DEPARTMENT of
FORESTRY and
ENVIRONMENTAL
RESOURCES
NC STATE UNIVERSITY

Assessment of the Economic Feasibility of the Gypsy Moth Slow the Spread Project

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Objectives

The Gypsy Moth Slow the Spread Program (STS) has successfully reduced the rate of spread of the gypsy moth, *Lymantria dispar* (L.), by detecting and eradicating isolated populations that establish outside of the infested zone. The objectives of this study were to:

1. Estimate the incremental benefits of this reduced rate of spread during the full operational phase of STS, 2000 – 2006, and compare to the costs of the program.
2. Project and compare benefits and costs of STS for the next 20 years, 2007 – 2026.

Acknowledgements

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Introduction

The gypsy moth, *Lymantria dispar* (L.), has been gradually expanding its range in North America since its accidental release into Massachusetts in 1869. Gypsy moth caterpillars will defoliate over 300 species of trees, with both immediate impacts due to the nuisance factor as well as loss of leaves, and longer term impacts on the growth and health of trees, especially in cases of repeated heavy defoliation combined with other environmental stressors. While these negative impacts are well recognized in both the scientific and popular literature, they are challenging to predict and quantify over the full extent of the gypsy moth range.

Gypsy moth populations do not spread continuously along the population front. Instead, individual colonies become established beyond the expanding population front due to dispersal, or more commonly through inadvertent anthropogenic transportation of gypsy moth life stages. As these colonies grow, they coalesce and contribute to the range expansion of gypsy moth. Previous work that modeled gypsy moth range expansion observed that natural movement could account for a range expansion of approximately 3 km/yr. However, the observed rate of range expansion from 1965 to 1990 in the northeastern U.S was approximately 21 km/yr. This greater rate of spread is largely thought to be due to the formation, growth and coalescence of isolated populations ahead of the population front. Thus, one approach to reducing gypsy moth spread is to detect and eradicate these isolated populations. This is the objective of the Gypsy Moth Slow the Spread Program (STS): locate and eradicate isolated populations to prevent them from growing, coalescing, and contributing to the progression of the population front.

In 1990, the USDA Forest Service contracted the services of an economist to conduct a rapid and approximate analysis to indicate the general order of magnitude of benefits and costs that might be expected if a program to contain the spread of the gypsy moths was initiated. In this assessment, a scenario was developed that described what might happen within the next 25 years to the distribution and abundance of gypsy moth populations within the project area, and what activities and impacts would be realized with and without enactment of a containment project to slow the progression of spread. Because the potential benefits of such a containment program far outweighed the costs, the STS Program, after several years as a pilot project in selected areas, was formally integrated into USDA's national strategy to manage gypsy moth in 1999.

Because much has changed in the gypsy moth range and its management, and possibly in the potential economic costs and benefits, since this previous report was completed, a new economic assessment was proposed. One option considered for this analysis was to estimate the costs and benefits of the STS program as implemented 1990 – 2005 (actual) and 2006 – 2015 (predicted), following a similar methodology as in the 1990 study. However, it was judged to be more policy relevant to focus on the full operational phase of the STS program for an ex post analysis of all costs and benefits that accrued during the years 2000 – 2006 (reported in $2000, using 1999 population distribution as baseline). A separate ex ante analysis compares (a) termination of the program starting in 2007 vs. (b) continuation of the program through 2026 (reported in $2007, using 2006 population distribution as a baseline).

Time line and intermediate products

Work on this study began in September 2006, with initial conference calls with Patrick Tobin, and an initial structured discussion with USFS scientists in Research Triangle Park. During the fall of 2006, doctoral student Tzu-Ming Liu compiled literature and information on the program.

In January 2007, he presented a poster and sought expert input via a brief questionnaire at the Invasive Species Forum. Also in January of 2008, Erin Sills met with Patrick Tobin in Morgantown, and masters student Kevin Bigsby joined the project as the GIS research assistant. Over the course of 2007, we considered and discussed with Patrick Tobin various way to model the spread of gypsy moth, the STS zone, and the quarantine. In the February of 2007, Donna Leonard provided information on the STS budget. By September 2007, we produced an initial set of spread scenarios. Over the past year, we have refined those scenarios, examined various options and compiled data to model costs of STS, gathered information on the benefits of slow the spread through interviews with key informants, and implemented a survey of residents of areas affected by gypsy moth. At various points, we have discussed preliminary results in the following presentations and reports, all included in appendix 1:

- Interim progress report and conference call with STS board, October 2007
- Presentation to *Annual Gypsy Moth Review*, October 2007
- Presentation to *Invasive Species Forum*, January 2008
- Presentation and interim progress report to STS board, February 2008

Parameters for cost-benefit assessment

The first cost-benefit assessment of STS was conducted *ex ante* by Leuschner et al. (1996), and this study was motivated by interest in revisiting that study *ex post*, incorporating new information on actual program costs and revised estimates of benefits based on new information. More fundamentally, this study is motivated by interest in returns on public investment in STS. Thus, the parameters for this study were designed to both ensure policy relevance and allow comparison to the former cost-benefit assessment.

<u>Accounting framework:</u> This study considers impacts on US residents only, i.e., ignoring any benefits of STS for Canadians. Because of data limitations, the study does not quantify most benefits that would accrue to people who live outside of the area that may become infested with gypsy moth in the next 20 years. These include (a) maintenance of ecosystem services by avoiding defoliation and tree mortality, (b) scientific advances in understanding of invasive species based on extensive database generated by STS, and (c) reduced probability of anthropogenic spread to those areas, due to reduced source area (i.e., reduced generally infested zone).
<u>Time frame:</u> The ex post analysis considers the operational phase of the program to date, from 2000 through 2006 (excluding 2007 because data were not available when study was begun); the ex ante analysis considers costs and benefits from 2007 through 2026. In both cases, this includes all costs of the program, but only the benefits that actually accrue in that time period. Even if STS had been cancelled at the end of 2006, the benefits of delayed infestation would continue until gypsy moth has infested the entire US (see figure 1). Likewise, the benefits of investments in STS from 2007 to 2026 will continue past 2026, although this has less of an impact on NPV because of the effect of discounting.
<u>Discount rate:</u> The primary benefit of STS is simply delaying the costs imposed by gypsy moth infestation, and thus the discount rate is key to the analysis. The USDA Forest Service uses a real discount rate of 4%. This is similar to the 3.375% average real treasury rate for the period from 1999 to 2006. The OMB recommends a standard discount rate of 7%. Thus, results are

computed using both 4% and 7%. For the ex post analysis, all results are reported in 2000 dollars, using the CPI deflator. For the ex ante analysis, all results are reported in 2007 dollars.
Counter-factual scenario: We assume that there would be no new programs (e.g., no replacement barrier zone program) and no changes in the operating procedures of other government programs in the absence of STS. Specifically, we assume that the rate of spending on suppression in the GIZ will remain the same under both scenarios, thus increasing in absolute value as the GIZ expands. In the eradication zone, we assume no change in costs with and without STS, based on the assumption that multiple effects counter-balance (with STS, there is a larger eradication zone that requires detection trapping, but a lower probability of outbreaks, reducing the costs of delineation and eradication by APHIS, USFS, and the states; close to the STS boundary, APHIS and the states may invest more than they would otherwise in delineation and eradication but STS balances this out by assisting with eradication treatments in this area). However, most STS dollars would be re-directed to other spending priorities (not gypsy moth).

Excluded Benefits

We focus on the benefits of delaying infestation by the gypsy moth in new areas, and thus delay of imposition of the quarantine and delay of defoliation. There are potentially other benefits of slowing down the spread, not quantified here. These include more time for public awareness and adaptation, for example, selecting less vulnerable species when street or landscape trees are replaced, or allowing forest landowners to learn about silvicultural options and not fall prey to unscrupulous loggers encouraging panic sales of timber. Areas infested later also benefit from research conducted during the delay, which potentially reduces the cost of suppression treatments, e.g., by limiting environmental impacts by making optimal choices between various control options (Dimilin®, Btk and Gypchek®), identifying the minimum necessary concentrations for aerial applications, developing new options to protect urban trees such as Eradicoat®, and perhaps in the future, and learning how to leverage the impact of *Entomophaga maimaiga*.

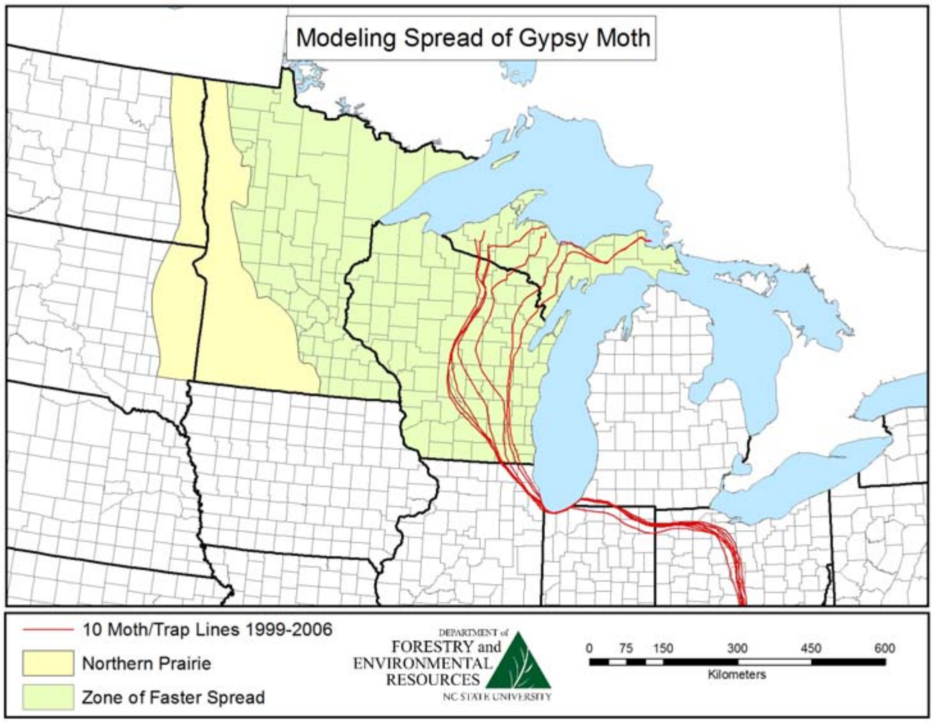
Spread scenarios

STS originally set a target of reducing the spread of gypsy moth by half, from 20.8 km/ year to 10 km/ year. The 20.8 km/ year spread rate was estimated by Liebhold et al. (1992) and confirmed to be in the range of 19.5 to 21.1 km/ year by Tobin et al. (2007), using county quarantine data from 1966 to 1989 (excluding Michigan).

Spread in the UP of WI and MI has been estimated in the same range of 15.9 to 28.6 km/ year during the period 1994 – 2005 while STS has been in place (Tobin et al. 2007), with a maximum observed spread of 45.5 km/ year. It has been suggested that the faster spread rate in the northern part of the range is related to allee effects and to high winds across the great lakes. This differentiated spread has continued with STS, which has achieved an average spread rate of 6 km/ year, but significantly higher in WI (11.5 km/ year) than in the rest of the range (2.9 km/ year). We assume that Entomophaga maimaiga will not have a significant effect on spread rates (as opposed to defoliation rates), because establishment of the fungus lags population front of gypsy moth.

Thus, we develop assumptions about ex post spread without STS and ex-ante spread with and without STS. Two key issues to address are (a) the temporal transition from observed rates of spread under STS (including the pilot phase in place before 1999) to the assumed rate of spread without STS, and (b) the spatial transition from higher rates of spread in the north to slower rates of spread in the remainder of the range. We use both constant annual rates that assume no spatial variation and instantaneous temporal adjustment in spread rates (6, 10, and 20.8 km/year flat rates), and dynamic differentiated rates that assume a gradual increase in spread rates with time and a faster rate of spread in WI and MN until the prairies (see figure 1).

Figure 1



The exact spread scenarios that we model are as follows:

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 rate increasing over 7 years to maximum (DD7): spread in WI is initiated at 19.56 km/ year and increases to 46.45 km/ year, while spread in the rest of the range is initiated at 3 km/ year and increases to 20.78 km/ year.

Ex ante

1. With STS spread at 6KM/ year compared to spread without STS at 20.78 km/ year
2. With STS spread at 6KM/ year compared to spread without STS at dynamic differentiated rate increasing over 7 years to maximum (DD7): spread in WI and continuing into MN is initiated at 11.5 km/ year and increases to 46.45 km/ year until it slows down to 20.78 km/ year once the population front reaches the prairies, while spread in the rest of the range is initiated at 2.87 km/ year and increases to 20.78 km/ year.
3. With STS spread at 10KM/ year compared to spread without STS at dynamic differentiated rate increasing over 20 years to maximum (DD20): spread in WI and continuing into MN is initiated at 11.5 km/ year and increases to 46.45 km/ year until it slows down to 20.78 km/ year once the population front reaches the prairies, while spread in the rest of the range is initiated at 2.87 km/ year and increases to 20.78 km/ year.

For the ex post analysis, scenario 2 is most realistic in that the spread rate without STS starts at actual observed spread rate, rather than jumping immediately to 10.78 km/ year throughout the entire range. In contrast, for the ex ante analysis, scenario 2 is less realistic because in most of the range, the rate of spread without STS is initiated at a rate slower than the assumed rate with STS. We also considered a differentiated rate of spread under STS, consisting of 2.87 km/ year in most of the range and 11.5 km/ year in WI and MN. However, there is weak justification for assuming both that such a low rate of spread will be maintained in most of the range and for deciding how far west the faster rate of spread will continue in the northern part of the range. Therefore, the preferred ex ante scenario is the simple comparison of flat rates. While the STS program has not consistently achieved even the target rate of 10 km/ year (let alone 6 km/year) in the northern-most portion of the range, it has slowed spread well below 6 km/year in most of the range. We assume that with re-allocation of resources and effort, the program could slow spread to 6 km/ year throughout the range. The third ex ante scenario provides a very conservative picture of STS impacts, potentially consistent with a reduced budget for the program, but as with scenario 2, not very realistic in the initial years in most of the range.

All of the scenarios project the 10 moth/ trap line, that is, the rate of spread indicates the distance between these lines in any two consecutive years. The 10 moth/ trap line is believed to provide the most consistent measure of the gyspy moth population front. The area to the north and east of this list is considered part of the generally infested zone (GIZ), while the rest of the country to the south and west is considered to be uninfested, or the zone where APHIS seeks to eradicate any isolated populations. The STS project operates in a transition zone (TZ) established approximately 50 km to the NE and 120 km to the SW of the 10 moth/ trap line. Figures 2 and 3 show the interpolated lines along which the STS program caught 10 moths/ trap in 1999 and 2006. These are the baselines for the ex post and ex ante spread scenarios. Figure 4 illustrates the process of buffering that 10 moth/ trap line to project spread into the future.

Figure 2

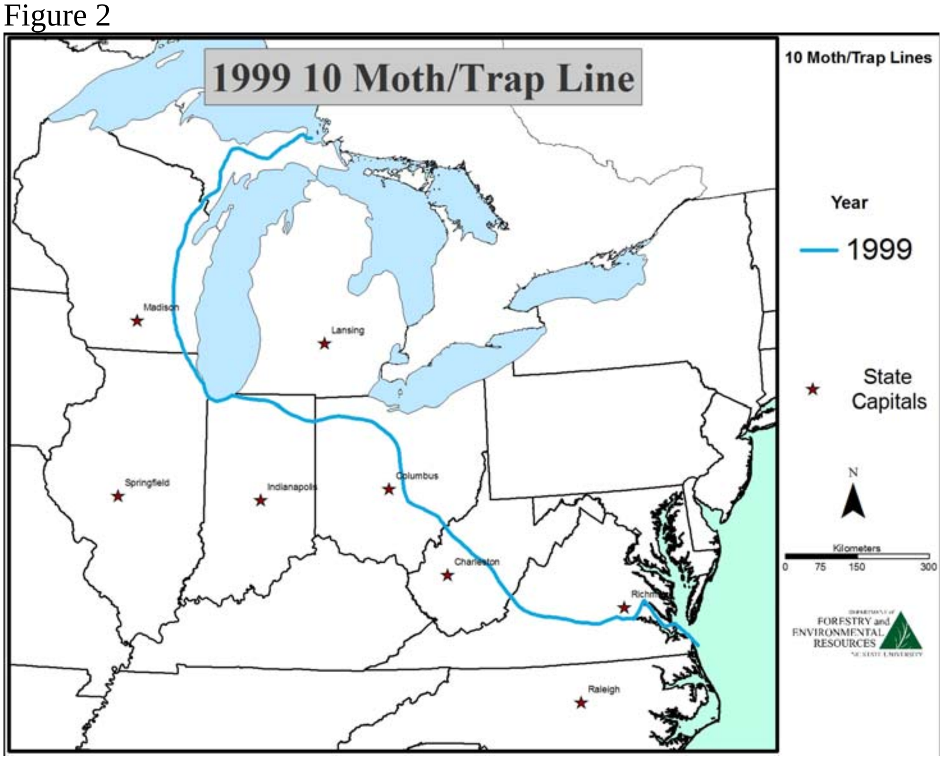


Figure 3

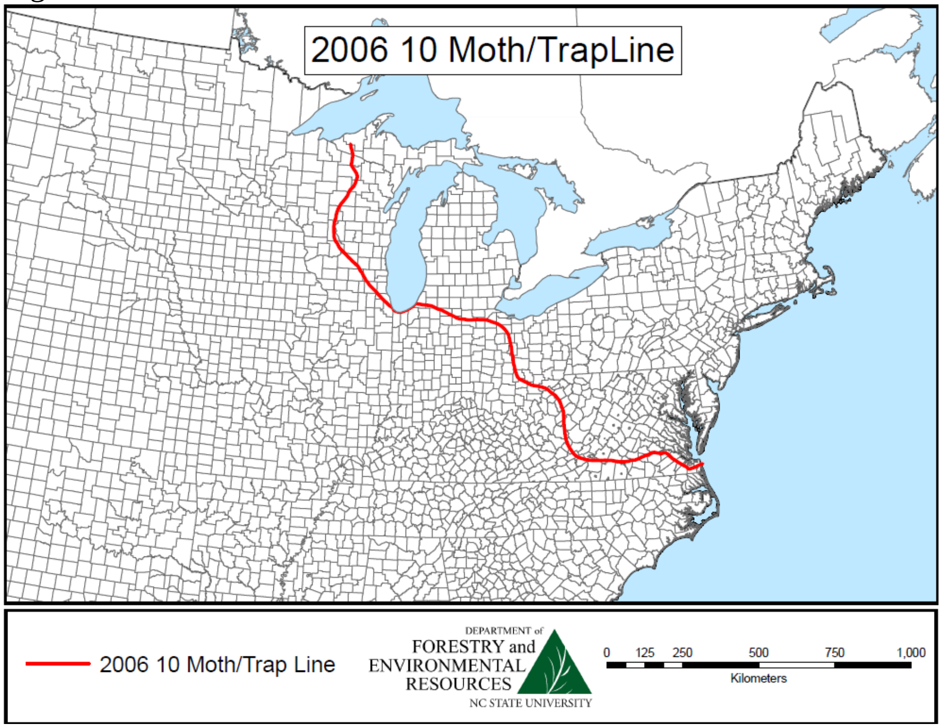
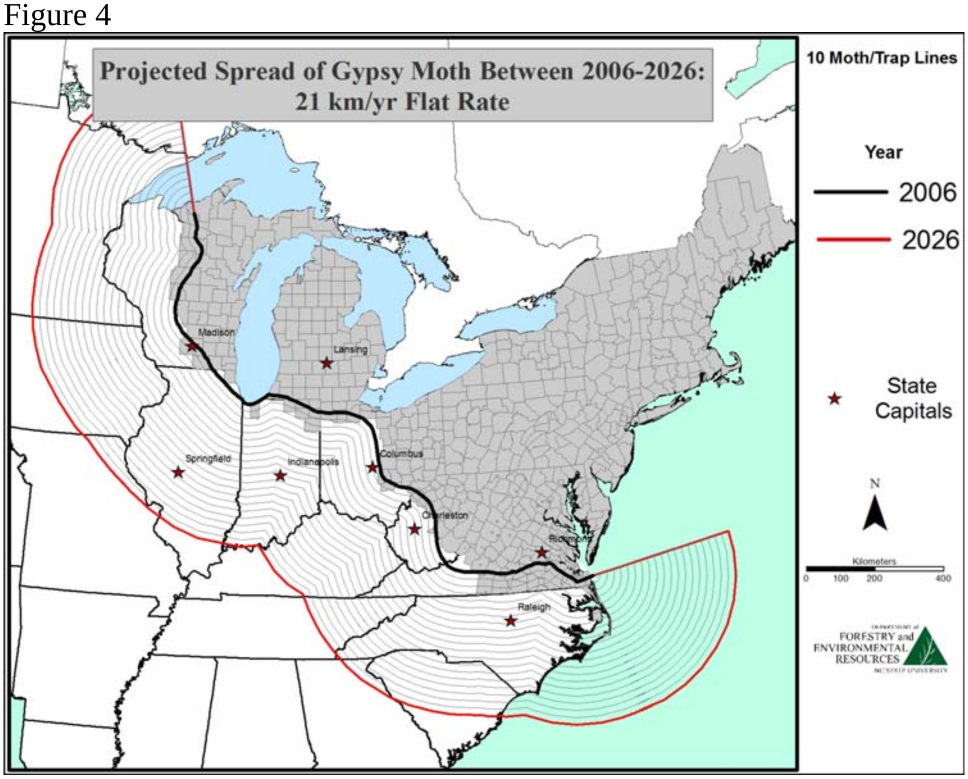
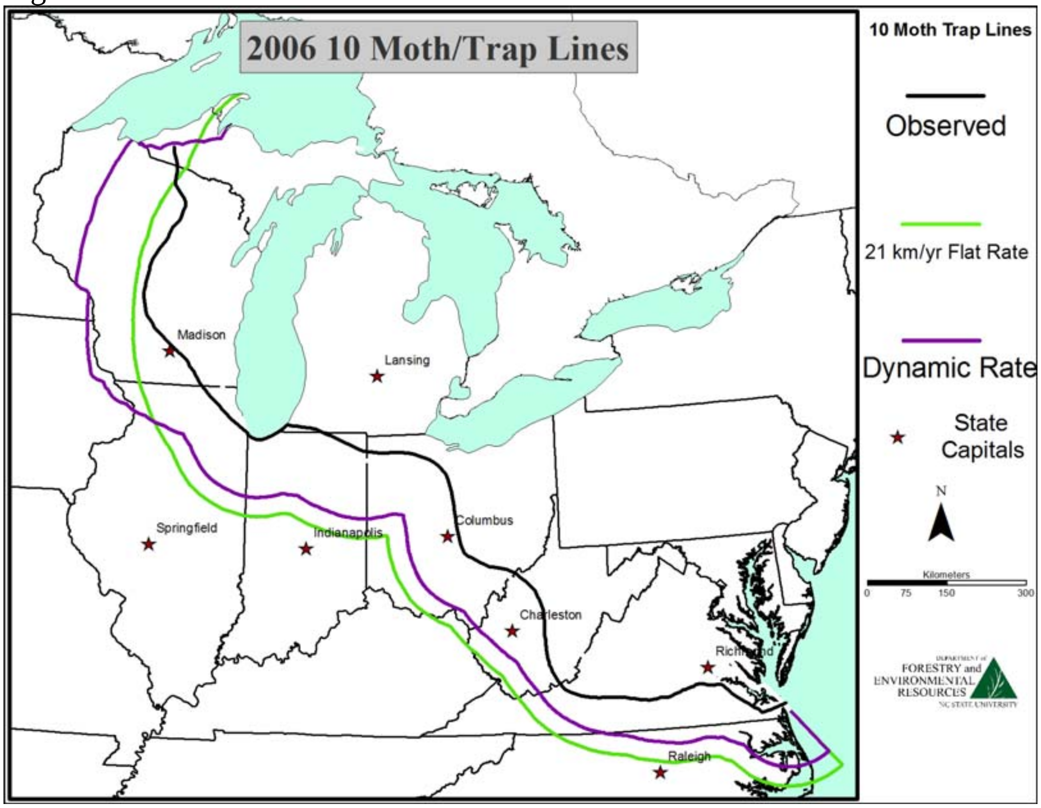


Figure 4



The ex post scenarios project the 10 moth/trap line under the assumptions of flat rate and dynamic differentiated (DD7) spread without STS, comparing those to the actual spread that occurred with STS. Figure 5 summarizes the advance of gypsy moth through year 2006 under these alternatives.

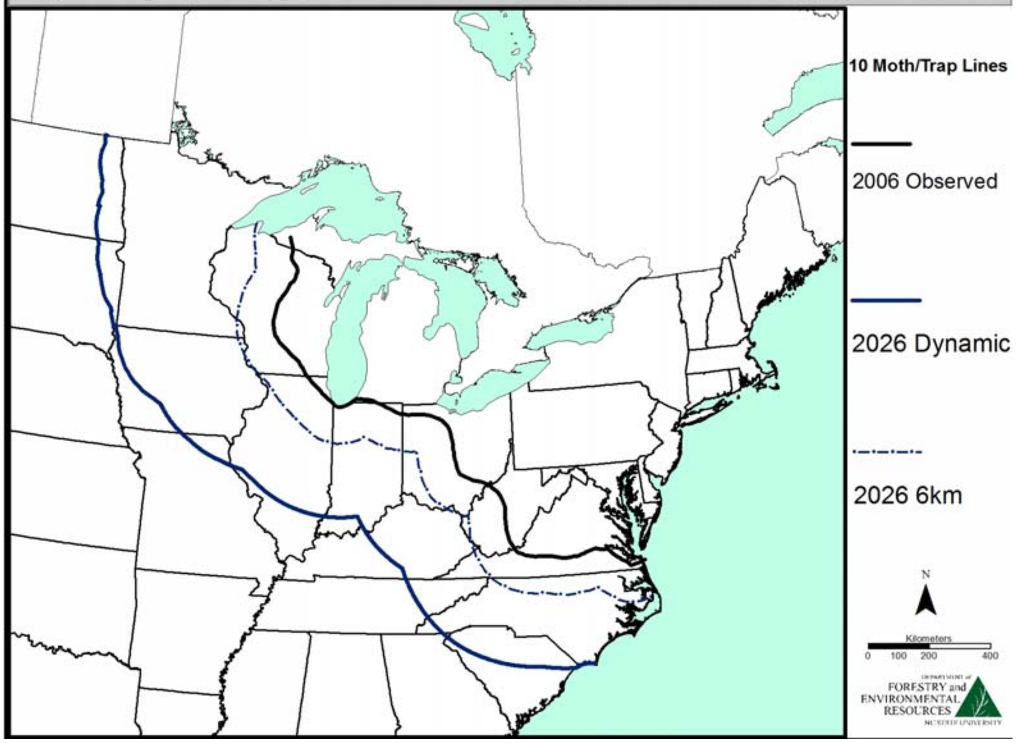
Figure 5



Likewise, the ex ante scenarios project the 10 moth/trap line into the future, with and without STS; see figure 6 for an example of this comparison in 2026. Finally, we also project the transition zone for each year of the STS scenarios, based on the assumption that it includes 50 km to the NE and 120 KM to the SW of the 10 moth/ trap line.

Figure 6

Projected Spread of Gypsy Moth With STS (6km/yr) and Without STS (dynamic rates)



Results

Summary findings for objective 1: estimate the incremental benefits of the reduced rate of spread with STS during the full operational phase of STS, 2000 – 2006, and compare to the costs of the program

To evaluate the costs and benefits of the STS (Gypsy Moth Slow the Spread) program during its fully operational phase from 2000 to 2006, we consider all quantifiable costs and benefits that accrue within the United States, deflated and discounted to the year 2000, using the CPI (consumer price index) and either 4% or 7% discount rates. The costs were taken directly from a report by the STS program, with variation due solely to financial reporting smoothed in order to better represent real costs, and the cost of detection trapping that would have occurred anyway netted out. To determine the counties that would have been quarantined and the area that would have become generally infested without STS, we project the counterfactual spread of the gypsy moth population represented by the 10 moth/trap line at a dynamic differentiated rate, slowly increased from the spread rate of the late 1990s to the observed historical rates without management, including the higher rate observed for Wisconsin and assume to continue into Minnesota east of the prairies. We assume that the rate of spread and defoliation without STS would have been at least as great as the spread and defoliation with STS in any given year. Under the counterfactual rate of spread, we assume that counties would be quarantined when the 10 moth/trap line crosses more than half of the county.

We estimate defoliation based on the known ratio of area defoliated (according to aerial sketch maps) to susceptible forest area (>20% basal area in preferred species) in each year. We also consider the long-run average defoliation rate, about 6% of susceptible forest. Based on these estimates of defoliation, we find the number of additional campsites, total number of households, and number of households occupying single family homes ("residential") that would have been affected by defoliation in the absence of STS. We present two estimates of residential costs, one including only direct costs of suppression and mitigation of gypsy moths, and the other including willingness to pay to reduce the presence of gypsy moth, including nuisance, defoliation, and tree mortality, both in private yards and neighborhoods. The latter uses the lower bound on the best fitting models of willingness to pay from a contingent valuation survey conducted in 1991. The survey closely followed best practices for this method, and its findings on gypsy moth suppression are similar to results obtained in a more recent survey in the same region.

In sum, at a 4% discount rate, the total program costs are \$66 million and the total benefits are \$19 million (based mostly on out-of-pocket costs) or \$22 million (including willingness to pay) (Table 1). At a 7% discount rate, the present value of program costs over just this seven year period is \$61 million, while the benefits are \$17 - \$19 million (Table 2). There are three critical factors to consider in interpreting these numbers. First, the benefits of the program's actions in any one year will continue to accrue over many years. That is, even if the program had ended in 2006, there would still be fewer counties quarantined and less area in the generally infested zone for many years to come (see figure 7 for an example). Second, the benefits do not include forest ecosystem benefits or any net impact on timber value. These benefits are likely to have been small, because at low rates of defoliation – and especially low rates of repeat defoliation - there may be some benefits from gypsy moth "thinning" the forest that counter-balance any loss in forest products and services.

Third, gypsy moth populations were in a cyclical low for the first seven years of the program, partly as predicted by past patterns and partly due to *Entomophaga maimaiga*. However, there is always a risk of higher population levels and thus greater defoliation, especially when the spring-time weather is dry (as occurred in 2007). Thus, the STS program has some insurance value, reducing the probability that an area will be infested when the next big outbreak of gypsy moth occurs. This insurance was not "cashed in" during the first seven years of the program, but given the first factor noted above, it certainly will be at some point in the future, and the second factor noted above suggests that its value will be much larger than the estimates presented here. To reflect this, the benefits of STS can be estimated based on the long-run average of 6% of susceptible forest defoliated. In that case, the program comes much closer to breaking even in just the first seven years (Table 3). Assuming continuation of benefits at the 2006 level expanding by 0.5% per year to reflect the increasing area of the (avoided) generally infested zone, the payback period for the first seven years of the project is just 8 years; that is, the net present value is positive after just one more year of benefits.

Figure 7

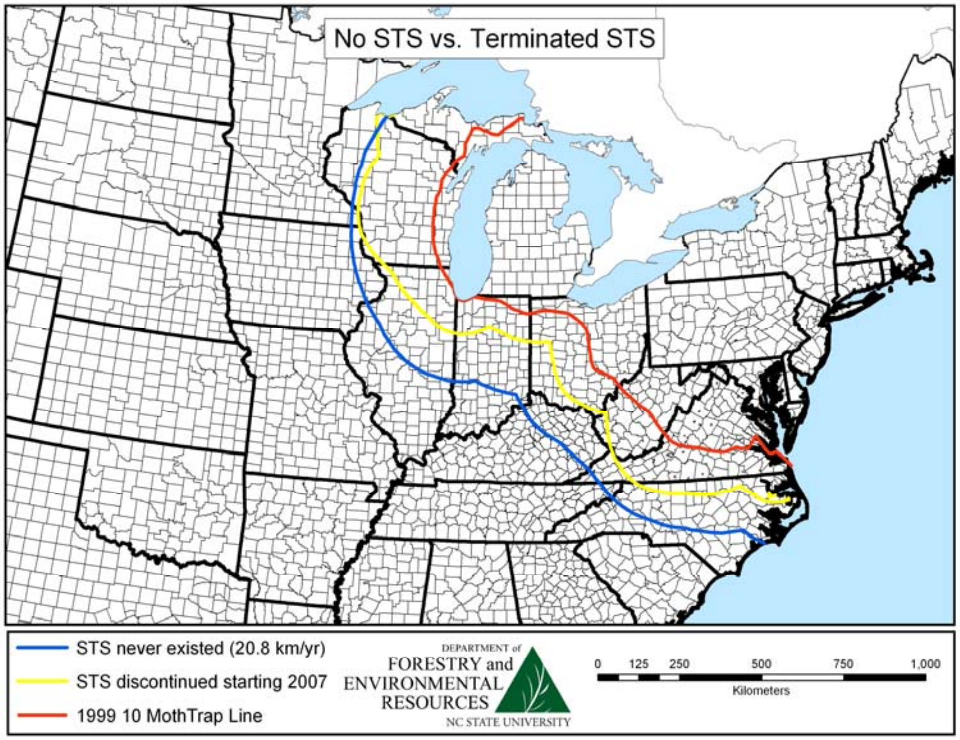


Table 1 Ex post costs and benefits of STS program in $2000 at 4% discount rate

PV r=4%	Cost	Benefits					
		Quarantine Costs	Suppression Costs	Camping WTP	Health	Residential Yard costs	WTP
2000	$9,599,503	$111,347	$175,933	$2,690	$621	$114,729	$321,477
2001	$9,349,791	$166,228	$264,642	$15,673	$1,030	$213,951	$581,241
2002	$10,285,939	$203,700	$851,488	$12,030	$1,195	$210,647	$589,413
2003	$9,213,076	$225,605	$1,510,474	$11,308	$1,337	$238,471	$665,382
2004	$10,102,797	$355,888	$2,929,254	$3,061	$324	$60,279	$164,671
2005	$8,843,213	$529,322	$4,095,819	$15,092	$3,169	$598,547	$1,662,614
2006	$8,815,497	$774,608	$5,183,473	$5,321	$590	$111,200	$299,413
Total	$66,209,818	$2,366,700	$15,011,083	$65,175	$8,265	$1,547,826	$4,284,211

Table 2 Ex post costs and benefits of STS program in $2000 at 7% discount rate

PV r=7%	Cost	Benefits					
		Quarantine Costs	Suppression Costs	Camping WTP	Health Costs	Residential Costs	WTP
2000	$9,599,503	$111,347	$175,933	$2,690	$621	$114,729	$321,477
2001	$9,111,049	$161,568	$257,222	$15,234	$1,001	$207,953	$564,945
2002	$9,757,321	$192,438	$804,410	$11,365	$1,129	$199,001	$556,825
2003	$8,511,219	$207,156	$1,386,954	$10,384	$1,227	$218,970	$610,969
2004	$9,071,946	$317,622	$2,614,299	$2,732	$289	$53,798	$146,965
2005	$7,720,508	$459,164	$3,552,946	$13,091	$2,749	$519,214	$1,442,246
2006	$7,477,207	$653,100	$4,370,370	$4,487	$497	$93,756	$252,446
Total	$61,248,754	$2,102,396	$13,162,134	$59,982	$7,513	$1,407,421	$3,895,873

Table 3 Ex post costs and benefits of STS program under long-run average defoliation rates

PV r=4%	Cost	Benefits: Quarantine Costs	Suppression Costs	Camping WTP	Health Costs	Residential Costs	Residential WTP
2000	$9,599,503	$111,347	$351,866	$6,591	$837	$171,605	$474,149
2001	$9,349,791	$166,228	$529,284	$17,710	$1,032	$211,058	$568,017
2002	$10,285,939	$203,700	$1,702,976	$65,888	$4,247	$812,232	$2,242,610
2003	$9,213,076	$225,605	$3,020,949	$83,601	$5,968	$1,146,680	$3,143,695
2004	$10,102,797	$355,888	$5,858,508	$120,404	$9,637	$1,893,760	$5,144,665
2005	$8,843,213	$529,322	$8,191,638	$133,952	$10,565	$2,102,764	$5,620,314
2006	$8,815,497	$774,608	$10,366,945	$154,378	$13,228	$2,604,392	$6,933,870
Total	$66,209,818	$2,366,700	$30,022,165	$582,524	$45,514	$8,942,491	$24,127,321

Summary findings for objective 2: Project and compare benefits and costs of STS for the next 20 years, 2007 – 2026

We develop several projections of gypsy moth spread with and without the STS program. Figure 8 shows the scenario based on the simplest assumptions about temporal and spatial variation in spread rates: gypsy moth is projected to spread at the historical average rates of 6km with and 21 km without the program. This results in a more even distribution of impacts across the landscape as compared to alternative scenarios that allow spread to increase gradually and proceed more quickly in the northern part of the range (*cf* figure 9). Tables 4 and 5 summarize projected costs and benefits of the program under 4% and 7% discount rates respectively.

Figure 8

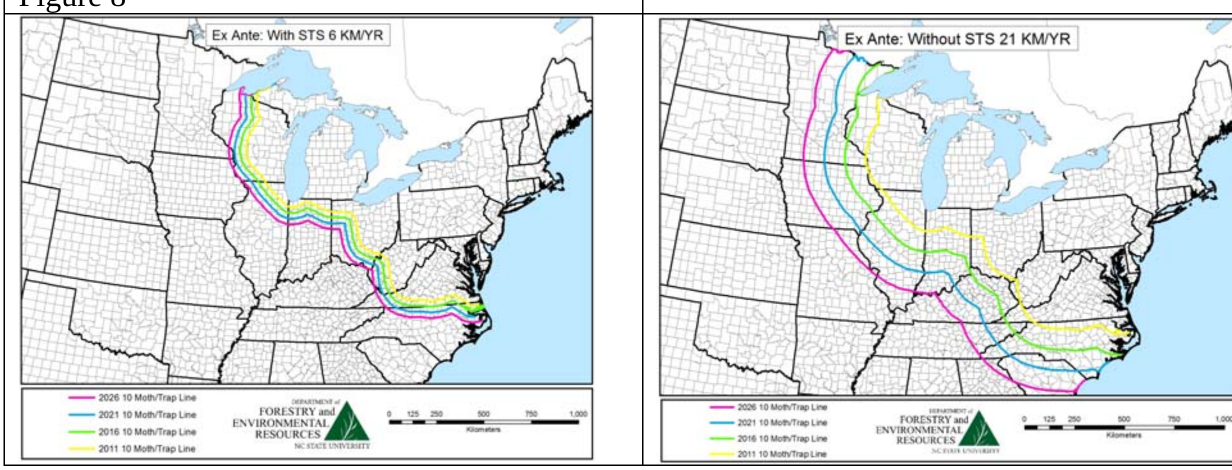
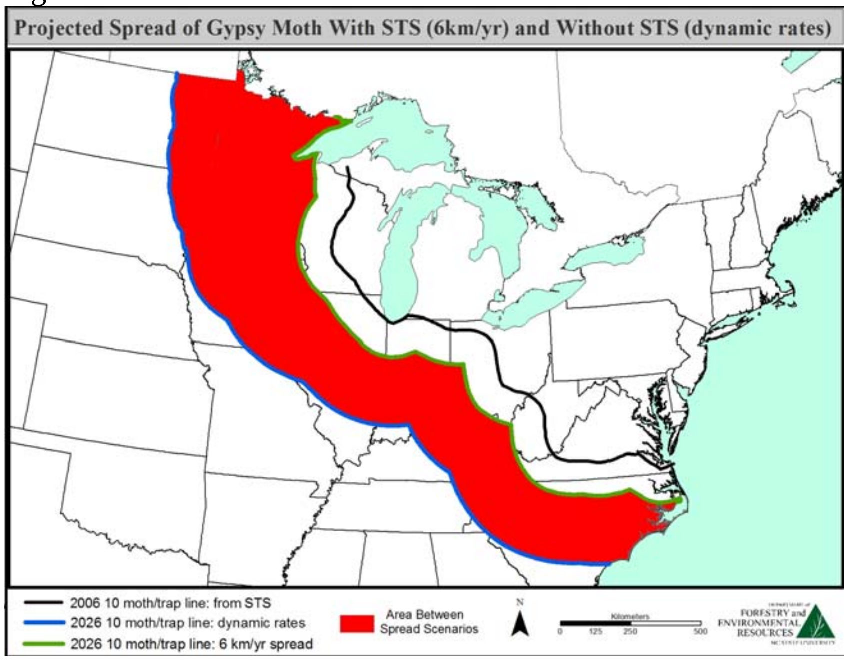


Figure 9



The program costs shown here are an upper bound, because they are based on the assumption that the costs of STS trapping and treatment per unit area remain constant, conditional on biophysical characteristics that drive spatial variation in trapping costs, rather than continuing to gradually decline over time. As with the ex post assessment, the quarantine benefits are based on the assumption that a county is quarantined when the 10 moth/ trap line crosses 50% of the county.

In contrast to the ex post assessment, the remainder of the ex ante benefits are not based on annual projections of defoliation by gypsy moth but rather an assumed long-run average defoliation rate is 6% of susceptible forest (defined as forest with more than 20% basal area in preferred species). While the tables include annual estimates for intermediate years, benefits are likely to be concentrated in just a few years, whenever the next cyclical increase in gypsy moth populations coincides with dry spring weather that limits the effect of *Entomophaga maimaiga*. In those years, the areas not yet infested with gypsy moth due to the slower rate of spread maintained by STS will not face the choice of an enormous increase in spending on suppression (both aerial applications and treatments of individual trees by homeowners) or huge negative impacts of gypsy moth defoliation. Note that the large projected expenditures on aerial suppression may not be possible, either in budgetary or logistic terms. This suggests that the benefits estimates are lower bounds, because suppression is undertaken when it costs less than the expected impacts in the absence of suppression; therefore if aerial suppression cannot expand as rapidly as the gypsy moth population, the cost of defoliation (in terms of forest products and services, as well as nuisance and defoliation costs to residents of forested neighborhoods) will be even higher.

Table 4

r=4%	**Cost**	**Benefits**						**Net**	
		Quarantine	Suppression	Camping	Health	Residential			
		Costs	Costs	WTP	Costs	Costs	WTP	Cost savings	WTP - costs
2011	$10,093,515	$276,957	$7,777,273	$85,446	$24,978	$2,861,594	$7,140,323	$847,286	$5,186,483
2016	$9,053,804	$685,725	$12,844,695	$138,836	$51,145	$5,642,765	$14,327,725	$10,170,525	$18,943,177
2021	$7,859,125	$889,312	$16,081,842	$187,856	$66,766	$7,331,963	$18,705,878	$16,510,758	$28,005,763
2026	$6,684,946	$1,017,633	$18,506,988	222633.3233	$69,976	$7,791,244	$19,803,266	$20,700,896	$32,865,575
Total								$183,618,097	$348,496,327

Table 5

r=7%	Cost	Benefits						Net	
		Quarantine	Suppression	Camping	Health	Residential			
		Costs	Costs	WTP	Costs	Costs	WTP	Cost savings	WTP - costs
2011	$9,008,255	$247,178	$6,941,056	$76,258	$22,292	$2,553,914	$6,372,592	$756,185	$4,628,830
2016	$7,009,340	$530,879	$9,944,200	$107,485	$39,596	$4,368,557	$11,092,343	$7,873,891	$14,665,568
2021	$5,277,984	$597,239	$10,800,147	$126,159	$44,839	$4,923,956	$12,562,381	$11,088,196	$18,807,942
2026	$3,894,391	$592,834	$10,781,456	$129,698	$40,765	$4,538,878	$11,536,617	$12,059,542	$19,146,214
Total								$119,641,670	$237,910,599

The flat rate spread scenario assumes that if the STS program ended in 2006, the rate of spread of gypsy moth would immediately return to the recent historical average of 20.8 km/yr, starting in 2007. The alternative scenario shown in figure 3 assumes that the rate of spread adjusts over a 7 year period (dynamic) to its recent historical maxima in Wisconsin (also applied to Minnesota east of the prairies) and in the rest of the range. As shown in Table 6, this results is somewhat lower benefit:cost ratios and net present values for the program going forward into the future. It is important to note that this is precisely because of the effect of the program over its first seven years, when it slowed down the rate of spread.

Table 6: Comparing STS spread at 6km/yr to alternative DD7 spread

r=4%	**Cost**	**Benefits**						**Net**	
		Quarantine	Suppression	Camping	Health	Residential			
		Costs	Costs	WTP	Costs	Costs	WTP	Cost savings	WTP - costs
2011	$10,093,515	$273,123	$5,314,034	$73,228	$12,436	$1,505,055	$3,761,419	-$2,988,867	-$671,710
2016	$9,053,804	$1,038,481	$14,744,430	$162,833	$41,447	$4,797,252	$12,208,724	$11,567,805	$19,100,664
2021	$7,859,125	$1,485,760	$17,480,368	$176,380	$57,247	$6,432,732	$16,348,655	$17,596,981	$27,632,038
2026	$6,684,946	$1,705,011	$17,458,301	$199,778	$61,679	$6,885,174	$17,527,672	$19,425,219	$30,205,816
Total								$166,044,677	$295,702,565

In sum, under the assumed flat-rate spread scenario, the benefit:cost ratio for the STS program is at least 2, assuming that an average of 6% of susceptible basal area is defoliated annually and considering only the cost of aerial suppression (cooperative and private), medical expenditures (by 10% of households in defoliated zone affected by gypsy moth rash), and suppression and mitigation expenditures by households occupying single family homes (labeled net cost savings). Considering household willingness to pay to avoid all impacts of gypsy moth (including impacts on developed recreation, and the impacts of nuisance and defoliation in yards, neighborhoods, and local parks in defoliated zones), the benefits are estimated to be three times as high as the costs of operating the program. At a 4% discount rate, the total net present value of the program is $21 to $33 million, depending on which benefits are included. As with the ex ante assessment, these estimates exclude the benefits that would continue to accrue after 20 years of STS.

References Consulted

Blacksten, R., Herzer, I., & Kessler, C. (1978). *Final report: A cost benfit analysis for gypsy moth containment* No. KFR 161-78)Submitted by Ketron, Inc.; Submitted to USDA APHIS (PPQ).

Born, W., Rauschmayer, F., & Bräuer, I. (2005). Economic evaluation of biological invasions-a survey. *Ecological Economics, 55*, 321-336.

Buhyoff, G. J., & Leuschner, W. A. (1978). Estimating psychological disutility from damaged forest stands. *Forest Science, 24*(3), 424-432.

Buhyoff, G. J., Leuschner, W. A., & Arndt, L. K. (1980). Replication of a scenic preference function. *Forest Science, 26*(2), 227-230.

Burgess, A. F. (1917). *Suppression of the gipsy and brown-tail moths and its value to states not infested*U.S. Department of Agriculture, Yearbook of the United States Department of Agriculture for the year 1916.

Byrne, S. V., Wehrle, M. M., Keller, M. A., & Reynolds, J. F. (1987/2). Impact of gypsy moth infestation on forest succession in the north carolina piedmont: A simulation study. *Ecological Modelling, 35*(1-2), 63-84.

Chornesky, E. A., Bartuska, A. M., Applet, G. H., Britton, K. O., Cummings-Carlson, J., Davis, F. W., et al. (2005). Science priorities for reducing the threat of invasive species to sustainable forestry. *BioScience, 55*(4), 335-348.

Colbert, J. J., Perry, P., & Onken, B. (1997). Preparing for the gypsy moth-- design and analysis for stand management: Dorr run, wayne national forest. *Communicating the Role of Silviculture in Managing the National Forests: Proceedings of the National Silviculture Workshop,* Warren, PA. *, Gen. Tech. Rep. NE-238* 76-84.

Council of Tree and Landscape Appraisers. (2000). *Guide for plant appraisal, 9th edition* (9th ed.). Champaign, IL: International Society of Arboriculture.

Cumming, A. B., Nowak, D. J., Twardus, D. B., Hoehn, R., Mielke, M., & Rideout, R. (2007). *National forest health monitoring program, urban forests of wisconsin: Pilot monitoring project 2002* No. NA-FR-05-07). Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry.

Davidson, C. B., Gottschalk, K. W., & Johnson, J. E. (1999). Tree mortality following defolaition by the european gypsy moth (*lymantria dispar* L.) in the united states: A review. *Forest Science, 45*(1), 74-84.

Davidson, C. B., Gottschalk, K. W., & Johnson, J. E. (2001). *European gypsy moth (lymantria dispar L.) outbreaks: A review of the literature* No. Gen. Tech. Rep. NE-278). Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station.

Elkinton, J. S., & Liebhold, A. M. (1990). Population dynamics of gypsy moth in north america. *Annual Review of Entomology, 35*, 571-596.

Gansner, D. A., Drake, D. A., Arner, S. L., Hershey, R. R., & King, S. L. (1993). *Defoliation potential of gypsy moth* No. NE-INF-117-93). Radnor PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Gansner, D. A., & Herrick, O. W. (1987). *Estimating the benefits of gypsy moth control on timberland* No. Res. Note NE-337). Broomball, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Gansner, D. A., Herrick, O. W., Mason, G. N., & Gottschalk, K. W. (1987). Coping with the gypsy moth on new frontiers of infestation. *Southern Journal of Applied Forestry, 11*(4), 201-209.

Gansner, D. A., Herrick, O. W., & White, W. B. (1978). *Economic analysis of the gypsy moth problem in the northeast: IV. forest stand hazard ratings for gypsy moth* No. Forest Service Research Paper NE-410). Broomball, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Giedriaitis, J. P., & Kielbaso, J. J. (1982). *Municipal tree management*. Washington, DC: International City Management Association.

Gilbert, M., Grégoire, J. -., Freise, J. F., & Heitland, W. (2004). Blackwell publishing, ltd. long-distance dispersal and human population density allow the prediction of invasive patterns in the horse chestnut leafminer cameraria ohridella. *Journal of Animal Ecology, 73*, 459-468.

Gottschalk, K. W., Colbert, J. J., & Feicht, D. L. (1998). Tree mortality risk of oak due to gypsy moth. *Eur. J. for. Path., 28*, 121-132.

Gottschalk, K. W. (1990). Economic evaluation of gypsy moth damage in the united states of america. Montreal, Canada. 235-246.

Gottschalk, Kurt W. ed. (2005). Proceedings 16th U.S. department of agriculture interagency research forum on gypsy moth and other invasive species, 2005. Annapolis, MD. *, Gen. Tech. Rep. NE-337* 107 p.

Gottschalk, Kurt W. ed. (2007). Proceedings 17th U.S. department of agriculture interagency research forum on gypsy moth and other invasive species, 2006. Annapolis, MD. *, Gen. Tech. Rep. NRS-P-10* 117 p.

Gottschalk, K. W., & MacFarlane, W. R. (1992). *Photographc guide to crown condition of oaks: Use for gypsy moth silviculture* No. Gen. Tech. Rep. NE-168). Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Haefele, M. A., & Loomis, J. B. (2001). Using the conjoint analysis technique for the estimation of passive use values of forest health. *Journal of Forest Economics, 7*(1), 9-27.

Haefele, M., Kramer, R. A., & Holmes, T. P. (1991). Estimating the total value of forest quality in high-elevation spruce-fir forests. *The economic value of wilderness: Proceedings of the conference* (). Asheville, NC: Southeastern Forest Experiment Station. USDA Forest Service.

Hajek, A. E. (1997). Fungal and viral epizootics in gypsy moth (lepidoptera: Lymantriidae) populations in central new york. *Biological Control, 10*(1), 58-68.

Hennigar, C. R., MacLean, D. A., & Norfolk, C. J. (2007). Effects of gypsy moth defoliation on softwood and hardwood growth and mortality in new brunswick, canada. *North. J. Appl. for., 24*(2), 138-145.

Herrick, O. W. (1981). Forest pest management economics-application to the gypsy moth. *Forest Science, 27*(1), 128-138.

Hicks, Ray R., Jr., Riddle, K. S., & Brock, S. M. (1989). Direct control of insect defoliation in oak stands is economically feasible in preventing timber value loss. Carbondale, IL. 86-94.

Holmes, T. P., Murphy, E., & Bell, K. P. Exotic forest insects, neighborhood externalities and residential landscape values. *NAREA Workshop on Invasive Species,* Annapolis, Maryland.

Holmes, T. P., Bell, K. P., Byrne, B., & Wilson, J. S. (2008). Chapter 19: Economic aspects of invasive forest pest management. In T. P. Holmes, J. P. Prestemon & K. L. Abt (Eds.), *The economics of forest disturbances: Wildfires, storms, and invasive species* (pp. 381-406). Dordrecht, Netherlands: Springer.

Iverson, . (2000). *Urban forest cover of the chicago region and its relation to household density and income*. London, England: Chapman Hall.

Jakus, . (1994). *Averting behavior in the presence of public spillovers: Household control of nuisance pests*. Madison: University of Wisconsin.

Jakus, P., & Smith, K. *Measuring use and nonuse values for landscape amenities:A contingent behavior analysis of gypsy moth control.* Unpublished Resources for the Future,

Jakus, P. M. (1994). Averting behavior in the presence of public spillovers: Household control of nuisance pests. *Land Economics, 70*(3), 273-285.

Jakus, P. M. (1992). Valuing the private and public dimensions of a mixed good: An application to pest control. (Ph.D., North Carolina State University).

Jenkins, D. H., Sullivan, J., Amacher, G. S., Nicholas, N. S., & Reaves, D. W. (2002). Valuing high altitude spruce-fir forest improvements: Importance of forest condition and recreation activity. *Journal of Forest Economics, 8*(1), 77-99.

Jim, C. Y. (2006). Formulaic expert method to integrate evaluation and valuation of heritage trees in compact city. *Environmental Monitoring and Assessment, 116*(1-3), 53-80.

Johnson, D. M., Liebhold, A. M., Tobin, P. C., & Bjørnstad, O. N. (2006). *Allee effects and pulsed invasion by the gypsy moth.*

Kaval, P. (2006). *US park recreation values (1968-2003): A review of the literature*University of Waikato, Department of Economics.

King, J. A., Ridgway, R. L., Straka, T. J., Tichenor, R. H., Jr., & Hedden, R. L. (1994). Cost analysis of a specialized gypsy moth (lepidoptera: Lymantriidae) management program for suburban parks. Harrisburg, PA. 103-115.

Krcmar-Nozic, E., Wilson, B., & Arthur, L. (2000). *The potential impacts of exotic forest pests in north america: A synthesis of research* No. Information Report BC-X-387). Victoria, British Columbia: Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre.

Krist, Frank J., Jr., Sapio, F. J., & Tkacz, B. M. (2007). *Mapping risk from forest insects and diseases* No. FHTET 2007-06). Fort Collins, CO: US Department of Agriculture, Forest Service, Forest Health Protection, Forest Health Technology Enterprise Team.

Kuser, J. E. (2000). *Handbook of urban and community forestry in the northeast*. New York: Kluwer Academic/Plenum Publishers.

Laverne, . (2003). *The influence of trees and landscaping on rental rates at office buildings.* Champaign, Ill., etc.: International Society of Arboriculture.

LeDoux, C. B. (1990). Determining the economic feasibility of salvaging gypsy moth-killed hardwoods. *Forest Products Journal, 40*(5), 43-46.

Leefers, L. A., & Vasievich, J. M. (2001). An analysis of campground resources in the lake states. *In Trends 2000: Shaping the Future, the Fifth Outdoor Recreation and Tourism Symposium,* East Lansing, MI. 176-183.

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.

Leuschner, W. A., & Young, R. L. (1978). *Estimating the southern pine beetle's impact on reservoir campsites*. [Bethesda, MD, etc.,: Society of American Foresters].

Leuschner, W. A. (1991). *Gypsy moth containment program economic assessment final report*

Levin, D. B. (2005). Human health impact assessment after exposures to *bacillus thuringiensis* subspecies *kurstaki*. *6th Pacific Rim Conference on the Biotechnology of Bacillus Thuringiensis and its Environmental Impact,* Victoria, BC. 61-63.

Liebhold, . (1993). *Geostatistics and geographic information systems in applied insect ecology*. Palo Alto, Calif. [etc.]: Annual Reviews [etc.].

LIEBHOLD, . (1996). *Use of a geographic information system to evaluate regional treatment effects in a gypsy moth(lepidoptera: Lymantriidae) management program*. [Lanham, Md., etc.]: Entomological Society of America [etc.].

Liebhold, . (2000). *What causes outbreaks of the gypsy moth in north america?*. Tokyo: Society of Population Ecology and Springer-Verlag.

Liebhold, . (2006). *Growth of newly established alien populations: Comparison of north american gypsy moth colonies with invasion theory*. Tokyo: Society of Population Ecology and Springer-Verlag.

Liebhold, A. M., & Sharov, A. A. Testing for correlation in the presence of spatial autocorrelation in insect count data. *Population and community ecology for insect management and conservation* (pp. 11-117). Rotterdam: Balkema.

Liebhold, A. M., Gottschalk, K. W., Mason, D. A., & Bush, R. R. (1997). Forest susceptibility to the gypsy moth. *Journal of Forestry, 95*, 20-24.

Liebhold, A., Thorpe, K., Ghent, J., & Lyons, D. B. (1994). *Gypsy moth egg mass sampling for decision-making: A user's guide* No. NA-TP-04-94)U.S. Department of Agriculture, Forest Service, Northeastern Area, Southern Region, Forest Health Production.

Lovett, G. M., Canham, C. D., Arthur, M. A., Weathers, K. C., & Fitzhugh, R. D. (2006). Forest ecosystem responses to exotic pests and pathogens in eastern north america. *BioScience, 56*(5), 395-405.

MacDonald, H., McKenney, D. W., & Nealis, V. (1997). *A bug is a bug is a bug: Symbolic responses to contingent valuation questions about forest pest control programs*. Ann Arbor, Mich.: University Microfilms, Economics Society.

Mack, . (2000). Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications, 10*(3), 689.

Mahr, D. L. (1994). Gypsy moth: A future wisconsin cranberry pest? *Wisconsin Cranberry School 1994 Proceedings, , 5* 44-47.

Mansfield, C., Pattanayak, S. K., McDow, W., McDonald, R., & Halpin, P. (2005). Shades of green: Measuring the value of urban forests in the housing market. *Journal of Forest Economics, 11*(3), 177-199.

Marler, R. L., & McCrea, J. C. (1977). *New york and pennsylvania private homeowner attitudes toward gypsy moth* No. Applied Forestry Research Institute Research Report No. 34). Syracuse, NY: State University of New York College of Environmental Science and Forestry.

Mayo, J. H., Straka, T. J., & Leonard, D. S. (2003). *The cost of slowing the spread of the gypsy moth (lepidoptera: Lymantriidae).* [Lanham, Md., etc.]: Entomological Society of America [etc.].

McCay, R. E., & White, W. B. (1973). *Economic analysis of the gypsy moth problem in the northeast: I. applied to commercial forest stands* No. Research Paper NE-275). Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

McPherson, G., Simpson, J. R., Peper, P. J., Maco, S. E., & Xiao, Q. (2005). Municipal forest benefits and costs in five US cities. *Journal of Forestry, 103*(8), 411-416.

Mcpherson, E. G. (1992). Accounting for benefits and costs of urban greenspace. *Landscape and Urban Planning, 22*(1), 41-51.

McPherson, E. G., Nowak, D., Heisler, G., Grimmond, S., Souch, C., Grant, R., et al. (1997). Quantifying urban forest structure, function, and value: The chicago urban forest climate project. *Urban Ecosystems, 1*(1), 49-61.

Michalson, E. L. (1975). Economic impact of mountain pine beetle on outdoor recreation. *Journal of Agricultural Economics, 7*, 43-50.

Miller, J. D., & Lindsay, B. E. (1993). Influences on individual initiative to use gypsy moth control in new hampshire, USA. *Environmental Management, 17*(6), 765-772.

Miller, J. D., & Lindsay, B. E. (1993). Willingness to pay for a state gypsy moth control program in new hampshire: A contingent valuation case study. *Forest Entomology, 83*(3), 828-837.

Minnesota Department of Agriculture. Gypsy moth. *Brochure: Minnesota Department of Agriculture, Plant Protection Division, Gypsy Moth Unit,*

Minnesota Department of Agriculture. Gypsy moth quarantine pest alert: How to protect your nursery from this devastating pest. *Brochure: Minnesota Department of Agriculture, Gypsy Moth Unit,*

Moeller, G. H., Marler, R. L., McCay, R. E., & White, W. B. (1977). *Economic analysis of the gypsy moth problem in the northeast: III. impacts on homeowners and managers of recreation areas*

No. Research Paper NE-360). Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Morales, D. J., Boyce, B. N., & Favretti, R. J. The contribution of trees to residential property value: manchester, connecticut. *Valuation, 23*(2), 26-43.

Morancho, A. B. (2003/12/15). A hedonic valuation of urban green areas. *Landscape and Urban Planning, 66*(1), 35-41.

Mullenn, J. D., Alston, J. M., Sumner, D. A., Kreith, M. T., & Kuminoff, N. V. (2005). The payoff to public investments in pest-management R&D: General issues and a case study emphasizing integrated pest management in california. *Review of Agricultural Economics, 27*, 558-573.

Muzika, R. M., & Liebhold, A. M. (1999). Changes in radical increment of host and nonhost tree species with gypsy moth defoliation. *Can. J. for. Res., 29*, 1365-1373.

Myers, J H Savoie, A van Randen,E. (1998). *Eradication and pest management.* Palo Alto, Calif. [etc.]: Annual Reviews [etc.].

Netusil, . (2005). *The effect of environmental zoning and amenities on property values: Portland, oregon*. Madison: University of Wisconsin.

Nowak, D. J., Crane, D. E., & Dwyer, J. F. (2002). Compensatory value of urban trees in the united states. *Journal of Arboriculture, 28*(4), 194.

Nowak, D. J., United States. Forest Service. Northeastern Research Station, & Brooklyn. (2002). *Brooklyn's urban forest*. Newtown Square, PA: U.S. Dept. of Agriculture, Forest Service, Northeastern Research Station.

Nowak, D. J., United States. Forest Service. Northeastern Research Station, & Brooklyn. (2002). *Brooklyn's urban forest*. Newtown Square, PA: U.S. Dept. of Agriculture, Forest Service, Northeastern Research Station.

Olson, L. J. (2006). The economics of terrestrial invasive species: A review of the literature. *Agricultural and Resource Economics Review, 35*(1), 178-194.

Onstad, D. W., Nowak, D. J., & Jeffords, M. R. (1997). Potential defoliation of trees by outbreak populations of gypsy moth in the chicago area. *Journal of Arboriculture, 23*(2), 57-64.

Payne, B. R., & Strom, S. (1975). The contribution of trees to the appraised value of unimproved residential land. *Valuation, 22*(2), 36-45.

Payne, B. R., White, W. B., Mccay, R. E., & Mcnichols, R. R. (1973). *Economic analysis of the gypsy moth problem in the northeast: II. applied to residential property* No. Research Paper NE-285). Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Pimentel, D., Zuniga, R., & Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the united states. *Ecological Economics, 52*(3), 273-288.

Potter, W. D., Deng, X., Li, J., Xu, M., Wei, Y., Lappas, I., et al. (2000). A web-based expert system for gypsy moth risk assessment. *Computers and Electronics in Agriculture, 27*(1-3), 95-105.

Ratnayake, Jay Dale, Pat E Sipe, Neil G Daniels,Peter. (2006). *Impact of biting midges on residential property values in hervey bay, queensland, australia.* [Fresno, Calif.]: The American Mosquito Control Association.

Raupp, M. J., Buckelew Cumming, A., & Raupp, E. C. (2006). Street tree diversity in eastern north america and its potential for tree loss to exotic borers. *Arboriculture & Urban Forestry, 32*(6), 297-304.

Reardon, R. C., Leonard, D. S., Mastro, V. C., Leonhardt, B. A., McLane, W., Talley, S., et al. (1998). *Using mating disruption to manage gypsy moth: A review*. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team.

Reardon, R. C., Podgwaite, J., & Zerillo, R. (1996). *Gypcheck- the gypsy moth nucleopolyhedrosis virus product*. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team.

Reardon, R., Venables, L., & Roberts, A. *The maryland integrated pest management gypsy moth project 1983-1987* No. NA-TP-07-93). United States Department of Agriculture, Forest Service Northeastern Area:

Reinhardt, F., Herle, M., Bastiansen, F., & Streit, B. (2003). *Economic impact of the spread of alien spieces in germany* No. Research Report 201 86 211). Berlin: Federal Environmental Agency (Umweltbundesamt).

Ridgway, R. L., Thorpe, K. W., Webb, R. E., & Venables, L. (1994). Gypsy-moth management in suburban parks - program-evaluation. *Journal of Entomological Science, 29*(4), 557-569.

Rosenberger, R. S., & Loomis, J. B. (2001). *Benefit transfer of outdoor recreation use values: A technical document supporting the forest service strategic plan (2000 revision)* No. Gen. Tech. Rep. RMRS-GTR-72). Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Sharov, . (1997). *Correlation of counts of gypsy moths (lepidoptera: Lymantriidae) in pheromone traps with landscape*. [Bethesda, MD, etc.,: Society of American Foresters].

SHAROV, . (1998). *Optimizing the use of barrier zones to slow the spread of gypsy moth(lepidoptera: Lymantriidae) in north america*. [Lanham, Md., etc.]: Entomological Society of America [etc.].

Sharov, A. A. (2004). *Bioeconomics of managing the spread of exotic pest species with barrier zones*. [Malden, MA]: Blackwell Publishers.

Sharov, A. A., Leonard, D., Liebhold, A. M., Roberts, E. A., & Dickerson, W. (2002). "Slow the spread" A national program to contain the gypsy moth. *Journal of Forestry, 100*(5), 30-35.

Sharov, A. A., & Liebhold, A. M. (1998). Bioeconomics of managing the spread of exotic pest species with barrier zones. *Ecological Applications, 8*(3), 833-845.

Sharov, A. A., & Liebhold, A. M. (1998). MODEL OF SLOWING THE SPREAD OF GYPSY MOTH (LEPIDOPTERA: LYMANTRIIDAE) WITH A BARRIER ZONE.. *Ecological Applications, 8*(4), 1170-1179.

Sharov, A. A., Liebhold, A. M., & Roberts, E. A. (1996). Spread of gypsy moth (lepidoptera: Lymantriidae) in the central appalachians: Comparison of population boundaries obtained from male moth capture, egg mass counts, and defoliation records. *Environmental Entomology, 25*(4), 783-792.

Sheppard, S., & Picard, P. (2006). Visual-quality impacts of forest pest activity at the landscape level: A synthesis of published knowledge and research needs. *Landscape and Urban Planning, 77*, 321-342.

Stein, K. J., & Ravlin, F. W. (2002). *Aesthetic and economic impacts of the gypsy moth in residential areas.* Retrieved August 14, 2008, from http://www.gypsymoth.ento.vt.edu/vagm/gm_impact.html

Straka, T. J., Ridgway, R. L., Tichenor, R. H., Hedden, R. L., & King, J. A. (1997). Cost analysis of a specialized gypsy moth management program for suburban parks. *Northern Journal of Applied Forestry, 14*(1), 32-39.

Strazanac, J. S., & Butler, L. (Eds.). (2005). *Long-term evaluation of the effects of baccillus thuringiensis kurstaki, gypsy moth nucleopolyhedrosis virus product gypchek, and entomophaga maimaiga on nontarget organisms in mixed broadleaf-pine forests in the central appalachians*. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team.

Taylor, C. M., & Hastings, A. (2005). Allee effects in biological invasions. *Ecology Letters, 8*, 895-908.

Tcheslavskaia, . (2005). *Effects of intentional gaps in spray coverage on the efficacy of gypsy moth mating disruption.* Berlin: P. Parey.

Thompson, . (1999). *Valuation of tree aesthetics on small urban interface properties*. Champaign, Ill., etc.: International Society of Arboriculture.

Thorpe, K. W., Tcheslavskaia, K. S., Tobin, P. C., Blackburn, L. M., Leonard, D. S., & Roberts, E. A. (2007). Persistent effects of aerial applications of disparlure on gypsy moth: Trap catch and mating success. *Entomologia Experimentalis Et Applicata, 125*(3), 223-229.

Tobin, . (2004). *Estimation of the spatial autocorrelation function: Consequences of sampling dynamic populations in space and time*. Copenhagen: Munksgaard International Publishers.

Tobin, . (2005). *Roles of dispersal, stochasticity, and nonlinear dynamics in the spatial structuring of seasonal natural enemy-victim populations*. Tokyo: Society of Population Ecology and Springer-Verlag.

Tobin, . (2007). *Comparison of methods for estimating the spread of a non-indigenous species*. [Oxford, Eng.]: Blackwell Scientific Publications.

Tobin, . (2007). *Invasion speed is affected by geographical variation in the strength of allee effects*. Oxford, UK: Blackwell Science.

Tobin, P. C. (2006). *Implementation of the gypsy moth slow-the-spead project: Technical considertaions and cost analyses*. Morgantown, West Virginia: USDA Forest Service, Northern Research Station.

Tobin, P. C., & Blackburn, L. M. (Eds.). (2007). *Slow the spread: A national program to manage the gypsy moth*. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Tobin, P. C., Sharov, A. A., Liebhold, A. A., Leonard, D. S., Roberts, E. A., & Learn, M. R. (2004). Management of the gypsy moth through a decision algorithm under the STS project. *American Entomologist, 50*(4), 200-209.

Tobin, P. C., & Whitmire, S. L. (2005). *Spread of gypsy moth (lepidoptera : Lymantriidae) and its relationship to defoliation*. [College Park, Md.]: Entomological Society of America.

Tobin, P. C., Whitmire, S. L., Johnson, D. M., Bjørnstad, O. N., & Liebhold, A. M. (2007). Invasion speed is affected by geographical variation in the strength of allee effects. *Ecology Letters, 10*, 36-43.

Tuthill, R. W., Canada, A. T., Wilcock, K., Etkind, P. H., O'Dell, T. M., & Shama, S. K. (1984). AN EPIDEMIOLOGIC-STUDY OF GYPSY-MOTH RASH. *American Journal of Public Health, 74*(8), 799.

Tyrvainen, . (2000). Property prices and urban forest amenities. *Journal of Environmental Economics and Management, 39*(2), 205.

Vaughn, C. D., Straka, T. J., Ham, D. L., Hedden, R. L., & Thorpe, K. W. (1997). Costs associated with urban gypsy moth control by arborists: A case study. *Journal of Arboriculture, 23*(5), 173-180.

Wallner, W. E. (1997). Global gypsy - the moth that gets around. *Exotic Pests of Eastern Forests,* Nashville, TN.

Wallner, W. E. (2004). Assessing exotic threats to forest resources. In K. O. Britton (Ed.), *Biological pollution : An emerging global menace* (pp. 82-95). St. Paul, Minn.: The American Phytopathological Society.

Walsh, . (1981). *Value of trees to residential property owners with mountain pine beetle and spruce budworm damage in the colorado front range*

Watts, R. D., Compton, R. W., McCammon, J. H., Rich, C. L., Wright, S. M., Owens, T., et al. (2007). Roadless space of the conterminous united states. *Science, 316*, 736-738.

Webb, R. E., Ridgway, R. L., Thorpe, K. W., Tatman, K. M., Wieber, A. M., & Venables, L. (1991). Development of a specialized gypsy-moth (lepidoptera: Lymantriidae) management program for suburban parks. *Journal of Economic Entomology, 84*(4), 1320-1328.

Webb, R. E., Peiffer, R., Fuester, R. W., Thorpe, K. W., Calabrese, L., & McLaughlin, J. M. (1998). An evaluation of the residual activity of traditional, safe, and biological insecticides against the gypsy moth. *Journal of Arboriculture, 24*(5), 286-293.

Weseloh, R. M. (2003). People and the gypsy moth: A story of human interactions with an invasive species. *American Entomologist, 49*(3), 180-190.

Weseloh, R. M. (2002). Modeling the impact of the fungus entomophaga maimaiga (zygomycetes: Entomophthorales) on gypsy moth (lepidoptera: Lymantriidae): Incorporating infection by conidia. *Environmental Entomology, 31*(6), 1071-1084.

White, W. B., & Schneeberger, N. F. (1981). Chapter 7 socioeconomic impacts. In C. C. Doane, & M. L. McManus (Eds.), *The gypsy moth: Research toward integrated pest management* (pp. 681-694) Expanded Gypsy Moth Research and development Program, Forest Service, US Department of Agriculture, Washington DC.

White, E. M., & Carver, A. D. (2004). Modeling timber mill procurement influence effects on interstate sawlog exportation. *Forest Policy and Economics, 6*(6), 529-537.

Whitehead, J. C., Haab, T. C., & Huang, J. (2000/10). Measuring recreation benefits of quality improvements with revealed and stated behavior data. *Resource and Energy Economics, 22*(4), 339-354.

Whitmire, . (2006). *Persistence of invading gypsy moth populations in the united states*. Berlin,: Springer-Verlag.

Wickman, B. E., & Renton, D. A. *Evaluating damage caused to a campground by douglas-fir tussock moth*. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

WILLIS, . (1992). *Amenity value of forests in great britain and its impact on the internal rate of return from forestry*. London: Oxford University Press.

Wolf, K. L. (2005). Business district streetscapes, trees, and consumer response. *Journal of Forestry, 103*(8), 396-400.

Appendix 1

- Interim progress report, October 2007
- Presentation to *Annual Gypsy Moth Review*, October 2007
- Presentation to *Invasive Species Forum*, January 2008
- Presentation to STS board, February 2008
- Interim progress report, February 2008

An Assessment of the Economic Feasibility of the Gypsy Moth Slow the Spread Project

Interim Progress Report to USDA Forest Service State & Private Forestry

October 2007

Grant number: 06-DG-11244225-337
Project duration: September 2006 – February 2008

Report period: September 2006 – September 2007

Researcher: Erin O. Sills, Associate Professor, Dept of Forestry & Environmental Resources, North Carolina State University

Context: The gypsy moth, *Lymantria dispar* (L.), has been gradually expanding its range in North America since its accidental release into Massachusetts in 1869. The Gypsy Moth Slow the Spread Program (STS) has slowed down the range expansion by detecting and eradicating isolated populations that establish outside of the infected zone. In 1990, the USDA Forest Service contracted an economist to conduct a rapid and approximate analysis to indicate the general order of magnitude of benefits and costs that might be expected if a program to contain the spread of the gypsy moths was initiated. Because much has changed in the gypsy moth range and its management, and possibly in the potential economic costs and benefits, since this previous report was completed, it is timely to conduct another economic analysis of the program.

Objectives:
1. Estimate the benefits of STS during its full operational phase, 2000 – 2006, and compare to the costs of administering the program (*ex post analysis*)
2. Project and compare the benefits and costs of STS for the next 20 years, 2007 – 2026 (*ex ante analysis*)

Personnel:
Two graduate students have provided research assistance:
Tzu-Ming Liu and Kevin Bigsby

Timeline:
- Plan of analysis was presented at the GM Research Forum in January 2007
- Status report was provided to the GM Review Board in October 2007
- Preliminary ex post analysis to be reported at GM Review in October 2007
- Final ex post and prelim ex ante analysis to be reported at GM Research Forum in January 2008

Tasks:

Completed:

- ✓ Establish parameters for analysis
  - o Discount rate 4% or 7% (PV of $100 in 20 years is $45 at 4%, or $25 at 7%)
- ✓ Determine cost of STS
  - o Ex post ~$11 million per year in 2000 dollars
- ✓ Model spread and quarantine without STS ex post, and with and without STS ex ante
  - o Spread without STS ~21K/ year, or 46.5K/ year in WI
  - o Spread with STS ~6K/ year, 10K/ year, or 11.5K/ yr in WI and 2.9K/ yr elsewhere
  - o Transition to spread without STS: increase over 0, 6, 10, or 20 yrs to non-STS rate
- ✓ Review literature for landscape, recreation, timber, and management benefits estimates
  - o Homeowner willingness to pay estimates $20 - $300 per household
  - o Regional databases on developed forest recreation sites
  - o Timber loss clearest with severe defoliation in oak dominated forest

On-going:

- ➢ Estimate defoliation probabilities as function of forest type and years in GIZ
- ➢ Request quarantine cost estimates from APHIS
- ➢ Collect primary data on private and local expenditures to mitigate GM impacts
- ➢ Model impact of individual state programs on spread (focus on TZ in neighboring states)

Next steps:

- ▪ Model anthropogenic influences on spread (highest cost, most likely reduced by STS)
- ▪ Estimate trends in suppression costs, population, recreation, and timber prices

Planned Outputs:

- ▪ NPV and Benefit-Cost Ratio for ex post and ex ante STS under range of spread scenarios
- ▪ NPV and Benefit-Cost Ratio for individual states under simple spread scenario
- ▪ Changes in benefits and costs that would drive NPV<0 or BCR<1

Balancing the costs & benefits of slowing the spread

Erin Sills and Kevin Bigsby

DEPARTMENT of FORESTRY and ENVIRONMENTAL RESOURCES
NC STATE UNIVERSITY

Road map

- Framework analysis
- Costs
- Benefits
  - Quarantine
  - Management costs + losses
- *Ex post* analysis: 2000 – 2006
- Next steps and related analyses

Conceptual framework

- Counterfactual (what happens without STS?)
  - No replacement barrier zone program
  - No change in suppression, quarantine, eradication programs
- Net present value (NPV) as summary metric

  = ∑PV{benefits – costs with STS}

  – ∑PV{benefits – costs without STS}

  = ∑PV{incremental benefits of STS} – PV{costs of STS}
- Accounting framework (whose costs and benefits count?)
  - Entire US (federal, state, local, private)
- Timeframe
  - *Ex post:* 2000 – 2006 (7 years in 2000 dollars)
  - *Ex ante:* 2007 – 2026 (20 years in 2007 dollars)
- Future discounted at 4% (7%)/year constant exponential rate

STS Costs

Ex post: ∑ PV of STS Budget 2000 – 2006

∑(Cost of STS in year t)$(1.04)^{-t}$ = **\$69 million** (2000)

Ex ante: ∑ PV of STS Budget 2007 – 2026

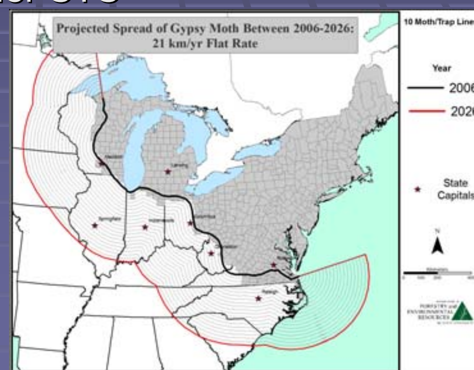
STS maintains same rate of spread at same cost

- STS Budget per HA = **\$0.45** (2007)
- ∑ (0.45 * HA in year t)$(1.04)^{-t}$

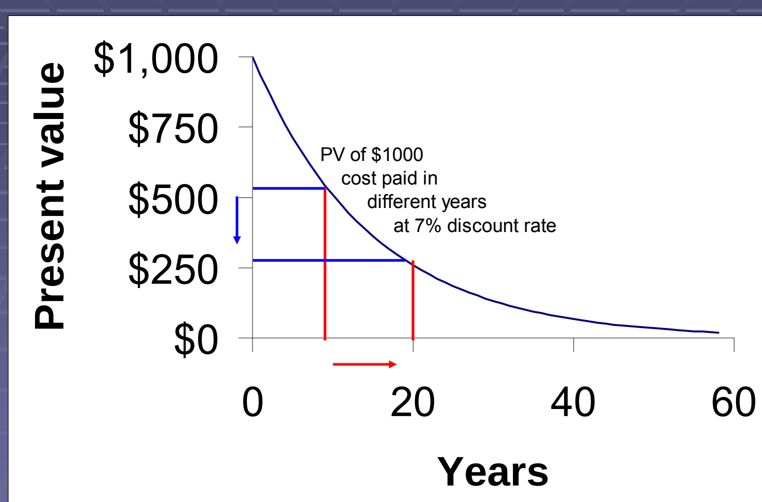
Project trapping costs as function of scale of state program, terrain, road density, and year

STS Benefits

- Smaller area enters the generally infested zone (GIZ) each year
  - 6 KM per year under STS
  - 20.8 KM per year without STS



Benefits of delay

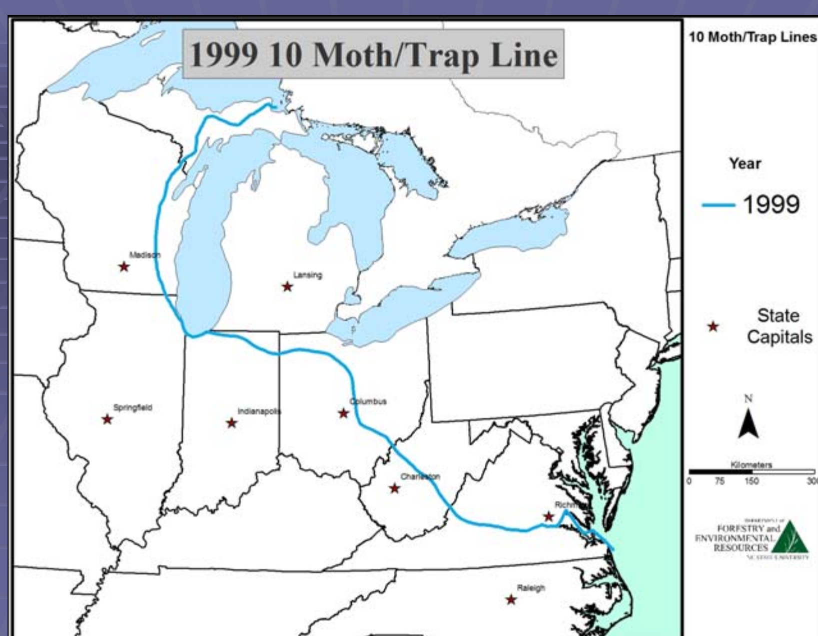


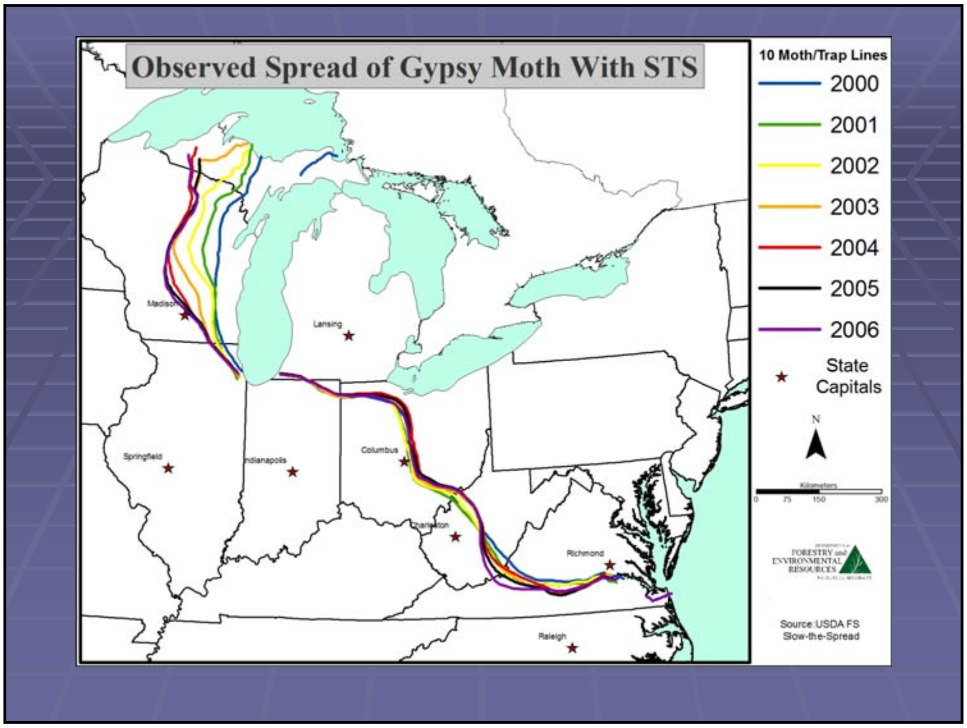
STS Benefits

- Impacts of entering the GIZ
  - Quarantine = APHIS, state, & industry
  - Costs = expenditures on suppression (preventing or reducing nuisance & defoliation by gypsy moths)
  - Losses = reduction in profits & utility due to nuisance & defoliation by gypsy moths = willingness to pay (WTP) to avoid impacts not prevented through suppression efforts

Minimum

Ex post …




Observed Spread of Gypsy Moth With STS
10 Moth/Trap Lines
2000
2001
2002
2003
2004
2005
2006
State Capitals
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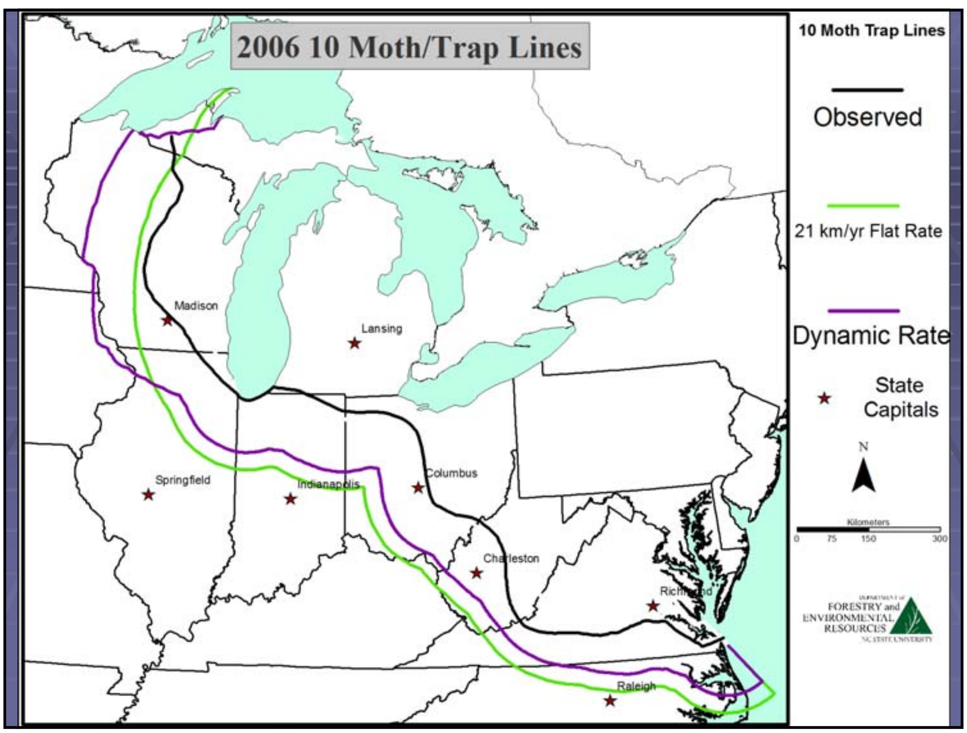
Springfield
Indianapolis
Columbus
Charleston
Richmond
Raleigh
Source:USDA FS Slow-the-Spread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Dynamic Rate
State Capitals
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FORESTRY and ENVIRONMENTAL RESOURCES

Impacts of STS on 2006 GIZ

24 million hectares

5.2 million HA oak- pine/hickory/gum-cypress

6.7 million households

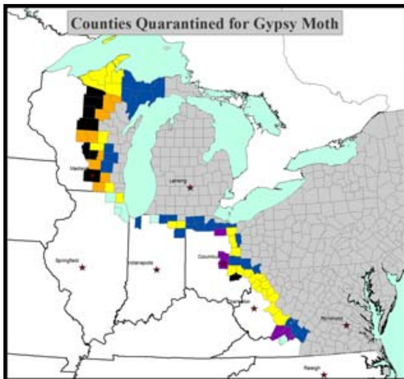
12 tourism-based rural counties

Quarantine delayed by STS

Incremental impacts in 2006

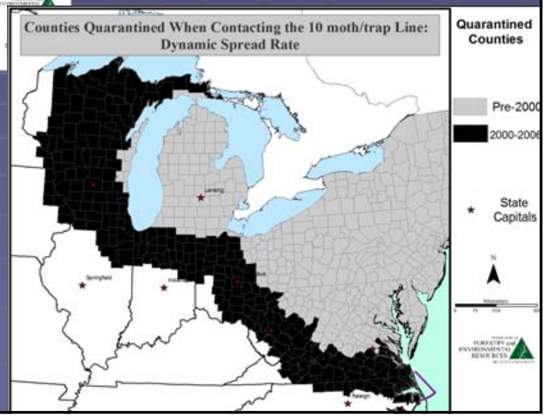
- 217 more counties in quarantine
- 374 more mills in quarantine
- counties quarantined when 50% in GIZ

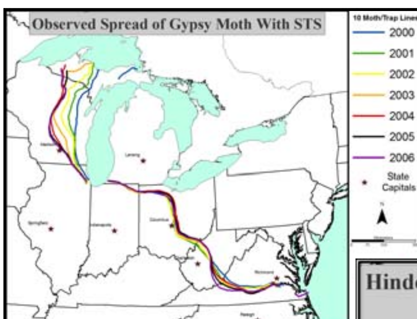
Alternative: once most of state is in the GIZ, quarantine counties as soon as any portion comes into the GIZ (“throw in the towel”)



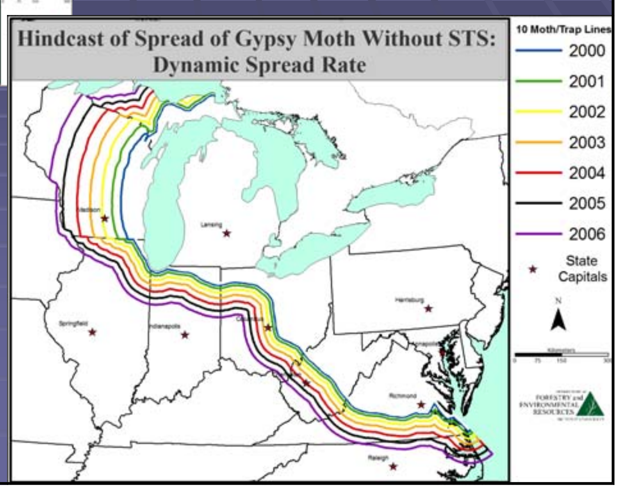
Contact quarantine rule
Spread without STS

With STS





Management Costs +
Losses from
defoliation & nuisance



Costs + losses

- Major losses are residential & recreational
- Leuschner et al. 1996 SJAF 20(2)
  - Average WTP per household
  - Decreased recreation at campgrounds & picnic areas
  - Average management per hectare
- Updated with recent experience & literature to obtain lower bound estimate
  - Average WTP for treatment programs
  - Decreased recreation at campgrounds
  - State suppression programs & homeowner treatments

Management costs delayed by STS

- Leuschner et al. $0.59 / HA
  - PV = $42 million

  OR
- Suppression (aerial spraying) programs
  - $0.08 - $0.18/HA for land area of state in the GIZ
  - PV = $6.6 million
- Homeowner costs
  - $50 to treat gypsy moths on 1/5 of single/dual family residences
  - PV = $18.3 million
- Aerial + homeowners = $25 million

Losses delayed by STS

Defoliation (despite suppression)

- Leuschner et al. (1996): 9.7% annual defoliation of susceptible areas (oak forest types, recreation sites, homesites)
- Alternative: extrapolate states average annual defoliation of 0.1% to 1.8% of land area

Losses delayed by STS

- Homeowners
  - Leuschner et al. (1996): $54/ household in the GIZ
  - PV = $331.1 million
  - Miller and Lindsay (1993): 50% of households, $90 per household annual WTP to have property treated for gypsy moths ***when facing defoliation (10% per year)***
  - PV = $118.1 million
- Recreation
  - 500 additional campgrounds in 2006 (NORSIS)
  - 10% per year defoliated
  - Benefit transfer from the literature (Leuschner et al. 1996)
  - PV = $4.9 million

Summary metric

- Benefits = $25 + $118.1 + $4.9 million
  = $148 million
- Costs = $69 million
- NPV > 0, B:C ratio > 2

Lower bound because excludes

- Timber
- Management costs of local govt and business
- Impacts after 6 years
- Benefits other than delay

Benefits in addition to delay

Future costs & losses could be reduced by

- R&D
- Reduced defoliation rates due to natural enemies
- Time to educate and adapt

Related work

- Impacts of GM defoliation in urban areas
  - Baltimore suburbs, Jersey City, Scranton
  - Benefits of urban forest lost due to defoliation and mortality; costs of clean-up and tree removal and replacement
- Anthropogenic factors in spread of GM
  - Gravity model
  - Non-linear component of spread into high-impact areas that is targeted by STS
- State by state

Thanks to

- Patrick Tobin
- Tzu-Ming Liu
- Subhrendu Pattanayak
- You!

… for your suggestions and questions:

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Balancing the costs & benefits of slowing the spread of the gypsy moths

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NC STATE UNIVERSITY

Road map

- Slow the spread program
- Framework for analysis
- Costs
- Benefits
  - Spread
  - Quarantine
  - Management costs + losses
- Non-market valuation of losses
- Related analyses

Slow the Spread Program

- Targets gypsy moth (*Lymantria dispar*), which was introduced to MA in 1860s
- Monitors and eradicates isolated colonies of GM in the transition zone (TZ) in front of the generally infested zone (GIZ)
- Supported by USDA and state gov'ts, coordinated by Slow the Spread Fdn
- Fully operational since 1999

Conceptual framework

- Timeframe
  - *Ex post:* 2000 – 2006 (7 years in 2000 dollars)
  - *Ex ante:* 2007 – 2026 (20 years in 2007 dollars)
- Counterfactual (what happens without STS?)
  - No replacement barrier zone program
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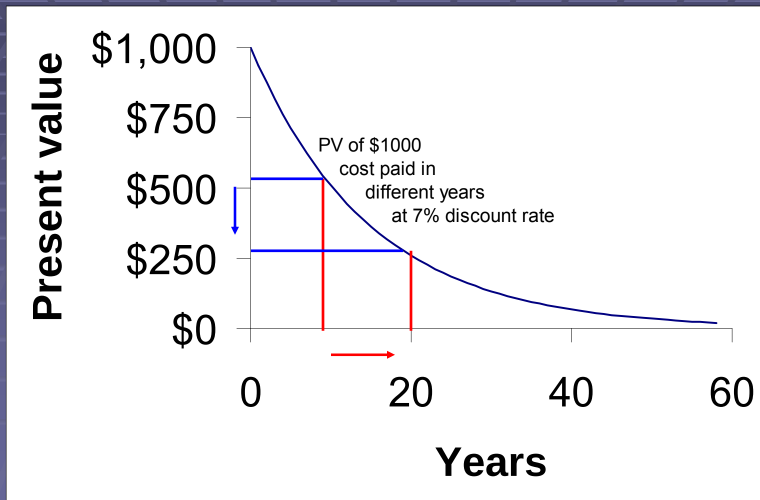
Benefits of delay



STS Costs

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Ex ante: ∑ PV of STS Budget 2007 – 2026

STS maintains same rate of spread at same cost

- STS Budget per HA = **$0.45** (2007)
- ∑ (0.45 * HA in year t)$(1.04)^{-t}$

Cost per trap as function of (1) total number of traps and (2) hectares of mountain area in each state's TZ (explains ~ 70% of variation)

Treatment cost as fixed ratio to HA in TZ

Indirect costs as fixed multiplier on # of states in TZ

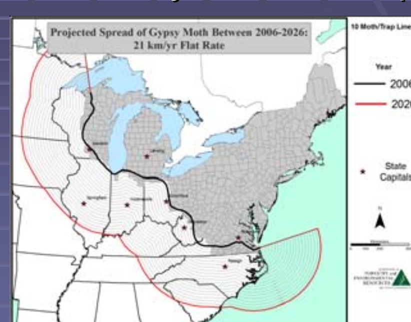
STS Benefits

- Smaller area enters the generally infested zone each year

- Counties are quarantined later
- Smaller area requires suppression and is defoliated every year
- Smaller costs and losses from gypsy moth

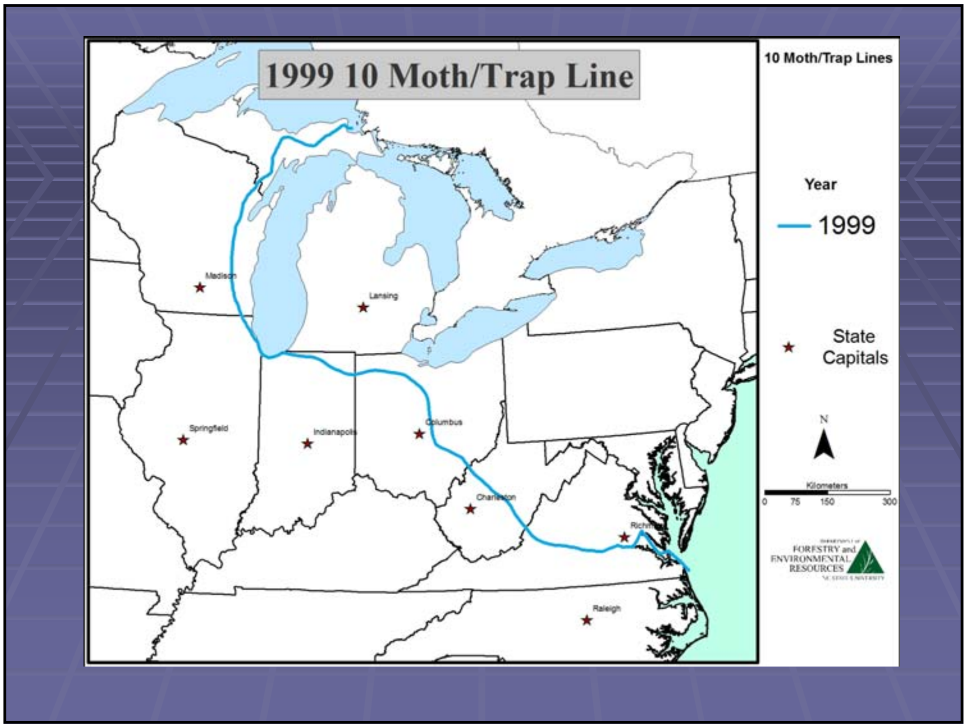
Spread rates without STS

Rate of expansion of GIZ, defined by 10 moth/ trap line



- 20.8 km/ year
- Dynamic differentiated

  Faster in UP, WI, MN (11.5 to 45 vs. 2.9 to 20.8) until prairies, with boundary effect


1999 10 Moth/Trap Line
10 Moth/Trap Lines
Year
1999
State Capitals
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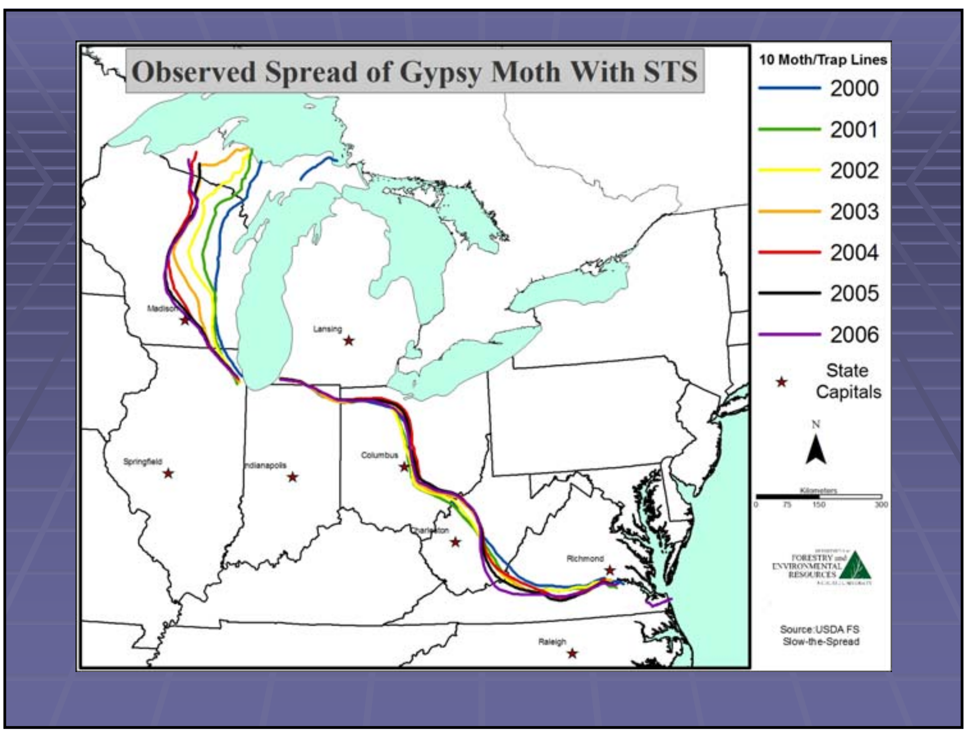
Springfield
Indianapolis
Columbus
Charleston
Raleigh
N
Kilometers
0 75 150 300
FORESTRY and ENVIRONMENTAL RESOURCES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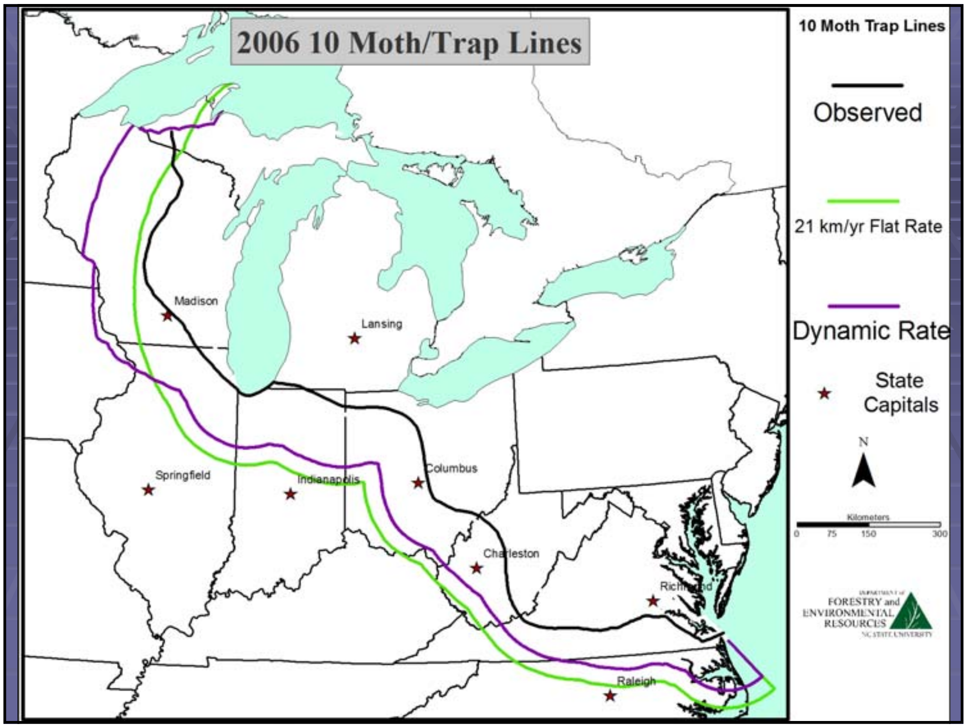
FORESTRY and ENVIRONMENTAL RESOURCES
Source:USDA FS Slow-the-Spread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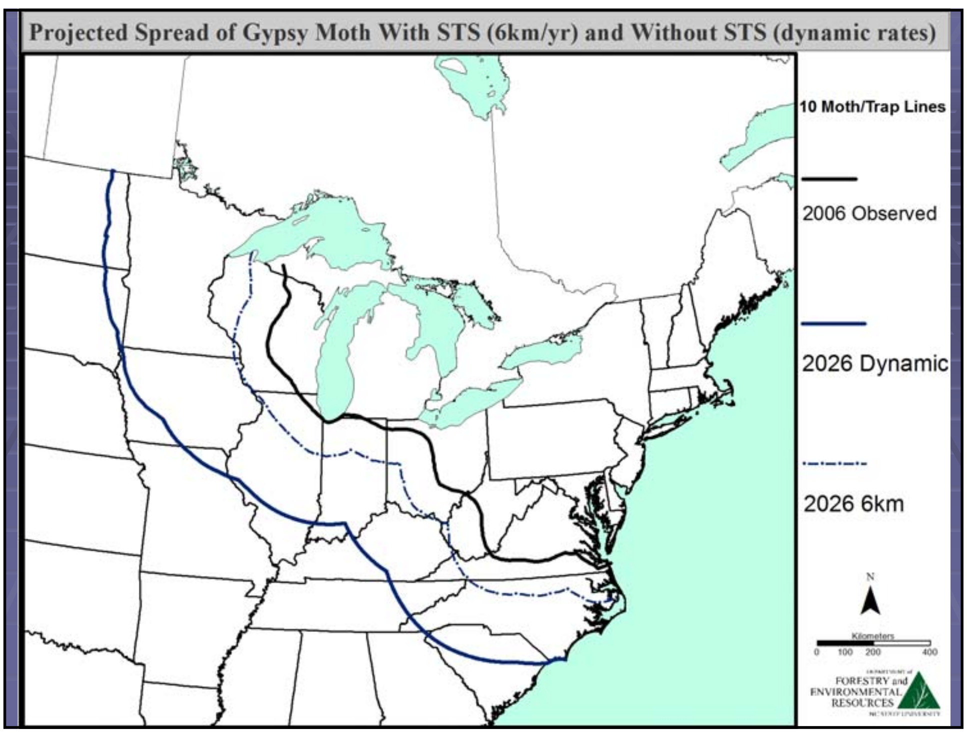
Projected Spread of Gypsy Moth With STS (6km/yr) and Without STS (dynamic rates)
10 Moth/Trap Lines
2006 Observed
2026 Dynamic
2026 6km
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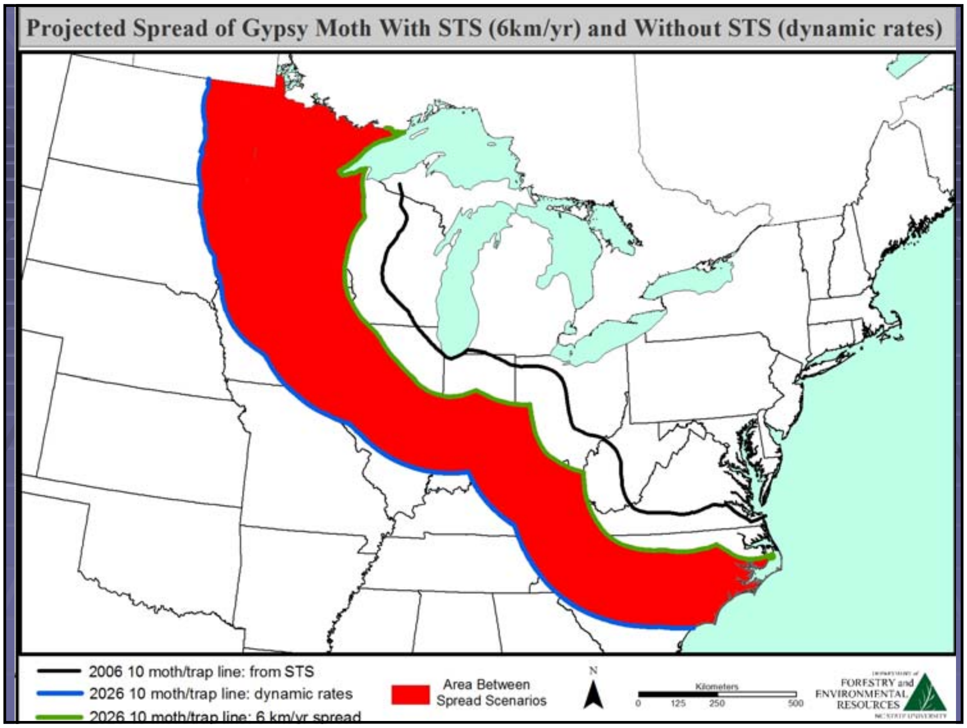
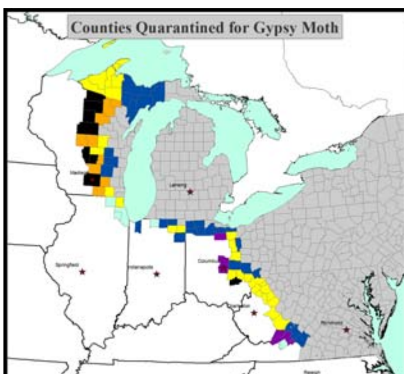
Kilometers
0 100 200 400
FORESTRY and ENVIRONMENTAL RESOURCES

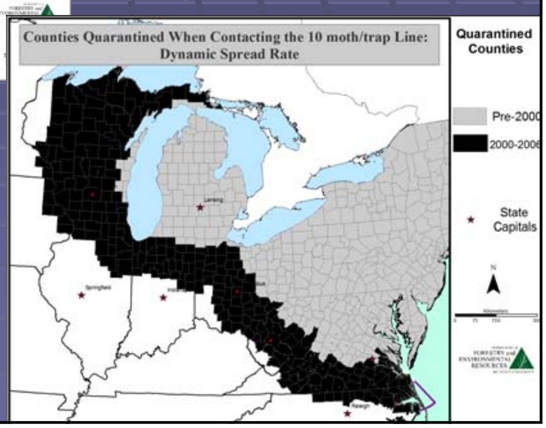




With STS

Contact quarantine rule
Spread without STS

50%
Spread with STS



Quarantine delayed by STS

Quarantine rules
- 50%
- Contact
- “Throw in the towel” – 100% then contact

Costs postponed (APHIS study)
- Administrative: APHIS and states
- Private: 6km/yr vs. 20.8km/yr in 2026
  - 526 fewer counties
  - 7229 fewer nurseries
  - 2861 fewer Christmas tree farms

STS Benefits

Minimum

Management costs = expenditures on suppression (public and private spraying)

Losses = reduction in profits & utility due to nuisance & defoliation by gypsy moths = willingness to pay (WTP) to avoid impacts not prevented through suppression efforts

Costs + losses

- Leuschner et al. 1996 SJAF 20(2)
  - 9.7% annual defoliation of susceptible forest types
  - Average management costs per hectare
  - 10 year loss in growth of timber value
  - Average annual household willingness to pay
  - Decreased recreation at campgrounds & picnic areas
- Major losses are residential & recreational
- Update with recent experience, literature, data

Losses

- Predicted defoliation over time
  - Natural forest
  - Urban/ suburban forest
- Reduces
  - Timber value, recreation
  - Quality of life (aesthetics, existence value, energy, air quality, health, outdoor activities)

"Non-market valuation"
What is the equivalent of the market price?
Willingness (and ability) to pay in a market

Non-market valuation

- Indirect: look for clues in real market
  - Hedonic analysis of real estate prices
- Direct: elicit WTP in hypothetical market
  - Contingent valuation
  - NOAA Blue Ribbon Panel (1993)
  - Jakus (1992) survey of households in MD/ PA

Contingent valuation

NOAA (1993) - Jakus (1992)

- Describe the service and why have to pay
  - Booklet with background info and photos
- Realistic payment vehicle
  - Property tax, focus group and pre-test
- Incentive compatible payment format
  - Referendum: yes or no to a stated price
- Sample non-response issues
  - 25% correction for non- respondents
  - Follow-up question to identify protest 0s
- Theoretical validity: probability of yes
  - Negatively related to price
  - Positively related to reduction in defoliation, and income

Losses from gypsy moth

WTP for spraying to reduce defoliation by 40% (25%, 65%) in neighborhood and nearby green space in year when facing defoliation

Captures all private suppression costs and quality of life losses in urban-suburban zone

$560 per urban household (2007 $)
$418 per rural household

Apply only to households with single family homes

What percent of households in GIZ face 40% defoliation every year?

2 – 5% (depending on spread scenario) covers program cost

Related work

- Poster on Gypsy Moth Sex in the City
  - Student project to triangulate on costs and losses due to gypsy moth outbreaks in urban and suburban areas

Anthropogenic factors in spread of GM

  - Gravity model
  - Non-linear component of spread into high-impact areas that is targeted by STS

Thanks to

- Kevin Bigsby
- Patrick Tobin
- Tzu-Ming Liu
- Subhrendu Pattanayak
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Assessment of the Economic Feasibility of the Gypsy Moth Slow the Spread Project

Erin Sills

DEPARTMENT of
FORESTRY and
ENVIRONMENTAL
RESOURCES
NC STATE UNIVERSITY

Road map

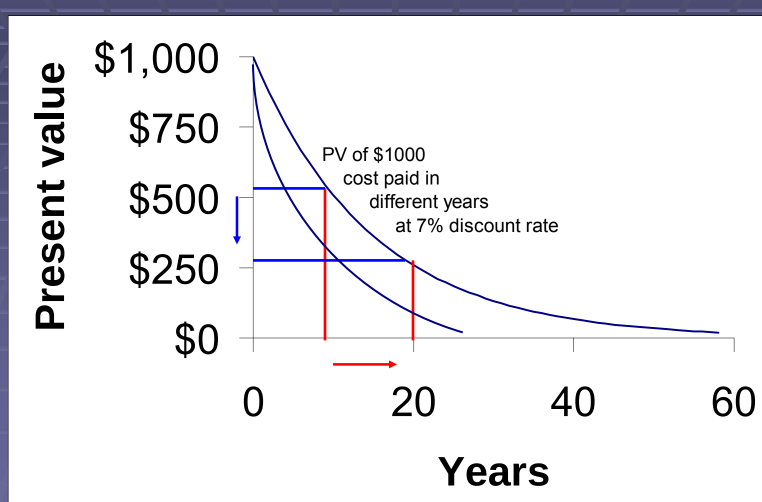
- Framework for analysis
- Costs
- Benefits
  - Spread
  - Management costs + losses
  - Non-market valuation of losses
- On-going analysis
  - Quarantine

Conceptual framework

- Timeframe
  - *Ex post:* 2000 – 2006 (7 years in 2000 dollars)
  - *Ex ante:* 2007 – 2026 (20 years in 2007 dollars)
- Counterfactual (what happens without STS?)
  - No replacement barrier zone program
  - No change in suppression, quarantine, eradication programs
- Net present value (NPV) as summary metric

  = ∑PV {incremental benefits of STS} – PV {costs of STS}
  - *Ex ante* ∑PV { cost of actual – modeled suppression, defoliation, and quarantine }
  - *Ex post* ∑PV { cost of suppression, defoliation, and quarantine beyond 2006 GIZ modeled with STS – cost modeled without STS }
- Accounting framework (whose costs and benefits count?)
  - Entire US (federal, state, local, private)
- Future discounted at 4% (7%)/year constant exponential rate

Benefits of delay



STS Costs

Ex post:

∑ PV of STS Budget 2000 – 2006 (with adjusted indirect and travel)

∑(Cost of STS in year t)$(1.04)^{-t}$ = **$69.5 million** (2000)

Average annual cost was $11.17 million (2000)

- 2% higher than Leuschner et al. (1996)'s lower bound estimate
- only 5% of Leuschner et al. (1996)'s upper bound estimate

Ex ante: ∑ PV of STS Budget 2007 – 2026

STS maintains same rate of spread at same cost per hectare

- STS Budget per HA = **$0.36** (2007)
- ∑ (0.36 * HA in year t)$(1.04)^{-t}$ = $195 million

  ~ ∑ 13.45(1.0348)^{-t}$ (current cost adjusted for 0.5%/yr expansion)

STS maintains same rate of spread through same operations

(1) fixed data management and technology development,

(2) travel and indirect fixed on per state basis,

(3) treatment costs per hectare with time trend, and

(4) fixed number of traps per hectare, with cost per trap as a function of hectares, terrain, and road density.

$150 million

STS Benefits

- Smaller area enters the generally infested zone each year

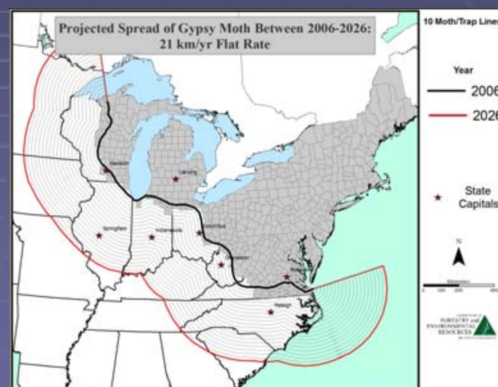
- Smaller area requires suppression and is defoliated every year →

  Smaller costs and losses from gypsy moth
- Counties are quarantined later

Spread rates without STS

Rate of expansion of GIZ, defined by 10 moth/ trap line

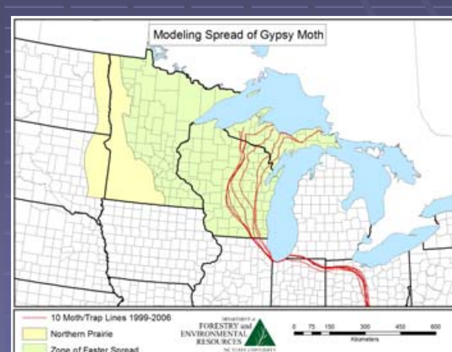
- 20.8 km/ year

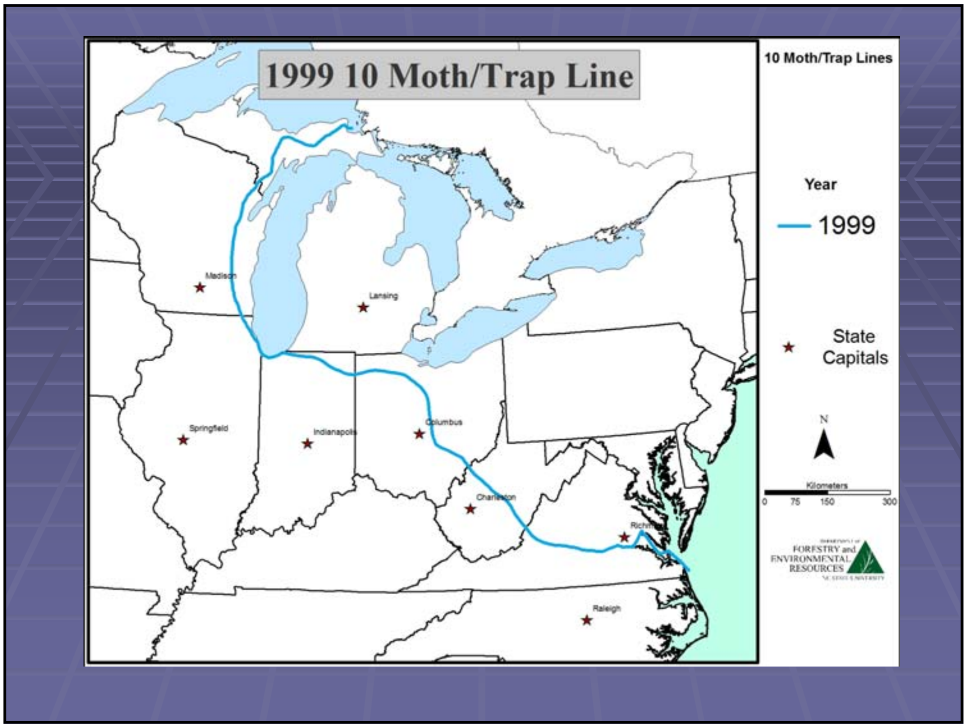


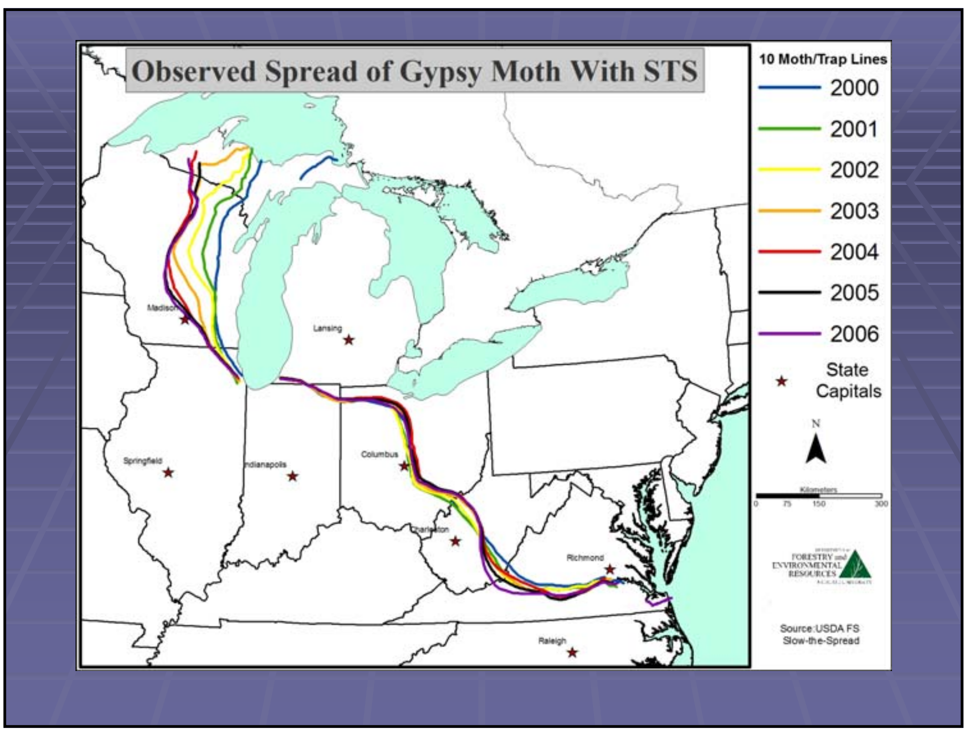
Spread rates without STS

Rate of expansion of GIZ, defined by 10 moth/ trap line

- Dynamic differentiated
  Faster in UP, WI, MN
  until prairies,
  (11.5 to 45 vs.
  2.9 to 20.8)
  with boundary effect




1999 10 Moth/Trap Line
10 Moth/Trap Lines
Year
1999
State Capitals
N
Kilometers
0 75 150 300
Madison
Lansing
Springfield
Indianapolis
Columbus
Charleston
Raleigh
FORESTRY and ENVIRONMENTAL RESOURCES


Observed Spread of Gypsy Moth With STS
10 Moth/Trap Lines
2000
2001
2002
2003
2004
2005
2006
State Capitals
N
Kilometers
0 75 150 300
Madison
Lansing
Springfield
Indianapolis
Columbus
Charleston
Richmond
Raleigh
FORESTRY and ENVIRONMENTAL RESOURCES
Source:USDA FS
Slow-the-Spread

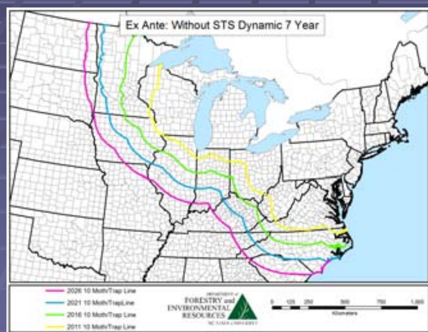
Ex post no STS 21 km/yr spread

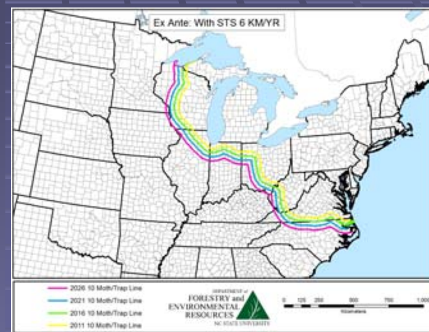
Ex post no STS dynamic spread

Ex ante no STS dynamic

Ex ante STS with project area

Ex ante comparison





STS Benefits

Minimum

- Management costs = expenditures on suppression (public and private spraying)

- Losses = reduction in profits & utility due to nuisance & defoliation by gypsy moths = willingness to pay (WTP) to avoid impacts not prevented through suppression efforts

STS Benefits

Aerial suppression costs average $1.80 per susceptible hectare, including:

- Cost share suppression costs $86/ HA, plus 15% indirect costs for administration and outreach, applied to 1.6% of susceptible hectares
- Private suppression costs $84/ HA, applied to 0.26% of susceptible hectares

STS Benefits

Quality of life (aesthetics, existence value, energy, air quality, health, outdoor activities associated with nuisance, defoliation, and tree mortality)

- Leuschner et al. 1996 SJAF 20(2) found that these impacts in residential area are largest cost of gypsy moth infestation, and most people in the field agree.

"Non-market valuation"

What is the equivalent of the market price?

Willingness (and ability) to pay in a market

Direct: elicit WTP in hypothetical market

- Contingent valuation
- NOAA Blue Ribbon Panel (1993)
- Jakus (1992) survey of households in MD/ PA

STS Benefits

- Postponed nuisance, defoliation, and tree mortality impacts in residential zones:
- $955 ($563) per urban (small town and rural) household occupying single family or duplex home in year facing 40% defoliation (in 2007 $)
- 25% less for households facing 25% defoliation
- What percent of households face defoliation each year?

STS Benefits

- *Ex ante:* long-term average defoliation of 6% of susceptible hectares is assumed to be half 40% defoliation and half 25% defoliation
- *Ex post:* known defoliation as percent of susceptible HA

Bottom line …

Ex post

- Cost = $69.5 million
- Benefits = $29 million

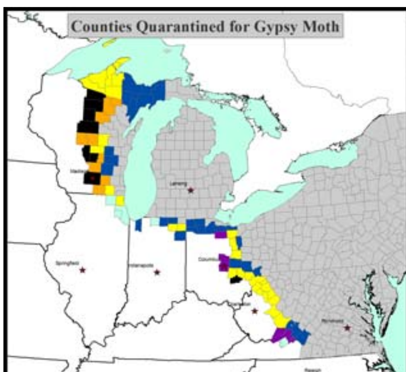
2000 dollars
6 year period

- Benefits > Costs after 2 more years at long-term average defoliation rate

Ex ante

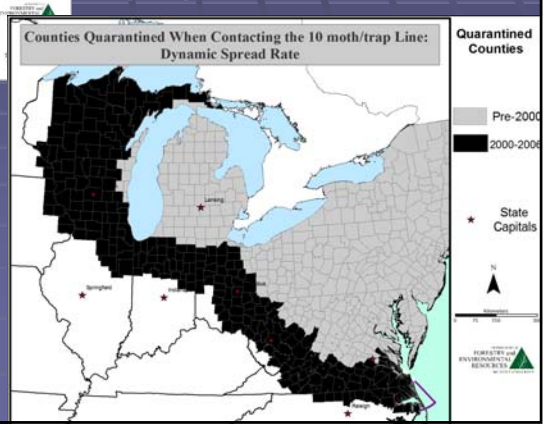
- Cost = $195 million
- Benefits = $488
- B:C > 2.5

under conservation assumptions



With STS

Contact quarantine rule
Spread without STS



Quarantine delayed by STS

Quarantine rules

- 50%
- Drag your feet and then throw in the towel

- Administrative: APHIS and states
- Private: 6km/yr vs. 20.8km/yr in 2026
  - 526 fewer counties
  - 7229 fewer nurseries
  - 2861 fewer Christmas tree farms

Quarantine

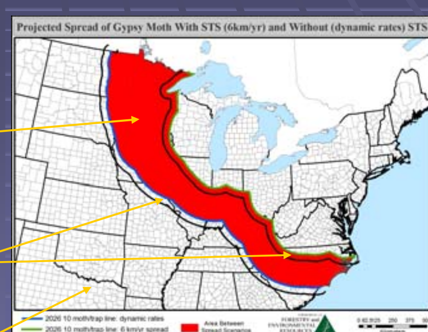
Costs of state quarantine partially covered under STS regulatory program

APHIS

Additional quarantined area requires more regulation of producers, but less trapping and less regulation of intra-regional trade

Larger area close to GIZ that requires more regulation and trapping

Rest of the country: smaller area, but perhaps more likely to be infested



Related work

- Poster on Gypsy Moth Sex in the City
  - Student project to triangulate on costs and losses due to gypsy moth outbreaks in urban and suburban areas

Anthropogenic factors in spread of GM

  - Gravity model
  - Non-linear component of spread into high-impact areas that is targeted by STS

Thanks to

- Kevin Bigsby
- Patrick Tobin
- Tzu-Ming Liu
- Subhrendu Pattanayak
- You!

… for your suggestions and questions:

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Assessment of the Economic Feasibility of the Gypsy Moth Slow the Spread Project

Preliminary Results, February 2008

The Gypsy Moth Slow the Spread Program (STS) has successfully reduced the rate of spread of the gypsy moth, *Lymantria dispar* (L.), by detecting and eradicating isolated populations that establish outside of the infected zone. The objectives of this study are to:

1. Estimate the incremental benefits of this reduced rate of spread during the full operational phase of STS, 2000 – 2006, and compare to the costs of the program (*ex post*)
2. Project and compare benefits and costs of STS for the next 20 years, 2007 – 2026 (*ex ante*)

Spread scenarios

In the most recent period with no barrier zone policies, the gypsy moth spread at 20.8 KM/ year. However, spread of up to 45.5 KM/ year has been observed in a zone including the UP of MI, WI, and MN. Based on these observations, the following scenarios are employed:

Ex post

1. Actual observed spread with STS
2. Without STS at 20.8 KM/ year over entire range
3. Without STS at dynamic rate of spread increasing to 20.8 (45.5) KM/ year by 2006

Ex ante

1. With STS spread at 6KM/ year or 10 KM/ year
2. Without STS at 20.8 KM/ year over entire range
3. Without STS at dynamic rate of spread increasing to 20.8 (45.5) KM/ year by 2013
4. Without STS at dynamic rate of spread increasing to 20.8 (45.5) KM/ year by 2026

Moderate estimates of the incremental benefits of STS are obtained by comparing
Ex post: Dynamic spread increasing over 7 years vs. actual observed spread with STS
Ex ante: Dynamic spread increasing over 7 years vs. 6 KM/ year spread with STS
The most significant benefits are

- Postponed aerial suppression costs, and
- Postponed nuisance, defoliation, and tree mortality impacts in residential zones.

Preliminary results reported here employ a 4% discount rate.

Ex post: costs and benefits deflated and discounted to 2000
The pay back period is 9 years: the benefits of postponing suppression & residential impacts over a 9 yr period are greater than the costs of the first 7 years of the program.
The total cost of the program was $69.5 million. The average annual cost was $11.17 million, which is within 2% of the lower bound estimate and less than 5% of the upper bound estimate of the annual equivalent of the program benefits as calculated by Leuschner et al. (1996).

The total benefits of postponed aerial suppression and residential impacts during this 6 year time period are $26 million, assuming that defoliation rates would have been similar to rates observed in the zone that had been infested most recently before implementation of STS. Given the periodicity of gypsy moth outbreaks, it can be assumed that average defoliation will revert to historical levels (~6% of hectares with >20% susceptible basal area). Therefore, the program would break-even if only two more years of benefits were considered.

Ex ante: costs and benefits deflated and discounted to 2007
Over a 20 year period, the Benefit-Cost Ratio is 2.5, under conservative assumptions.
The total cost of the program will be in the range of $150 to $195 million. The $195 million estimate is based on a fixed average cost of $0.36 per hectare. The $150 million estimate is based on summing (1) constant data management and technology development, (2) travel and indirect per state, (3) treatment costs per hectare declining over time, and (4) number of traps per hectare, with cost per trap as a function of hectares, terrain, and road density.
The total benefits during this 20 year time period are at least $488 million. This includes $163 million in postponed suppression costs, and $325 million in postponed residential impacts.

Benefit estimates are developed based on following conservative estimates:
Susceptible hectares are forested with >20% of basal area in species preferred by gypsy moth.
Postponed aerial suppression costs are $1.80 per susceptible hectare, calculated as follows:

- Cost share suppression costs $86/ HA, plus 15% indirect costs for administration and outreach, applied to 1.6% of susceptible hectares
- Private suppression costs $84/ HA, applied to 0.26% of susceptible hectares

Postponed nuisance, defoliation, and tree mortality impacts in residential zones:

- $955 ($563) per urban (small town and rural) household occupying single family or duplex home in year facing 40% defoliation; 25% less for households facing 25% defoliation (Jakus)
- Long-term average defoliation of 6% of susceptible hectares is assumed to be half 40% defoliation and half 25% defoliation

Recreation benefits have also been estimated based on NORSIS campground data, following Leuschner et al. (1996) method, but results are not included here because they do not significantly impact results and the source data are of extremely poor quality.

Quarantine
Slowing the spread of gypsy moth also postpones the imposition of quarantine, and a key remaining objective of this study is to estimate the impacts of quarantine. An index is provided by counts of counties, nurseries, nursery hectares in the open, Christmas tree farms and hectares, and wood mills of various types that would come under quarantine sooner without STS. The cost of operating under a compliance agreement is typically the opportunity cost of employee time diverted from other activities. In some states, inspection and/or treatment costs are more regularly imposed. From the public perspectives, states with internal quarantines are likely to receive assistance from APHIS via the STS regulatory program. Spread of the gypsy moth quarantine has several implications for the APHIS budget, including expanding regulation of producers, but eliminating regulation of trade and transferring responsibilities for trapping to STS within the expanded quarantined area. Simultaneously, the un-infested area is reduced in size but most likely comes under additional pressure from an expanded source area for people and products that may carry gypsy moth infestation to new areas.