

The Cost of Monitoring the Spread of the Gypsy Moth in the Eastern United States

by

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Abstract

The Slow-The-Spread (STS) pilot project is a multi-agency cooperative effort aimed at evaluating the feasibility of reducing the gypsy moth spread rate in the eastern United States. The methods employed by STS include extensive monitoring of the area immediately ahead of the advancing gypsy moth front using grids of pheromone-baited traps. When an "isolated" gypsy moth population is detected in this "transition zone", it becomes a candidate for pesticide treatment. The STS goal is to eradicate isolated populations and prevent their coalescence with the advancing area of general infestation. These actions should result in an overall reduction in the rate of gypsy moth spread.

Gypsy moth trapping expenditures account for more than 59% of total pilot project expenditures. Trapper labor and trapper vehicle expense compose over 90% of the direct trapping expenditures. Trapper labor requirements can be expressed as a function of trapper productivity. A model relating average trapper productivity to county-level physical characteristics including road density and average elevation is developed. Trappers establishing or "placing" traps have a lower productivity rate than when subsequent inspections are done. Vehicle expense can be expressed as a function of the number of miles traveled. A model relating the daily miles traveled to the number of traps visited daily is developed.

INTRODUCTION

The gypsy moth (*Lymantria dispar* L.) was accidentally introduced into Medford, Massachusetts in about 1869. It is now well established as a serious defoliator of forest, shade, fruit and ornamental trees over much of the northeastern United States. Annually the gypsy moth (GM) defoliates millions of acres of forestland and acts as a general public nuisance throughout the area of infestation. Perhaps no forest insect has been studied as completely or has been the target of such intense containment, control or eradication efforts (Doane and McManus, 1981). Despite all historical management activities, the GM has persisted and continues to expand its range.

Expansion of the infested area or spread of the GM can be visualized as a front moving from the northeast in a south / southwesterly direction. While wind is a primary means of natural dispersal, long distance spread also occurs as people inadvertently move egg masses and other life forms when transporting items from infested to uninfested areas. Liebold et al. (1992) demonstrates that the rate of spread of the GM since 1965 has increased when compared to spread rates of prior historical periods.

Monitoring of GM populations is typically done by survey techniques involving grids of sticky traps baited with female sex pheromone. Male moth captures in these pheromone-baited traps are the standard means of monitoring the spread of the GM into previously

uninfested areas.

To better understand the dynamics of GM spread, it is helpful to think of the infestation front as being divided into three zones. The Generally Infested Zone (GIZ) is defined as the area behind the frontier where GM populations have gone through at least one outbreak episode and are spatially continuous to the north and east. Typically all life stages are present within the GIZ. This area also serves as the location of most defoliation and subsequent economic impact. The Transition Zone (TZ) has population colonies that are spatially discontinuous, but not well separated, and are usually represented by male moth captures only. The Uninfested Zone (UZ) has only occasional moth captures in highly localized areas that are well-separated from one another and appear only as isolated infestations.

Historically, the emphasis of GM pest management programs has been suppression of potentially defoliating populations within the GIZ and eradication of isolated populations within the UZ. The need existed for a program to specifically target spread rate reduction by controlling populations within the TZ. Beginning in 1992, the Slow-The-Spread Pilot Project (STS) was initiated to meet this need. The project area is located in four states: Michigan, North Carolina, Virginia and West Virginia. Multiple state and federal agencies are involved cooperatively in both the planning and operational aspects of the program. The STS operational strategy is to detect and monitor GM

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colonies that develop within the TZ and to eradicate these colonies before they grow, coalesce and contribute to the overall rate of spread. The benefits derived from the STS project will be determined as the marginal value of the delayed GM impact. The general objective of the pilot project is to evaluate the feasibility of using current Integrated Pest Management (IPM) Strategies to slow the rate of spread of the GM over a large geographic area. If this evaluation reveals that STS is a viable and effective strategy, a plan for integration of STS technology into a national strategy will be developed and implemented. As part of the economic evaluation of the STS pilot project, a simple cost accounting system was developed and cost data was collected from each cooperating agency for expenditures that occurred during the fiscal years of 1993, 1994 and 1995. These data were summarized and Mayo, et al. (1996) reported preliminary results. During this three-year period, 59% of the total expenditures were spent on trapping activities, 28% on pesticide treatments and 13% on data management. Clearly, trapping is a significant part of STS expenditures.

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

Those who are charged with deploying and collecting data from the pheromone traps are known as trappers. Employment as a trapper is seasonal work with the GM trapping season beginning in April or May and extending until August or September (depending on location). Trappers work full-time for approximately a 12-week period. These workers must possess basic physical skills (such as the abilities to drive and traverse rough terrain), as well as technical skills. The technical skills required include the ability to read and follow maps, collect data, code data forms and use instruments such as a hand compass and Global Positioning System (GPS) unit. Relatively high levels of skill are required from a GM trapper.

Trappers must visit each trap at least 3 times per trapping season. All traps are placed early in the season, prior to the beginning of moth flight, and are revisited at approximately mid-season. Male moths

captured by mid-season are counted and recorded during the mid-season visit. Each trap is revisited again near the end of moth flight to count and record the moth capture for the second half of the season. This is also an opportunity to retrieve the used traps for disposal. Occasionally, as time allows, there are additional visits made to readily accessible traps between mid-season and the final inspections. The goal for each trap placed is a minimum of three visits (placement, mid-season inspection and final inspection).

Since 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. It is highly desirable to have the ability to predict or estimate the expense of GM trapping for a given area. No GM trapping cost functions currently exist. Therefore, the objectives of this study are to investigate gypsy moth trapping cost data and develop a trapping cost model for application to the management issues associated with the Slow-The-Spread project.

Study Area

The study area for this project includes over 3.5 million acres located within the states of North Carolina, Virginia and West Virginia. This area includes most of the STS action area during the 1995 trapping season. A total of 25 counties over this three-state area were involved. Each county was classified into one of three broad physiographic categories. This included 8 coastal plain counties, 3 transition counties (between the piedmont and mountains) and 14 mountain counties. In addition, there were three separate state agencies involved with the trapping efforts. All 8 coastal plain counties were trapped by a single agency. A second agency trapped the 3 transition counties and 8 mountain counties, while the third agency trapped the remaining 6 mountain counties. In total, 75 trappers placed 16,217 traps over the three-state area. On average, each trap was visited more than 3 times during the 1995 season. The placement and inspection of these traps required a total of 4370 trapper-days to complete.

The county level data was determined as follows. An estimate of the existing road mileage in each county was determined by public domain information available for North Carolina through the North Carolina Department of Transportation (January 1995), for Virginia through the Commonwealth of Virginia Department of Transportation (December 1995) and for West Virginia through the West Virginia Department of Transportation (January 1996). Road density was then determined as the linear miles of road in each county divided by the size of the county in square miles. Road density was considered to represent the

relative "remoteness" of the county being trapped.

An estimate of average elevation was also determined for each county. Elevation data for the STS action area was developed using a geographic information system (Roberts, 1996). A USGS 1:250,000 scale digital elevation model with elevation rounded to the closest 10 meters was used. These elevations were associated with county boundaries and weighted average elevation was determined for each county. Average elevation was measured in meters.

Individual trapper data was collected from the three state agencies executing the trapping activities. For each trapper, the daily productivity rate was determined (the number of traps visited for a given day). These were identified as being either an initial placement visit or an inspection visit (midseason or final). From additional agency supplied information, the hours worked and vehicle miles traveled daily by each trapper were determined. These data were screened and observations where trappers had both placed and inspected traps within a single day were dropped. In addition, only the traps placed at grid spacings of 1-kilometer or less (250m or 500m) were considered.

METHODS

Direct gypsy moth trapping cost can be reduced to three cost components. Mayo et al. (1996) reported that the average direct cost for STS GM trapping from 1993 to 1995 was \$35.03 per trap. This consists of 69.3% for trapper labor, 21.4 % for vehicle expense and 9.3 % for equipment and supplies. Over 90% of the direct costs are accounted for by trapper labor and vehicle cost. Equipment and supply expenditures can be easily estimated by multiplying the average unit rate (\$3.25) by the number of traps placed. The other components are less direct. Trapper labor requirements are related to trapper productivity. If one knows trapper productivity (the average rate at which traps are visited), trapper labor requirements can be easily determined. Likewise, vehicle expense is related to the number of miles traveled. If the number of miles traveled can be estimated, then vehicle expense can readily be determined.

In equation format, these cost components for a given area can be expressed as follows. Trapper labor cost per trap visit (L) can be expressed as

$$L = \frac{LR}{TPR} \quad (1)$$

where LR is the per hour trapper labor rate (\$/hr) and TPR is the trapper productivity rate (the average number

of traps visited per trapper hour worked). The average value of LR from 1993-1995 was determined to be \$7.27 per hour. The vehicle expense per trap visit (V) can be expressed as

$$V = \frac{(MT)(SMR)}{(TPR)(HR)} \quad (2)$$

where MT is the number of miles traveled per workday, SMR is the standard mileage rate (the standard rate from the Internal Revenue Service for 1995 was \$0.30 per mile traveled) and HR is the average number of hours trappers work daily.

If it is assumed that trapper productivity is not the same for both placing and inspecting traps, then the trapper labor cost per trap placed (L_p) is

$$L_p = \frac{LR}{TPR_p} \quad (3)$$

where TPR_p is the trapper productivity rate for placing traps. Likewise, the trapper labor cost per inspection visit is

$$L_i = \frac{LR}{TPR_i} \quad (4)$$

where TPR_i is the trapper productivity rate for inspection visits. If it is further assumed that vehicle travel is proportional to trapper productivity (i.e. the more traps visited, the more miles traveled per work day) then the vehicle expense per trap placed (V_p) is

$$V_p = \frac{(MT)(SMR)}{(TPR_p)(HR)} \quad (5)$$

where all variables are as defined previously. The average vehicle expense per trap visit for trap inspections (V_i) is given as

$$V_i = \frac{(MT)(SMR)}{(TPR_i)(HR)} \quad (6)$$

where (again) all variables are as defined previously.

If the equipment and supply cost (assumed to be a constant \$3.25 per trap) is allocated to trap placement, the average cost to place a trap (C_p) can be written as

$$C_p = L_p + V_p + 3.25 \quad (7)$$

Likewise, the average cost to inspect a trap (C_i) can be written as

$$C_i = L_i + V_i \quad (8)$$

Thus the average total cost per trap (TCPT) in a given area per trapping season can be written as

$$TCPT = C_p + (C_i)(NI) \quad (9)$$

where NI is the average number of inspection visits made per trap during a trapping season. The average value of NI during the 1995 STS trapping season was determined to be 2.283. Furthermore, the total cost of trapping a given area during a trapping season (TCPA) can be expressed as

$$TCPA = (TCPT)(NT) \quad (10)$$

where NT is the number of traps placed within the area.

It is clear from an examination of these equations that estimating TPR and MT are the keys to development of the cost functions. Thus statistical models were developed to estimate TPR and MT.

The trapper productivity rate (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 3178 trapper days) were collapsed into a set of average trapper productivity rates (traps visited per hour worked) for both placement and inspection within each county. Means with less than 3 observations were also omitted. This resulted in a data set with 48 observations. Since each mean did not have the same number of observations, weighted least squares (WLS) was used to fit the TPR equation as recommended by Kmenta (1986).

The miles traveled (MT) equation was also developed using the individual trapper productivity data. In this case, there was no need to omit the observations involving traps located in more than one county. Thus for each productivity rate (traps visited per day) the average miles traveled per day were determined. Means with less than 4 observations were omitted resulting in a data set with 53 observations. As before, WLS was used to fit the MT equation due to unequal numbers of observations for each mean.

RESULTS AND DISCUSSION

A trapper productivity rate model was developed that relates average TPR_p and TPR_i to physical characteristics of the county where the traps are located (see Table 1). All variables included in the model are statistically significant at $\alpha=0.01$. The variables, road density (RD) and elevation (ELEV) are as previously defined. It was determined that TPR decreases as the average county elevation increases. This is intuitive since elevation is a proxy for "roughness", and as "roughness" increases trapper productivity should decline.

Table 1. Weighted least squares parameter estimates for the regression equation relating LTPR or natural logarithm of the trapper productivity rate (average trap visits per hour) to physical variables of the area being trapped.

| Variable name | Estimate | t-ratio |
|-------------------------------|-----------|---------|
| Intercept | 1.286563 | 5.151 |
| PLACE (1 or 0) | -0.298784 | -9.055 |
| RD (miles/mile ²) | -0.396113 | -2.864 |
| RD*CP (CP=1 or 0) | 0.376360 | 3.776 |
| ELEV (meters) | -0.001635 | -4.242 |
| RD*ELEV | 0.000611 | 2.756 |
| Observations | N=48 | |

The variable PLACE is a dummy variable with value=1 when TPR_p is desired and value=0 when TPR_i is of interest. TPR is significantly less when traps are being placed, as opposed to when they are being inspected. The average ratio of (TPR_i / TPR_p) for the 1995 trapping season was 1.3424.

CP is a dummy variable with value=1 when the county being considered is located within the coastal plain and value=0 otherwise. 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 the 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 about 100 meters), TPR decreases as road density increases. However, in other counties where average elevations are above approximately 550 meters, TPR increases as road density increases. The positive impact of road density at higher elevations has intuitive appeal since increased road density should mean greater access and possibly less walking to be done by the trappers. Thus increased road density at higher elevations may compensate for some of the effect of "rough" terrain.

During development, the TPR model was tested for heteroskedasticity using the methods suggested in Maddalla (1992). A heteroskedastic condition was determined to be present and was addressed using a natural log transformation of TPR. Following 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. Since all of the coastal plain counties were trapped by the same agency, this suggests the possibility that the increased productivity rate might be due to 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 expert opinion of STS operation managers from each of the three agencies². The experts do not believe that such an agency effect is present. Instead they conclude that differences in trapper productivity are due to the physical characteristics of the area being trapped. Each agency instructs trappers to follow the trapping procedures in the STS Male Moth Survey Trapper's Manual (Carroll, et al., 1994); thus procedures between agencies should be reasonably similar. If an agency effect is present, the impact of elevation on TPR may be overstated. More data is needed to conduct statistical testing for the presence of an agency effect.

A vehicle mileage model was also developed which relates miles traveled to the number of traps visited. A simple linear model was assumed for trapper vehicle travel such that

$$MT = D_{H,1} + D_{1,2} + \dots + D_{N-1,N} + D_{N,H} \quad (11)$$

where MT is the mileage traveled by a trapper to visit N traps per day, $D_{H,1}$ is the driving distance in miles from home to the first trap site, $D_{1,2}$ is the driving distance in miles from the first to the second trap site, ..., and $D_{N,H}$ is the driving distance on the return trip from the Nth trap to home. This expression can be algebraically manipulated such that

$$MT = (D_{H,1} + D_{N,H}) + \sum_{J=1}^{N-1} D_{J,J+1} \quad (12)$$

or by substitution

$$MT = (D_{H,1} + D_{N,H}) + \mu(N - 1) \quad (13)$$

where μ is the average inter-trap driving distance from trap 1 to trap N. Equation (13) can easily be estimated using standard regression techniques (see Table 2).

Table 2. Weighted least squares parameter estimates for regression equation relating vehicle miles traveled per day (MT) to the number of traps visited daily minus 1 (Traps-1).

| Variable name | Estimate | t-ratio |
|---------------|-----------|---------|
| Intercept | 69.051567 | 33.616 |
| (Traps - 1) | 0.914752 | 9.467 |
| Observations | N=53 | |

The intercept term can be interpreted as the average daily round trip distance traveled by trappers to their assigned trapping area. The slope represents the average inter-trap driving distance traveled by all trappers. Of course this estimate of inter-trap driving distance is only valid at the 1-kilometer or less grid spacing.

CONCLUSIONS

It is important for the successful management of the Slow-The-Spread project to be able to control gypsy moth trapping costs. Trapping cost functions would assist this cost control effort. Trapping cost accounts for a very significant portion of the STS project expenditures with direct trapping cost being composed primarily of trapper labor and vehicle expense.

Trapper labor expenditures are related to trapper productivity rate and this productivity rate can be represented as a function of physical characteristics of the county where the traps are located. Trappers are less productive (in terms of trap visits per hour worked) during the placement or initial establishment of trap sites relative to productivity rates seen during subsequent inspection visits. It simply takes longer to place traps than to inspect them. The county-level characteristics of average elevation and average road density are adequate proxies for trapping area "remoteness and roughness" characteristics. These variables are useful indicators of expected trapper productivity rates within a given area.

²Information obtained during informal telephone conversations in January 1997 with Dan Wall of the North Carolina Department of Agriculture, George Anderson of the Virginia Department of Agriculture and Consumer Services and Tim Brown of the West Virginia Department of Agriculture.

The possibility exists that the value of average elevation as an indicator of trapper productivity has been overstated due to the presence of an "agency effect". More data is required to statistically test for the presence of such an "agency effect", especially in the coastal plain counties. This should be made a research priority during future refinement efforts of trapping cost functions.

Trapper vehicle expense is related to the number of miles traveled by the trappers. The average daily miles traveled can be expressed as a function of the average number of traps visited daily. This simple model allows coefficient interpretation that has strong intuitive appeal.

Gypsy moth trapping cost for a given area can be easily estimated using the TPR model, the MT model and Equations (3) through (10). More data is needed for validation and testing of trapping cost estimates.

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. Each year as the GIZ moves forward, the STS action zone also moves into new territory (never before trapped). Historical trapping cost data may or may not be adequate to predict the costs of next years trapping area. Cooperating agencies must submit annual budget proposals for funding based on potentially inadequate information. Funds are allocated to execute specific trapping goals based on these proposals. Trapping cost functions relating county physical characteristics to average trapper productivity will improve cost estimates and facilitate program strategic and tactical planning. It may even be possible to develop allocation guidelines for funding distribution based on these trapping cost functions.

A second area of potential application is to facilitate determination of the number of trappers required to trap a given area. As stated above, if trapper productivity can be anticipated, better decisions can be made with regard to hiring the appropriate number of trappers. A trapping cost model would greatly facilitate this task.

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