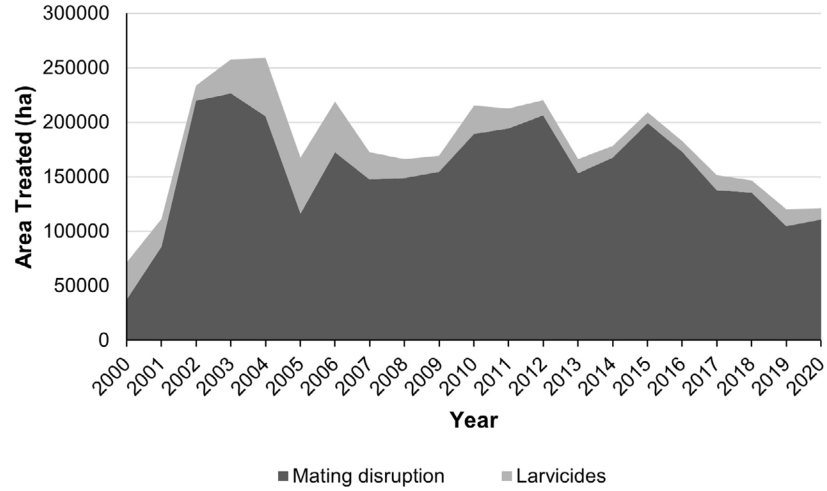


Figure 10.— Total area (ha) treated by the National Slow the Spread Program. Larvicide applications have remained fairly consistent since 2012. Mating disruption hectares have declined since 2015.

Overall, STS treatments have been in a modest decline since 2015 (Fig. 10). The annual decreases are due primarily to reductions in funding from the federal government for the STS Program, and each winter an estimated $100,000 to $300,000 of planned treatments have been eliminated in order to balance the annual program budget. Ultimately, these reductions do not appear to have severely affected the program's success. The program annually treated a mean 22,292 (±3,089) ha with larvicide treatments [*Bacillus thuringiensis* var. *kurstaki* (*Btk*), nucleopolyhedrosis virus (NPV, Gypchek), and insect growth regulators]. Peak larvicide treatment hectares occurred in 2004 (56,458 ha), and the lowest larvicide treatment hectares occurred in 2015 (9,838 ha) (Table 4). The hectares of larvicide applications often include two applications on the same treatment block footprint. In addition, the program annually treated a mean of 156,784 (±10,423) ha with a mating disruptant. The most mating disruption hectares occurred in 2003 (226,685 ha), and the fewest occurred in 2000 (37,888 ha) as the program was transitioning to a national program (Table 4). Mating disruption applications are always applied as a single application per treatment block.

Larvicide applications (468,139 ha) accounted for 12 percent of the total treatments. Mating disruption applications (3,292,542 ha) represented 88 percent of the total. These treatments were overwhelmingly applied aerially by either fixed- or rotary-wing aircraft. The fraction of treatment areas that used larvicide applications has been in a general decline since 2004 and likely results from the advancement, reduced cost, and efficacy of mating disruption applications (Onufrieva 2023, this report), as well as declining program budgets and more effective treatment planning. For 2001 and 2006 through 2020, the mean treatment block size was 241 (±14.5) ha for *Btk* (double applications), 180 (±21.8) ha for *Btk* + mating disruption blocks, 124 (±91.9) ha for Diflubenzuron blocks (double applications), 10.9 ha for Tebufenozide (double applications), 6.9 (±0) ha for Tebufenozide + mating disruption, 167 (±23.1) ha for NPV (double applications), and 162 (±54.2) ha for NPV + mating disruption. The mean treatment block size was 2,029 (±113) ha for mating disruption applications (single application). The larvicide + mating disruption treatments represented a single application of each with the larvicide typically applied to a dense population core. Current management guidance suggests using larvicide applications in areas with either >60 moths/trap or where other *L. dispar* life stages (e.g., egg masses, pupae, pupal cases) are detected. Mating disruption applications are implemented in areas with <60 moths/trap and are preferred over larvicide applications because of the specificity to *L. dispar.* Hercon® Disrupt® II (Hercon Environmental, Emigsville, PA) was the primary mating disruption product used in the operational blocks from 2000 to 2016 (Table 4). However, SPLAT GM-Organic (ISCA Technologies, Riverside, CA) replaced the use of Hercon® Disrupt® II because it is biodegradable and certified organic by the USDA, and because it has an easier loading and application process. SPLAT GM-Organic has been used exclusively in the program operational treatment blocks since 2017. Hercon Environmental developed a biodegradable mating disruption flake formulation, Hercon® Bioflakes®, that was approved for program use (Onufrieva 2023, this report) but only had limited use (2015–2016) before the product registration was discontinued (Table 4).

A total of 3,174 low-density, isolated populations, or PPAs, were treated since 2000. The mean annual number of PPAs treated were 151 (±8.48), which is 1.3 times greater than the mean number of "treat" recommendations from the STS DA (Table 2). The STS Program treated the largest number of populations in 2004 (210) and the lowest (98) in 2008. The northern region had the greatest annual total treatment hectares [88,234 (±8,181) ha], followed by the central [45,749 (±4,719) ha] and southern [45,092 (±5,000) ha] regions (Fig. 11). The same trend was observed for larvicide applications across the three regions [northern: 14,069 (±2,034) ha; central: 5,112 (±989) ha; and southern: 3,111 (±868) ha] and mating disruption treatments [northern: 74,165 (±8,074) ha; southern: 41,982 (±10,350) ha; and central: 40,637 (±4,537) ha]. All states have conducted larvicide and mating disruption applications except Kentucky, which has never had treatments in the STS Program (Fig. 11). This is mostly attributable to the state's location in the distal part of the STS action area, away from quarantined areas, and to the success of the adjacent states. Mean annual treatment application costs were $12.96 (±0.95)/0.04 ha for all treatments.

Aerial applications were made in urban areas 709 times, representing 22 percent of the total number of applications and 9 percent of the total treatment area (Fig. 12). Applications in urban areas occurred mostly in the metropolitan areas of Chicago (IL), Columbus and Dayton (OH), Duluth (MN), and Ft. Wayne (IN). The majority of aerial applications occurred on nonfederal lands (1,939 applications, 61 percent). Aerial applications occurred on federal and tribal lands 1,235 times (39 percent). On federal lands, tracts managed by the USDA Forest Service; Department of Interior, National Park Service and U.S. Fish and Wildlife Service; Department of Energy; U.S. Army and Air Force; and Department of Defense, Army Corps of Engineers in southeastern Ohio, eastern Illinois, northern Indiana, northern Minnesota, central and western Virginia, and northern Wisconsin received the most treatments, representing 10 percent of total treatment area (Fig. 13). The Cherokee, Chequamegon-Nicolet, George Washington-Jefferson, Wayne, Pisgah, and Superior National Forests have had STS treatments. Tribal lands, including Bad River, Red Cliff, St. Croix Reservation, and Lac Courte Oreilles-Off Reservation Lands in Wisconsin and Grand Portage Reservation in Minnesota also have had STS treatments on their lands. Additional national forests and National Park Service lands in the southern Appalachian Mountains, including Chattahoochee, Daniel Boone, Nantahala, Blue Ridge Parkway, and Great Smoky Mountains, are anticipated for future treatments due to the increased spread in this region and the abundance of susceptible host species.

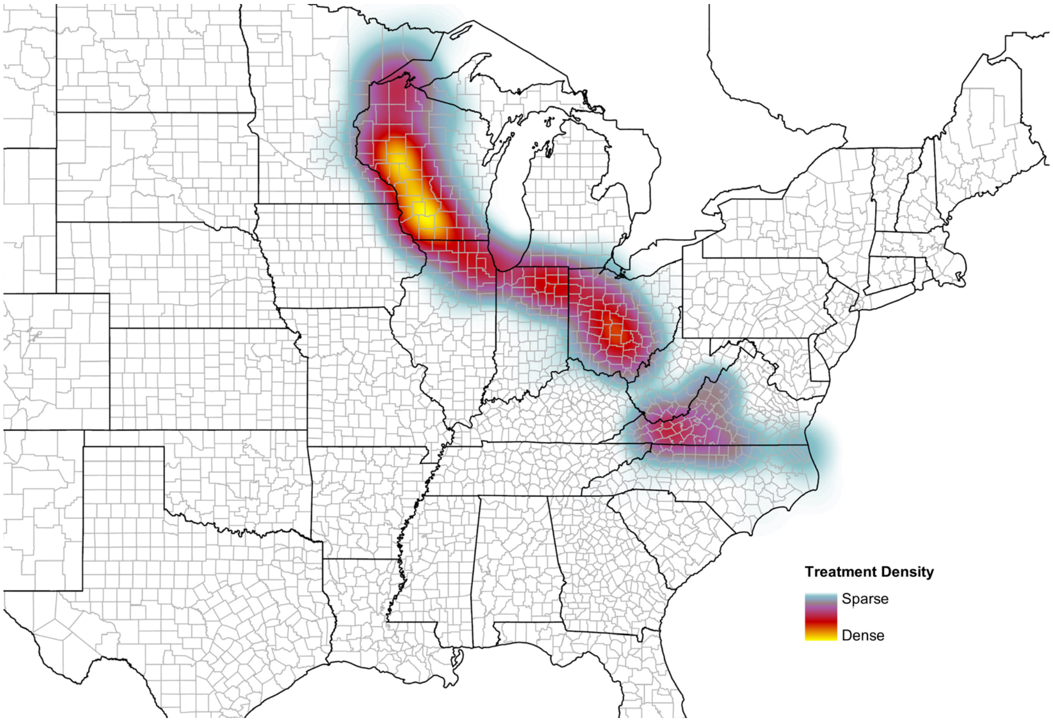


Figure 11.— Smoothed concentration of treatments from 2000 to 2020 in the National Slow the Spread Program. Note the lack of treatments in eastern Virginia and West Virginia.

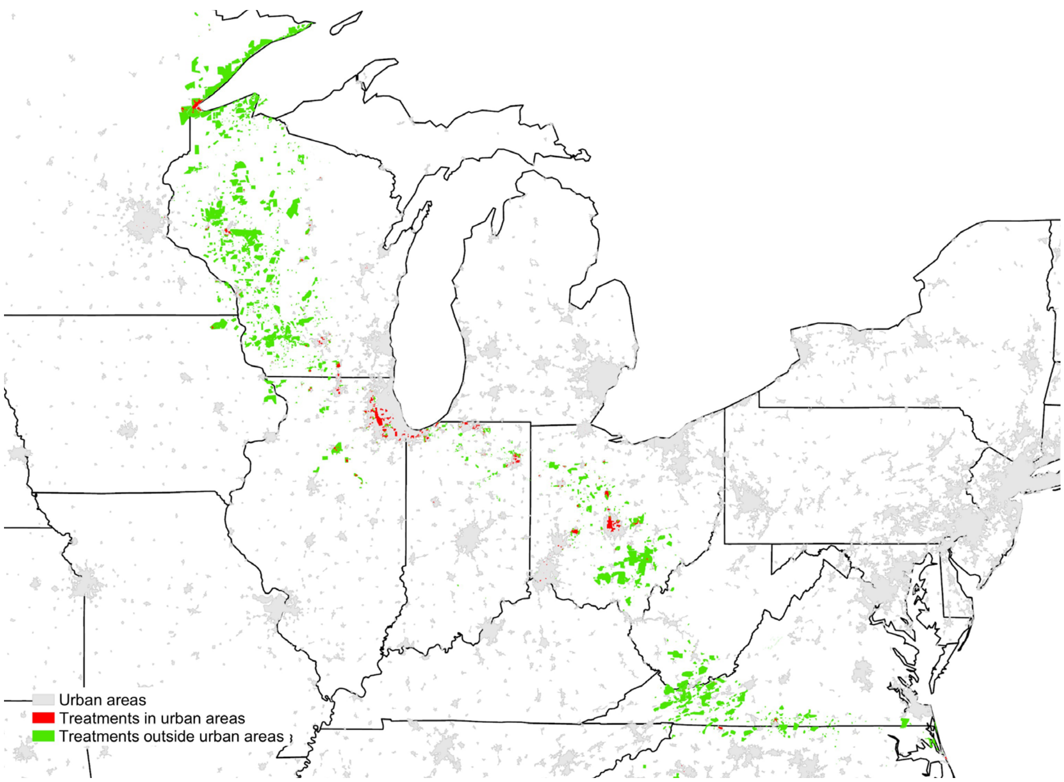


Figure 12.— Treatment in urban areas and outside urban areas by the National Slow the Spread Program. Aerial applications of a mating disruptant and *Bacillus thuringiensis* var. *kurstaki* dominated the treatments from 2000 to 2020.

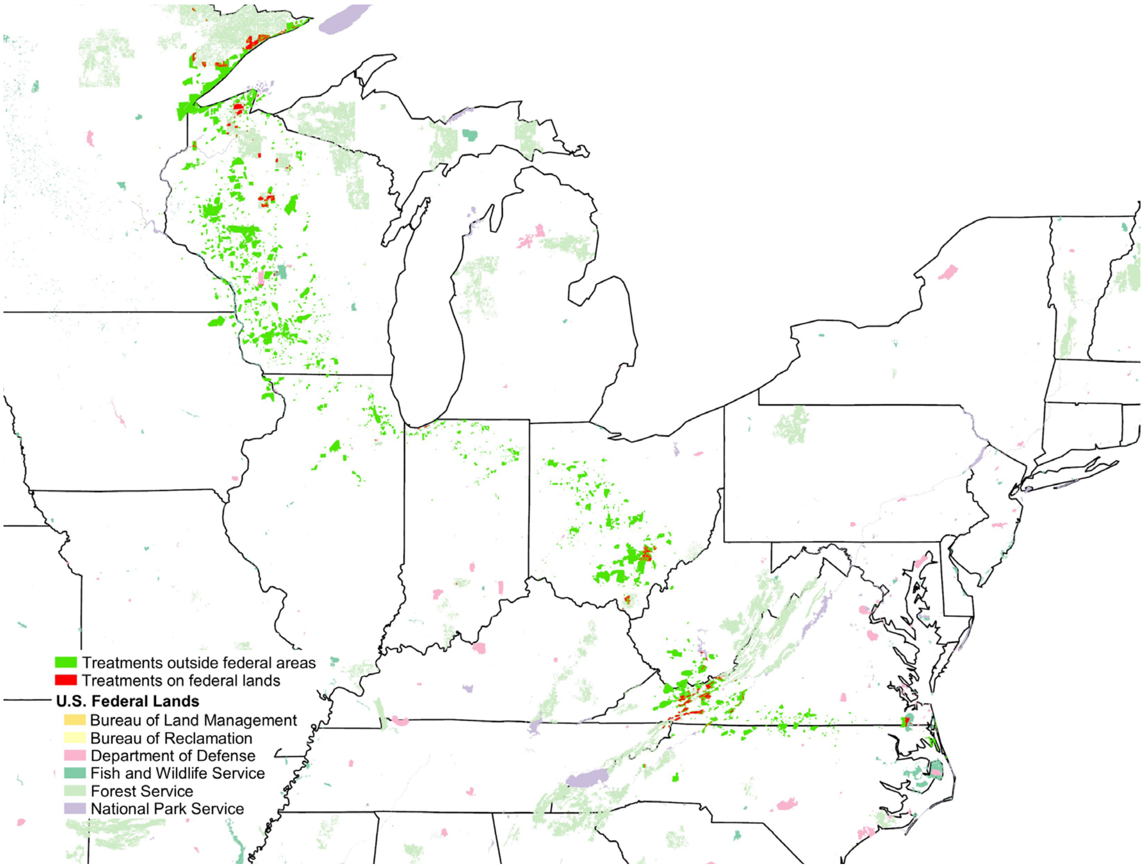


Figure 13.— National Slow the Spread Program treatments conducted from 2000 to 2020 that encompassed federal lands and nonfederal lands.

Post-treatment delimits were implemented following all treatment applications, either in the current year (larvicide applications) or the following year (mating disruption applications). Mean success of larvicide applications from 2002 to 2020 was 81.2 percent (±1.89), including full and partial success as defined by the *T* statistic (Sharov et al. 2002a), a trap catch-based metric that analyzes proportional changes in population density before and after treatment (Tobin et al. 2007). Mean mating disruption success (pooled full and partial successes represented as a percentage) from 2002 to 2020 was 91.4 percent (±0.87) (*T*+1-value). The STS Program has had a consistently high level of treatment success, and treatment success has increased since the start of the program (Walter et al. 2021). The lowest treatment success (64 percent) was reported in 2008 for larvicide applications, whereas the lowest mating disruption success was in 2004 (84 percent).

RATE OF SPREAD

Over the past two decades, the STS Program has surpassed its goal of slowing the rate of spread of *L. dispar* by greater than 60 percent from the historical rate of spread (19.6 km/yr), which is the average of two mid-range estimates (Liebhold et al. 1992, Sharov and Liebhold 1998). Mean spread across the program area from 2000 to 2020 was 2.6 km/yr (±1.8), with a goal of below 7.8 km/yr. Spread was highest in the northern region [9.62 (±4.13) km/yr], followed by the southern region [1.63 (±2.36) km/yr] and the central region [-2.31 (±2.26) km/yr]. The program area uses 12 zones to measure population spread (Fig. 14). The program has successfully pushed back the transition area and halted the rate of spread from Illinois to Ohio and in eastern and central Virginia and North Carolina (Table 5). The program boundaries have shifted westward in Wisconsin and southwestern in Virginia along the Appalachian Mountains, where moth spread has been the fastest. However, the central region, driven primarily by program activity in Ohio, slow spread rates, and sparse, disjunct host habitat, has successfully reversed the expansion of the proximal edge of the action area approximately 90 km into quarantined counties, delaying the advancement of *L. dispar* into Kentucky and causing a retreat of populations from previously invaded counties. Peak spread rates occurred in 2008, with 18.0 km/yr, which was only a 10 percent decrease when compared to the historic rate of spread (an average of spread rates across different regions and habitats) (Fig. 15) and coinciding with large outbreaks in quarantined counties (USDA FS 2021). There have been only five years since 2000 when the program has not achieved its goal of slowing the rate of spread by >60 percent (Fig. 15) and three years where the 3-year average spread rate elevated above the target spread rate. In 2008, spread rates were fastest in Wisconsin and Illinois (zones 3-8), ranging from 24.9 to 74.4 km/yr. In 2004, the rate of spread was its lowest at -9.66, causing populations to retreat in several zones from Wisconsin to Ohio (zones 2-5) and in West Virginia and Virginia (zones 10-12). Since 2013, the STS Program has consistently met its annual goal, despite reductions in treatment blocks due to a declining or flat federal budget. Without the STS Program, the current projected distribution of *L. dispar* would likely encompass all of North Carolina, Ohio, Indiana, Virginia, and Wisconsin and most of Illinois, Iowa, Minnesota, and Tennessee; and the distribution would likely include Missouri, Georgia, and South Carolina (Fig. 16). Liebhold et al. (1997) reported that Georgia, Minnesota, and Missouri have some of the highest concentrations of extremely susceptible forest type (preferred host species comprise >80% of the stand basal area on >1 million acres).

Table 5.—Mean (±s.e.) rates of spread of *Lymantria dispar* projected from 2000 to 2020 across the 12 zones (see also Fig. 14) in the National Slow the Spread Program

Zone	Region1	Rate of spread
1	Upper Peninsula of MI	12.2 (±8.96)
2	Northern WI, MN	14.5 (±7.17)
3	Central WI, MN	8.48 (±4.49)
4	Southern WI, northern IA	11.1 (±3.89)
5	IL	-4.39 (±5.24)
6	IN	-0.85 (±2.55)
7	Western OH	-1.64 (±3.33)
8	Eastern OH, KY	-3.02 (±3.70)
9	WV, KY, eastern TN, and western VA	4.23 (±1.74)
10	Central VA, NC	3.03 (±2.51)
11	Eastern VA, NC	1.03 (±4.73)
12	Appalachian Mountains in NC, TN, WV, VA	5.67 (±1.70)

Note: State abbreviations in order of appearance are MI (Michigan), WI (Wisconsin), MN (Minnesota), IA (Iowa), IL (Illinois), IN (Indiana), OH (Ohio), KY (Kentucky), WV (West Virginia), TN (Tennessee), VA (Virginia), NC (North Carolina).

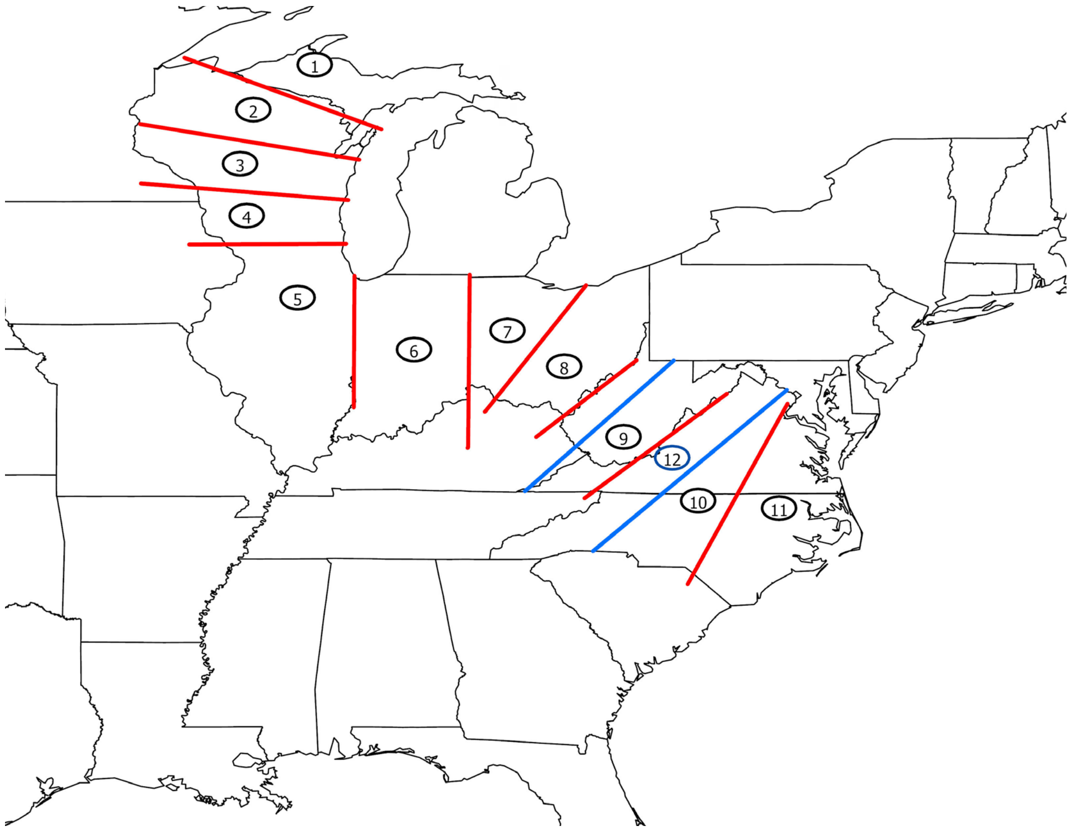


Figure 14.— The 12 zones used by the National Slow the Spread Program to calculate annual rates of spread. Zone 12 is noted by the blue boundary lines.

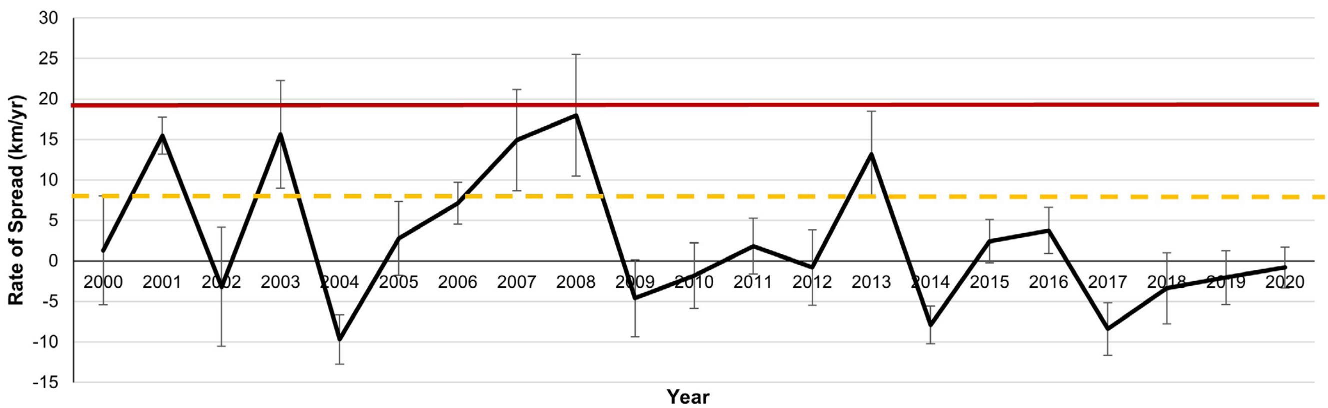


Figure 15.— Mean (±s.e.) rates of spread of *Lymantria dispar* from 2000 to 2020 across the 12 zones in the National Slow the Spread Program. The historical rate of spread (19.6 km/yr) and the 60 percent reduction in the historical rate of spread (7.8 km/yr) is noted by the red line and the dashed yellow line, respectively.

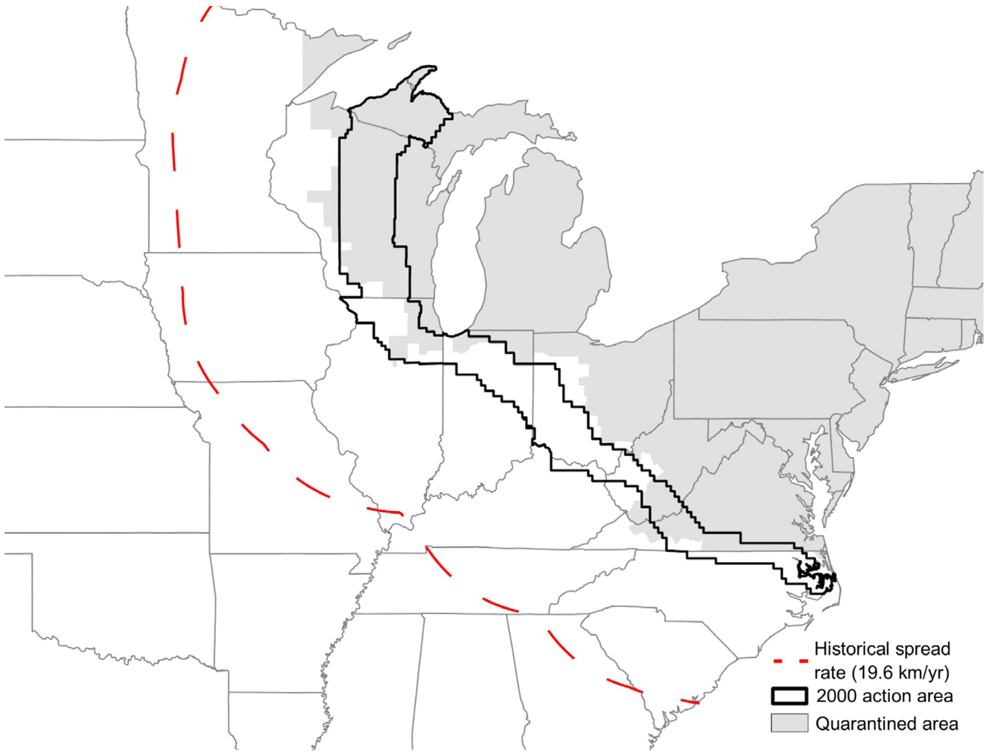


Figure 16.— The projected spread of *Lymantria dispar* from the 2000 action area, using the historical rate of spread (19.6 km/yr), had the National Slow the Spread (STS) Program never existed. The gray area (quarantined counties) represents the current distribution of *L. dispar* and the black boundaries represent the location of the STS Program in 2000.

FUTURE OF THE PROGRAM

Since *L. dispar's* introduction, the STS Program represents the longest running, most expansive, and most successful management program against this non-native defoliator in the United States (McManus 2007, Liebhold et al. 2021). Previous area-wide management programs were discontinued due to reductions in funding, limited program success, environmental concerns, and short-term program objectives (Coleman 2023, this report). In principle, some of these same issues could ultimately contribute to the end of STS. However, strong cross-collaboration among the USDA Forest Service, USDA Animal and Plant Health Inspection Service, and state government agencies has sustained and prioritized the program throughout its duration. The remarkable success of the STS Program, which generates data-driven, science-based management decisions using environmentally safe tactics, has been key to the program's longevity. Furthermore, without the additional supporting strategies of the USDA National Spongy Moth Management Program, specifically regulatory efforts and eradication treatments that target outlier populations in uninvaded areas, the STS Program would become ineffective. It is imperative for the STS Program to continue to delay the impacts of *L. dispar* on timber, recreation, and residential areas in currently uninfested areas (Leuschner et al. 1996).

Many of the trapping and treatment technologies utilized in STS were developed in previous management programs. In addition, years of research conducted by STS and collaborators have developed inexpensive, environmentally low-risk suppression strategies against low density *L. dispar* populations that are ideal for targeting isolated populations in the expansive transition area. The STS Program continues to advance trap data collection procedures and mating disruption treatment techniques to improve the program's efficacy and reduce costs. As a focus of forest integrated pest management programs in the United States, STS must continue to evaluate and implement new trapping and treatment methodology.

ACKNOWLEDGMENTS

The authors thank John Kyhl and Donna Leonard (retired), USDA Forest Service, Forest Health Protection; Andrew Liebhold, USDA Forest Service, Northern Research Station; Albert "Bud" Mayfield, USDA Forest Service, Southern Research Station; and Michael Falk, Wisconsin Department of Agriculture, Trade and Consumer Protection for reviewing early drafts of this chapter. This work was supported by USDA Forest Service, Forest Health Protection, Region 8; Wisconsin Department of Agriculture, Trade and Consumer Protection; and Department of Entomology, Michigan State University, and would have not been feasible without the support of STS state collaborators and the Departments of Entomology at Virginia Polytechnic Institute and State University (Denise Dodd, Mannin Dodd, Laura "Lola" Roghair, Peter Lee, and Laura Trujillo) and Michigan State University (Steven Crisp and Amos Lee).

LITERATURE CITED

Coleman, T.W. 2023. ***Lymantria dispar* and progression to management strategies in the United States.** In: Coleman, T.W.; Leibhold, A.M., eds. Slow the spread: a 20-year reflection on the national *Lymantria dispar* integrated pest management program. Gen. Tech. Rep. NRS-212. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station: 1–27. Chapter 1. https://doi.org/10.2737/NRS-GTR-212-chapter1.

Coleman, T.W.; Foelker, C.J.; Dodd, H.M. 2023. **Coordination and framework to a national integrated pest management program for *Lymantria dispar*.** In: Coleman, T.W.; Liebhold, A.M., eds. Slow the spread: a 20-year reflection on the national *Lymantria dispar* integrated pest management program. Gen. Tech. Rep. NRS-212. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station: 28–44. Chapter 2. https://doi.org/10.2737/NRS-GTR-212-chapter2.

Elkinton, J.S. 1987. **Changes in efficiency of the pheromone-baited milk-carton trap as it fills with male gypsy moths (Lepidoptera: Lymantriidae).** Journal of Economic Entomology. 80(4): 754–757. https://doi.org/10.1093/jee/80.4.754.

Hengeveld, R. 1989. **Dynamics of biological invasions.** London: Chapman and Hall. 160 p.

Leuschner, W.A.; Young, J.A.; Ravlin, F.W. 1996. **Potential benefits of slowing the gypsy moth's spread.** Southern Journal of Applied Forestry. 20(2): 65–73. https://doi.org/10.1093/sjaf/20.2.65.

Liebhold, A.M.; Gottschalk, K.W.; Luzader, E.R.; Mason, D.A.; Bush, R.; Twardus, D.B. 1997. **Gypsy moth in the United States: an altas.** Gen. Tech. Rep. NE-233. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 36 p. https://doi.org/10.2737/NE-GTR-233.

Liebhold, A.M.; Halverson, J.A.; Elmes, G.A. 1992. **Gypsy moth invasion in North America: a quantitative analysis.** Journal of Biogeography. 19(5): 513–520.

Liebhold, A.M.; Leonard, D.; Marra, J.L.; Pfister, S.E. 2021. **Area-wide management of invading gypsy moth (*Lymantria dispar*) populations in the USA.** In: Hendrichs, J.; Pereira, R.; Vreysen, M.J.B., eds. Area-wide integrated pest management: development and field application. Boca Raton, FL: CRC Press: 551–560. https://doi.org/10.1201/9781003169239.

Liebhold, A.M.; Sharov, A.A.; Tobin, P.C. 2007. **Population biology of gypsy moth spread.** In: Tobin, P.C.; Blackburn, L.M., eds. Slow the spread: a national program to manage the gypsy moth. Gen. Tech. Rep. NRS-6. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 15–32. Chapter 2. https://doi.org/10.2737/NRS-GTR-6.

McManus, M.L. 2007. **In the beginning: gypsy moth in the United States.** In: Tobin, P.C.; Blackburn, L.M., eds. Slow the spread: a national program to manage the gypsy moth. Gen. Tech. Rep. NRS-6. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 3–14. Chapter 1. https://doi.org/10.2737/NRS-GTR-6.

Onufrieva, K.S. 2023. **Analyses of *Lymantria dispar* mate-finding behavior in support of management in the STS program.** In: Coleman, T.W.; Liebhold, A.M., eds. Slow the spread: a 20-year reflection on the national *Lymantria dispar* integrated pest management program. Gen. Tech. Rep. NRS-212. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station: 86–130. Chapter 5. https://doi.org/10.2737/NRS-GTR-212-chapter5.

Reardon, R.; Venables, L.; Roberts, A. 1993. **The Maryland integrated pest management gypsy moth project 1983–1987.** NA-TP-07-93. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area. 35 p.

Régnière, J.; Saint-Amant, R.; Béchard, A.; Moutaoufik, A. 2017. **BioSIM 11.** Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre. 67 p.

Roberts, E.A.; Ziegler, A.H. 2007. **Gypsy moth population monitoring and data collection.** In: Tobin, P.C.; Blackburn, L.M., eds. Slow the spread: a national program to manage the gypsy moth. Gen. Tech. Rep. NRS-6. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 33–46. Chapter 3. https://doi.org/10.2737/NRS-GTR-6.

Sharov, A.A.; Leonard, D.; Liebhold, A.M.; Clemens, N.S. 2002a. **Evaluation of preventive treatments in low-density gypsy moth populations using pheromone traps.** *Journal of Economic Entomology.* 95(6): 1205–1215. https://doi.org/10.1603/0022-0493-95.6.1205.

Sharov, A.A.; Leonard, D.; Liebhold, A.M.; Roberts, E.A.; Dickerson, W. 2002b. **"Slow the spread": a national program to contain the gypsy moth.** Journal of Forestry. 100(5): 30–36.

Sharov, A.A.; Liebhold, A.M. 1998. **Model of slowing the spread of gypsy moth (Lepidoptera: Lymantriidae) with a barrier program.** Ecological Applications. 8(4): 1170–1179. https://doi.org/10.1890/1051-0761(1998)008[1170:MOSTSO]2.0.CO;2.

Sharov. A.A.; Liebhold, A.M.; Roberts, E.A. 1998. **Optimizing the use of barrier zones to slow the spread of gypsy moth (Lepidoptera: Lymantriidae) in North America**. Journal of Economic Entomology. 91(1): 165–174.

Tobin, P.C. 2008. **Cost analysis and biological ramifications for implementing the gypsy moth Slow the spread Program.** Gen. Tech. Rep. NRS-37. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 21 p. https://doi.org/10.2737/NRS-GTR-37.

Tobin, P.C.; Blackburn, L.M. 2007. **Slow the spread: a national program to manage the gypsy moth.** Gen. Tech. Rep. NRS-6. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 109 p. https://doi.org/10.2737/NRS-GTR-6.

Tobin, P.C.; Blackburn, L.M. 2008 **Long-distance dispersal of the gypsy moth (Lepidoptera: Lymantriidae) facilitated its initial invasion of Wisconsin.** Environmental Entomology. 37(1): 87–93. https://doi.org/10.1603/0046-225X(2008)37[87:LDOTGM]2.0.CO;2.

Tobin, P.; Sharov, A.A.; Thorpe, K.W. 2007. **The decision algorithm: project evaluation.** In: Tobin, P.C.; Blackburn, L.M., eds. Slow the spread: a national program to manage the gypsy moth. Gen. Tech. Rep. NRS-6. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 61–76. Chapter 5. https://doi.org/10.2737/NRS-GTR-6.

USDA Forest Service [USDA FS]. 2021. ***Lymantria dispar* digest**. https://apps.fs.usda.gov/nicportal/gmdigest/cfm/dsp/dspGypsyMothDigestHome.cfm (accessed August 17, 2021).

Walter, J.A.; Rodenberg, C.A.; Stovall, A.E.L.; Nunez-Mir, G.C.; Onufrieva, K.S.; Johnson, D.M. 2021. **Evaluating the success of treatments that slow the spread of an invasive insect pest.** Pest Management Science. 77(10): 4607–4613. https://doi.org/10.1002/ps.6500.

Whitmire, S.L.; Tobin, P.C. 2006. **Persistence of invading gypsy moth populations in the United States.** Oecologia. 147: 230–237. https://doi.org/10.1007/s00442-005-0271-5.