The Cost of Slowing the Spread of the Gypsy Moth (Lepidoptera: Lymantriidae)

JEFFERSON H. MAYO,[1] THOMAS J. STRAKA,[2] AND DONNA S. LEONARD[3]

Department of Forest Resources, Clemson University, Box 340331, Clemson, SC 29634–0331

J. Econ. Entomol. 96(5): 1448–1454 (2003)

ABSTRACT Beginning in 1992, the Slow The Spread (STS) pilot project was initiated to target gypsy moth (*Lymantria dispar* L.) spread rate reduction by controlling populations in the transition zone. The project uses intensive monitoring techniques, with pheromone-baited sticky moth traps, to detect low-level populations and target them for eradication. The primary objective of the pilot project was to evaluate the feasibility of using integrated pest management techniques to slow the spread of gypsy moths over a large geographical area. In this study, the cost of STS pilot project activities in 1993–1995 was investigated. A cost accounting system was developed and used as a framework to collect the cost data and to investigate cost patterns and characteristics. Total expenditures of STS activities for 1993–1995 were $7,685.2 million. Per unit cost was $49.67 per trap with the direct cost component being $35.03 per trap. Trapper labor and vehicle expense accounted for ≈90% of this direct cost. Per unit cost for treatment activities was found to average $27.86 per treated acre. In general, the STS pilot project is labor intensive, specifically the trapping component. From 1993–1995, 59% of total project expenditures were spent on trapping activities, 28% on pesticide treatments, and 13% on data management. A trapper productivity rate regression model is described.

KEY WORDS *Lymantria dispar* L., costs, spread

THE GYPSY MOTH (*Lymantria dispar* L.) is a defoliating forest insect pest accidentally introduced into the northeastern United States from Europe in 1869. It has not only persisted, but has been very successful at expanding its range, currently as far north as Maine, as far south as North Carolina, and as far west as Wisconsin. As of 2001, the total U.S. area infested exceeds 194 million acres and expansion of the infested area, or spread, continues each year. Around 1965, the rate of spread of this front began to accelerate dramatically from the historic level of ≈3 km/yr to ≈21 km/yr (Sharov and Liebhold 1998a). An increased spread rate is of obvious concern because the negative impacts of the gypsy moth, including the defoliation of millions of acres of forests and the public nuisance aspects in urban areas, increases as the infested area becomes larger. The gypsy moth will feed on a diverse range of tree species and it is likely its range will reach most of the United States and Canada (Liebhold et al. 1992, Sharov et al. 1997).

For more than a century, pest managers have sought to mitigate the impacts of the gypsy moth (Liebhold et al. 1995). The traditional approach to gypsy moth management involves two strategies: (1) to suppress outbreak populations in the generally infested zone (GIZ)–the area in which gypsy moth populations have gone through at least one outbreak episode and are spatially continuous to the north and east, and (2) to eradicate isolated populations discovered within the uninfested zone (UZ) – the area that has only occasional moth captures in highly localized areas that are well-separated from one another and appear as isolated infestations. Both of these strategies ignore gypsy moth population activity within the transition zone (TZ)–a band from 50 to 100 miles wide that separates the generally infested from the uninfested zone. Within the transition zone, isolated low-level gypsy moth populations develop that, if left unchecked, will grow and coalesce with the advancing front and contribute to the overall rate of spread. Alternatively, if these colonies are identified and eradicated as part of a systematic gypsy moth management program, there is an opportunity to reduce the overall rate of spread.

From 1988–1992, the Appalachian Integrated Pest Management (AIPM) Project attempted to suppress both isolated and high-density gypsy moth populations near the enlarging front in Virginia and West Virginia (Leonard and Sharov 1995). AIPM followed the historical emphasis of suppression of potentially defoliating populations within the GIZ and eradication of isolated populations within the UZ. The need was recognized for a program to specifically target spread rate reduction by controlling populations

[1] Current address: Wachovia Bank, N. A., Evergreen Timberland Investment Management, 191 Peachtree Street, Atlanta, GA 30303.

[2] E-mail: tstraka@clemson.edu.

[3] USDA Forest Service, Region 8, Forest Health Protection, 200 Weaver Blvd., Asheville, NC 28804.

within the TZ. In 1992, the Slow the Spread (STS) pilot project was initiated by the USDA Forest Service and Animal and Plant Health Inspection Service, in cooperation with eight state and university partners, to specifically target spread rate reduction by controlling populations within the transition zone (Mayo et al. 1997). The pilot project involved seven million acres and activities in four states in the TZ area: North Carolina, Virginia, West Virginia, and Michigan.

Unlike the AIPM project, the STS project targeted only small isolated colonies established just beyond the expanding population front (Sharov et al. 1998). The STS project was designed to slow the spread of gypsy moth with less pesticide application that the previous project (Sharov et al. 1997). STS had two primary thrusts: trapping (monitoring of gypsy moth populations via grid of pheromone-baited traps to allow early detection in areas thought to be uninfested) and suppression (once detected, populations are targeted for treatment using mating disruption, mass trapping, releasing sterile life stages, and spraying) (Leonard and Sharov 1995). The focus of STS is low-level populations in the TZ and intensive monitoring and timely control of growing isolated populations (Sharov et al. 1997).

The fundamental economic premise of STS was that delaying gypsy moth impacts will generate substantial societal benefits. Estimation of economic benefits for STS is complex. Both short-term and long-term benefits need to be addressed (Leuschner and Berck 1985). Benefits include timber, wildlife, recreation, esthetics, watershed, soil conservation, and grazing (Leuschner and Newton 1974). Leuschner et al. (1996) calculated the present value of potential benefits from slowing the spread of gypsy moth over a 25-yr period ranged from $800 million to $3,800 million in 1990 dollars. Key to evaluating the STS project is rate of spread estimation. Sharov and Liebhold (1998b) developed a mathematical rate of spread model based on two functions: colonization rate as a function of the distance from the population front and population numbers in a colony as a function of colony age. STS is now an operational program that has been implemented across the 1,200-mile gypsy moth frontier from Wisconsin to North Carolina.

Although benefits are often difficult to quantify, costs are much more readily accessible. Because of the absolute paucity of available cost data from national integrated forest pest management programs, the overall objective of this analysis is to determine a reliable estimate of the cost of slowing the spread of gypsy moth. More specifically, the research objectives were as follows: (1) to obtain detailed historical cost data available from agencies participating in STS pilot projects activities, and (2) to analyze the historic pilot project cost data for cost patterns and characteristics.

Methods

The Trapping Cost Model. The cost analysis focused on pilot project expenditures that occurred during the fiscal years of 1993, 1994, and 1995. During this time period, 59% of total expenditures were spent on trapping activities, 28% on pesticide treatments, and 13% on data management. Clearly, trapping is the most significant part of STS expenditures and because trapping is such a large component of total STS expenditures, the ability to control program costs depends heavily on the ability to control trapping costs. Geography must be recognized as impacting trapping cost comparisons. Because much of the STS action area was in the mountainous areas of Virginia and West Virginia, it is reasonable to assume that the overall trapping rate reflects this "rough" terrain. This means trapping cost may be higher within the STS area being evaluated than might be found in a more favorable trapping environment. The trapping cost developed for this project had to account for this geographical difference.

The gypsy moth trapping methods employed by STS were relatively straightforward. Pheromone-baited sticky traps were deployed within the TZ at various sampling intensities. A base-grid of traps was established over an area extending ≈100 km from the defoliating front. By monitoring male moth captures in the base-grid traps, an attempt was made to detect "isolated" colonies that may have developed. Once a colony was detected, a more tightly spaced grid of traps was deployed in the vicinity the following year. The goal of this intensive-grid was to delimit the location and size of the area to target for pesticide treatment. Intensive-grid tarps were normally spaced 250 or 500 m apart.

Trappers visited each trap at least three times per trapping season (placement, mid-season inspection, and final inspection). All traps were placed early in the season, before the beginning of moth flight. Male moths captured by mid-season were counted and recorded during the mid-season visit. Occasionally, as time allowed, there were additional visits made to readily accessible traps between mid-season and the final inspections.

The study area for this project included over 1.5 million ha located in the states of North Carolina, Virginia, and West Virginia. This included most of the active STS front. Twenty-five counties over the three-state area were involved. Each county was classified into one of three broad physiographic categories. This included eight coastal counties, three transition counties, and 14 mountain counties. In total, 75 trappers placed 16,217 traps over the three-state area using 4, 370 trapper days. Road density and average elevation were determined for each county. Individual trapper data included daily productivity rate for placement and inspection, hours worked, and vehicle expense.

A regression model was developed that related average trapper productivity rate (TPR) to physical characteristics of the county were the traps were located. The TPR equation was developed using the individual trapper productivity data combined with the county level elevation and road density data. All observations where more than one county was visited during a single day were dropped. The remaining individual trapper data (consisting of 3,178 trapper

Table 1. Weighted least squares regression analysis of model to estimate the dependent variable Ln(TPR), defined as the natural logarithm of the average trapper productivity rate (average trap visits per hour)

Variable	Coefficient	Standard error	t-ratio
Intercept	1.286563	0.249747	5.151
Place (1 or 0)	−0.298784	0.032995	−9.055
RD (miles/mile^2)	−0.396113	0.138326	−2.864
RD*CP (CP = 1 or 0)	0.376360	0.099666	3.776
ELEV (meters)	−0.001635	0.000385	−4.242
RD*ELEV	0.000611	0.000222	2.756

Statistical summary

Description	Value
Observations	$n = 48$
R-square	0.9213
Root MSE	0.9054
Dependent mean	0.1799
Weight for WLS	# per mean

days) were collapsed into a set of average TPRs (traps visited per hour worked) for both placement and inspection within each county. Means with <3 observations were omitted. This resulted in a data set with 48 observations. Because each trapper did not have the same number of observations, weighted least squares was used to fit the TPR equation as recommended by Kmenta (1986).

TPR was estimated for placement and inspections separately. The variable PLACE is a dummy variable with value = 1 for placement and value = 0 for inspections. CP is also a dummy variable with value = 1 when the county being considered is in the coastal plain and value = 0 otherwise. RD represents road density and ELEV represent elevation. All variables were significant at alpha = 0.01. Table 1 gives the results of weighted least squares estimation of TPR.

TPR decreases as the average county elevation increases. This is intuitive because elevation is a proxy for roughness, and as "roughness" increases, trapper productivity should decline. TPR is significantly less when traps are being placed, as opposed to when they are being inspected. For the 1995 trapping season, the average ratio of (inspection TPR/placement TPR) was 1.3424. The highest TPR values were found within the coastal plain counties. An interaction term, between road density and the coastal plain dummy variable (RD*CP), indicates that the impact of road density differs between the coastal plain and other areas. There is also a significant interaction term between road density and elevation (RD*ELEV). A closer investigation reveals that in coastal plain counties (where average elevation is below 100 m), TPR decreases as road density increases. However, in other counties where average elevations are above 550 m, TPR increases as road density increases. The positive impact of road density at higher elevations has intuitive appeal because increased road density should mean greater access and probably less trapper walking. Thus, increased road density at higher elevations may compensate for some the effect of "rough" terrain.

During development, the TPR model was tested for heteroskedasticity using the methods suggested by Maddalla (1992). A heteroskedastic condition was determined to be present and was addressed using a natural log transformation of TPR. After the transformation, testing revealed no further evidence of a heteroskedastic condition.

As indicated previously, the highest rates of trapper productivity were found in the coastal plain counties. Three state agencies were involved in trapper activity and all of the coastal plain counties were trapped by the same agency. This suggests that increased productivity might be a result of some organizational influence or "agency effect" and not the physical characteristics of the county. Data limitations do not allow direct statistical comparisons to test for the presence or magnitude (if present) of this agency effect. Indirect evidence is available through the expert opinion of STS operation managers from each of the three state agencies. These experts do not believe that such an agency effect is present. Instead they conclude that differences in trapper productivity are because of the physical characteristics of the area being trapped. Each agency instructs trappers to follow the tapping procedures in the STS Male Moth Survey Trapper's Manual (Carroll et al. 1994); thus, procedures between agencies should be reasonable similar.

The Cost Accounting System. Following startup in 1992, cooperating agencies, listed in Table 2, that participated in the STS pilot project annually applied for and received USDA Forest Service grants to perform STS activities. In addition to grant money, many agencies also directly funded or contributed "in-kind" to these operations. Because the total cost of STS activities was desired, expenditure data from all funding sources were collected. Although these historical cost data were available from each of the cooperating agencies, each used their own cost accounting system for a uniquely-defined fiscal year.

A standard cost accounting framework was developed (Fig. 1) and used by all cooperating agencies when reporting annual STS cost data. A fiscal year was defined as 1 October through the following 30 September. For example, fiscal year 1993 went from 1 October 1992 through 30 September 1993. The cost accounting system was designed to capture only operational costs from the STS program; therefore, funding for nonoperational activities (such as program evaluation research) was excluded from this analysis.

It is relatively easy to understand the organization of this cost accounting system if STS is viewed as a production process with two outputs or products: traps (that have been placed, inspected, and the data have been recorded) and acres (that have been treated for gypsy moth eradication). Cost objectives or centers are any organizational or process function for which costs are accumulated (Fultz 1980). Three cost centers are specified for STS: trapping, treatments, and data management. The first two are clearly production oriented and are obvious choices given the stated process outputs. The third cost center is a less obvious choice but is an integral service activity. Data management is required to process the large volume of trap data and to subsequently determine future

Table 2. Agencies involved with the Slow The Spread pilot project by fiscal year

Cooperating agency	Fiscal year		
	1993	1994	1995
State agencies			
1) Michigan Department of Agriculture	Yes	Yes	Yes
2) Michigan Department of Natural Resources	No	Yes	Yes
3) North Carolina Department of Agriculture	Yes	Yes	Yes
4) Virginia Department of Agriculture and Consumer Service	Yes	Yes	Yes
5) West Virginia Department of Agriculture	Yes	Yes	Yes
State universities			
6) Michigan State University	Yes	Yes	Yes
7) Virginia Polytechnic Institute and State University	Yes	Yes	Yes
USDA Forest Service			
8) Forest Health-Asheville, NC	Yes	Yes	Yes
9) Northeastern Area State and Private Forestry, Forest Health Protection-Radnor, PA and St. Paul, MN	Yes	Yes	Yes
10) Hiawatha National Forest	No	Yes	Yes
11) Jefferson National Forest	Yes	Yes	Yes
National Park Service			
12) New River Gorge National River	Yes	Yes	No
Total number of agencies reporting Slow The Spread-related costs	10	12	11

trapping locations and treatment areas. Also, STS management considers data management a significant enough expenditure to monitor its cost directly.

Other general cost designations used in this study are incurred, allocated, direct, and indirect costs. Incurred costs are easily traced to a single cost center. Allocated costs cannot be easily traced to a single cost center and therefore must be allocated across all applicable cost centers. In this analysis, allocated costs were assigned to each cost center based on the proportion of total incurred cost within that cost center. Direct costs are easily traceable to a specific cost

	Slow The Spread Cost Centers		
	Production		Service
	Trapping	Treatments	Data Management
Total Indirect Costs	**Allocated Costs**		
	Incurred Overhead	**Incurred Overhead**	**Incurred Overhead**
Total Direct	**Direct Costs**	**Direct Costs**	**Not Applicable**
Units of Production	Traps	Treated Acres	

Fig. 1. Cost accounting framework used for collection and analysis of Slow The Spread cost data.

center and are directly used for the production of a unit of output for that cost center. Thus, only trapping and treatments have direct costs and by definition all direct costs are incurred costs. Indirect costs are less easily identifiable, may or may not be traceable to a specific cost center, and are not directly used for output production. All STS cost centers have indirect costs. These costs may be either incurred or allocated. Each general cost designation can be further subdivided into categories: labor (salary and benefits), materials, services, and other. An example of a complete cost category designation would be indirect incurred labor costs.

Once the cost accounting framework was developed, cost data sheets were prepared to assist in the acquisition of data from cooperating agencies. Because 1992 was the initial pilot program year, it was omitted from the cost analysis to avoid problems with "startup" anomalies. Cost data were collected for fiscal years 1993 through 1995. To test the relative user-friendliness of the cost data sheets, the 1993 cost data were collected during the summer of 1995. Instructions and answers to frequently asked questions were also provided with the cost data sheets. Initial data collection (1992) did not identify any obvious problems with the process. Subsequently, the 1994 and 1995 cost data were collected during the summer of 1996. Cost data were received from each of the participating agency groups as shown in Table 2.

The Cost Analysis. Cost analysis is the rearrangement of cost data to determine cost patterns and characteristics (Openshaw 1980). A detailed cost analysis was conducted on the STS cost data from 1993 through 1995. In general, the cost data received from the agencies consisted of "hard" numbers pulled from their historical accounting records. There were, however, two exceptions. The first exception arose in the determination of vehicle expense. Each participating agency had a unique policy for vehicle cost management. The number of miles traveled was readily available but the cost of this vehicle use was difficult to determine. To alleviate this inconsistency, vehicle cost was calculated by multiplying the Internal Revenue Service standard mileage rate for the appropriate year by the business miles traveled.

A second problem involved the determination of miscellaneous overhead expense for federal agencies. Each state agency and university included an "indirect" charge in their STS grant requests to cover miscellaneous overhead expenses. This charge is often calculated as a simple proportion of the grant request and typically ranges from 20 to 40%. Federal agencies do not typically use a standard "indirect" charge and were unable to estimate these costs directly. To provide an estimate of the miscellaneous overhead expense for federal agencies, the average "indirect" rate for all state agencies and universities providing cost data were applied to the appropriate expenditure totals for each federal agency.

All expenditures were adjusted for inflation to a common base year (1995) using the all commodities producer price index obtained from the U.S. Department of Labor, Bureau of Statistics.

Table 3. Slow The Spread pilot project activities summarized by units of production and total expenditure (1995 = 100)

Activity	Fiscal year			
	1993	1994	1995	Total
Number of traps placed (recorded data)	31,107	33,900	26,799	91,806
Number of treated acres (all treatment types)	6,023	34,309	35,235	75,567
Total expenditures (thousands)	\$2,067.4	\$2,918.8	\$2,699.0	\$7,685.2

Results

STS pilot project activities summarized by total units of production and total expenditure for 1993–1995 are listed in Table 3. The number of traps placed in the field was relatively stable; on average 30,602 traps were placed per year. From 1993–1994 the number of treated acres increased dramatically, however, this is easily explained. Because of program initiation and sampling scheme, there was a lag in identifying acreage that required treatment. In fact, the number of acres treated in 1994 and 1995 may be more indicative of a "typical" year. The majority of the total funding, \$6.460 million (84.1%), was provided by USDA Forest Service grants. The balance of \$1.225 million (15.9%) was funded through in-kind contributions.

Total expenditures (\$7.685 million) were separated into incurred and allocated components for each cost center. Total incurred costs for the 3-yr period were \$6.350 million (82.6%) and total allocated costs for the 3-yr period was \$1.335 million or 17.4% of total expenditures. Expenditures for trapping, treatments, and data management, as a percent of the total, were 59.3%, 27.4%, and 13.3%, respectively. A closer look at the incurred costs by cost categories (Table 4) indicates that 54.2% of total incurred cost went for labor, 25.5% for materials, and 16.2% was spent on services. Although labor accounted for 72.7% of incurred trapping cost, it only accounted for 14.4% of incurred treatment cost. Gypsy moth monitoring is clearly

Table 4. Total incurred Slow The Spread pilot project expenditures (1995 = 100) by cost center—all allocated costs are omitted

Cost category	Cost center			
	Trapping	Treatments	Data Mgt.	Combined
Labor (thousand \$)	2,687.4	253.4	499.6	3,440.4
Percent of activity (%)	72.7%	14.4%	52.9%	54.2%
Material (thousand \$)	978.1	460.3	182.6	1,621.0
Percent of activity (%)	26.4%	27.4%	19.3%	25.5%
Services (thousand \$)	32.8	993.6	0.0	1,026.4
Percent of activity (%)	0.9%	58.2%	0.0%	16.2%
Other (thousand \$)	0.0	0.0	262.2	262.2
Percent of activity (%)	0.0%	0.0%	27.8%	4.1%
Total (thousand \$)	3,698.3	1,707.3	944.4	6,350.0
Percent of activity (%)	100.0%	100.0%	100.0%	100.0%

Table 5. Slow The Spread pilot project expenditures expressed as per unit costs (1995 = 100) by cost center and designation

Cost designation		Cost center		
General	Specific	Trapping ($/trap)	Treatments ($/acre)	Data management[a] ($/trap)
Indirect (allocated)	Project administration	$3.20	$1.80	$0.82
	Indirect/miscellaneous	6.19	3.47	
Indirect (incurred)	Supervision/support	5.25	1.80	5.44
	Materials			1.99
	Indirect/miscellaneous			2.86
Direct (incurred)	Field labor	24.02	1.55	
	Vehicle expense	7.43	0.41	
	Equipment/supplies	3.22	5.68	
	Services	0.36	13.15	
	Cost center totals	$49.67	$27.86	$11.11
	Total units	91,806 traps	75,567 acres	91,806 traps

[a] The Data Management cost center actually has no units of production. Unit cost is expressed on a per trap basis because this best reflects the magnitude of the data management task.

much more labor intensive than treatments activities. Expenditures on materials and services for treatments were 27.4% and 58.2%, respectively. As would be expected, data management is also labor intensive, with 52.9% of total incurred data management costs for labor. Unlike trapping and treatment activities, however, data management overhead charges were incurred and not allocated costs. These costs were therefore shown in the "Other" category (Table 4) representing 27.8% of the total data management incurred expenditures. In general, the pilot project cost data indicated that slowing the spread of the gypsy moth is indeed labor intensive, specifically trapping efforts.

Presented in Table 5 are per unit costs by cost center and designation. The information is divided by cost center into the general cost designations of allocated indirect, incurred indirect, and direct. Subsequently, each of these designations is subdivided into specific cost categories. Some were renamed from the general cost category labels (labor, materials, services, and other) to more descriptive designations. For example, incurred indirect labor was designated as supervision/support. Some categories were also divided into significant line items. In particular, notice that the direct materials designation has been divided into two line items: vehicle expense and equipment and supplies.

The average per unit cost for trapping from 1993 to 1995 was $49.67 (Table 5). This consists of $14.64 per trap in indirect cost and $35.03 per trap in direct cost. Approximately 90% of direct cost is attributed to field labor (68.6%) and vehicle expense (21.2%). The average per unit cost for treatments is $27.87 per acre of which $7.07 per acre is an indirect cost and $20.79 per acre is a direct cost. Ninety percent of the direct treatment cost is accounted for by equipment/supplies (27.3%) and services (63.3%). Trapping expenditures were spent primarily for trappers and their travel expense while treatment expenditures were spent primarily on treatment materials and their application.

The average unit cost for data management is $11.11 per trap. It is expressed here as the data management charge for one trap, although in this accounting system, data management actually had no units of production. The number of traps was considered to be an appropriate measure (for comparisons only) because this best reflects the magnitude of the data management task. Again, data management is treated totally as an indirect cost. The majority (92.6%) of data management expenditures are incurred indirect costs with 49.0% being attributed to supervision and support.

Discussion

The cost accounting system developed for this study provides a good framework for cost data collection and the investigation of cost patterns and characteristics of the STS program. The cost analysis of the STS pilot project from 1993 to 1995 represents perhaps the most complete cost analysis (in terms of all costs being considered) of any wide-scale forest pest management program. It would be valuable to compare the per unit rates for trapping and treatment costs with those from other national pest management programs, however, no cost figures from other programs could be located. Even if cost data from other programs were available, direct comparison would be difficult unless significant detail were available to assure an "apples to apples" comparison.

It is important for the successful management of the STS project to be able to control gypsy moth trapping costs. They are the most significant STS expenditure and are composed primarily of trapper labor and vehicle expense.

Trapper labor expenditures are related to TPR, which is a function of physical characteristics of the county where trapping takes place. Trappers are less productive (in terms of trap visits per hour worked) during placement than during subsequent inspection visits. The county-level characteristics of average elevation and average road density are adequate proxies for trapping area "remoteness and roughness." These variables are useful indicators of expected TPRs within a given area. Trapper vehicle expense is related to the number of miles traveled by the trapper. The average daily miles traveled can be expressed as a function of the average number of traps visited daily.

There are at least two specific opportunities for application of trapping cost functions within the STS program. The first is to facilitate annual budget development as the GIZ moves forward. Trapping cost functions relating county physical characteristics to average trapper productivity will improve cost estimates and facilitate program strategic and tactical planning. The second application is in the determination of the number of trappers required to trap a given area. Better hiring decisions can be made if trapper productivity can be estimated.

It may also be difficult to directly compare treatment costs. There was a wide range of treatment methods employed within the STS pilot project from 1993 to 1995. By design, many of these methods were the most "environmentally friendly" treatments available, but not necessarily the least expensive. Thus, STS average treatment rates may be somewhat higher than programs using less environmentally friendly but more economical treatment methods. A fair comparison would require knowing which treatment methods were employed.

References Cited

Carroll, B. S., E. A. Roberts, and J. L. Knighten. 1994. STS Male Moth Survey Trapper's Manual. Unpublished operations manual.

Fultz, J. F. 1980. Overhead: what it is and how it works. Abt Associates Inc., Cambridge, MA.

Kmenta, J. 1986. Elements of econometrics, 2nd ed. Macmillan, New York.

Leonard, D. S., and A. A. Sharov. 1995. Slow the Spread project update: developing a process for evaluation, pp. 82–85. *In* Proceedings of the U.S. Department of Agriculture Interagency Gypsy Moth Research Forum. U.S. Department of Agriculture Forest Service General Technical Report NE-213.

Leuschner, W. A., and C. M. Newton. 1974. Benefits of forest insect control. Bull. Entomol. Soc. Am. 20: 223–227.

Leuschner, W. A., and P. Berck. 1985. Impacts on forest uses and values, pp. 105–120. *In* W. E. Waters, R. W. Stark, and D. L. Wood [eds.], Integrated pest management in pinebark beetle ecosystems. Wiley, New York.

Leuschner, W. A., J. A. Young, S. A. Walden, and F. W. Ravlin. 1996. Potential benefits of slowing the gypsy moth's spread. Southern J. Appl. For. 20: 65–73.

Liebhold, A. M., J. A. Halverson, and G. A. Elmes. 1992. Gypsy moth invasion in North America: a quantitative analysis. J. Biogeogr. 19: 513–520.

Liebhold, A. M., W. L. MacDonald, D. Bergdahl, and V. C. Mastro. 1995. Invasion by exotic forest pests: A threat to forest ecosystems. For. Sci. Mono 30, For. Sci. 41(2).

Maddalla, G. S. 1992. Introduction to econometrics, 2nd ed. Macmillan. New York.

Mayo, J. H., T. J. Straka, R. L. Hedden, and D. S. Leonard. 1997. The cost of monitoring the spread of gypsy moth in the eastern United States, pp. 108–113. *In* R. A. Kluender, M. M. Corrigan, and N. B. Smith [eds.], Valuing nontimber forest resources: timber primacy is passe'. Proceedings 1997 Southern Forest Economics Workers Meeting. Little Rock, AR 19–21 March 1997.

Openshaw. K. 1980. Cost and financial accounting in forestry: A practical manual. Pergamon Ltd., New York.

Sharov, A. A., and A. M. Liebhold. 1998a. Bioeconomics of managing the spread of exotic pests species with barrier zones. Ecol. Appl. 8: 833–845.

Sharov, A. A., and A. M. Liebhold. 1998b. Model of slowing the spread of gypsy moth (Lepidoptera: Lymantriidae) with a barrier zone. Ecol. Appl. 8: 1170–1179.

Sharov, A. A., A. M. Liebhold, and E. A. Roberts. 1997. Methods for monitoring the spread of gypsy moth (Lepidoptera: Lymantriidae) populations in the Appalachian Mountains. J. Econ. Entomol. 90: 1259–1266.

Sharov, A. A., A. M. Liebhold, and E. A. Roberts. 1998. Optimizing the use of barrier zones to slow the spread of gypsy moth (Lepidoptera: Lymantriidae) in North America. J. Econ. Entomol. 91: 165–174.

Received for publication 17 October 2001; accepted 3 June 2003.