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Southern Journal of Applied Forestry 1996 v 20(65-73.
Leuschner, W. A., J. A. Young, S. A. Walden, and F. W. Ravlin. Potential benefits of slowing the gypsy moth's spread.

NAL Call Number: SD1.S63 Ver: AGRICOLA

Maximum Cost: n/a

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Potential Benefits of Slowing the Gypsy Moth's Spread

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ABSTRACT. *The potential benefits of a proposed program to slow the spread of the gypsy moth,* Lymantria dispar *(L.), are assessed. A GIS model, which may have application to other epidemiological analyses, was developed to assess the physical spread over a 25 year period. Economic models were developed to estimate potential benefits from reduced management activities, timber production, residential impacts, and recreation participation. Potential benefits for the greatest, medium, and least benefit scenarios were about $3,800, $2,300, and $800 million, present value, respectively. About 83% of these benefits were obtained from delaying residential impacts. South J Appl For 20(2):65–73.*

The gypsy moth, *Lymantria dispar* (L.), has received great attention and has been subjected to many management activities since its accidental introduction in the Boston, Massachusetts area in 1869. It initially spread north following the prevailing winds. However, it was not until the second half of the 20th century that the southern and westerly infestation accelerated (McManus and McIntyre 1981). This infestation has now reached West Virginia, Virginia, and parts of northeast North Carolina.

The general spread is expected to continue south and west. Individual isolated infestations, sometimes called "spots," can occur great distances in front of the general spread when egg masses or other life stages are transported by humans on vehicles or outdoor household articles. A Slow-The-Spread (STS) pilot project, initially called the gypsy moth Containment Program, to reduce the rate of spread, was proposed in 1990. This study assessed Slow-The-Spread's likely economic benefits.

The gypsy moth infestation may be conceived as moving forward in three zones, the Generally Infested Zone, the Transition Zone, and the Unifested Zone. The Generally Infested Zone ranges from continuous populations, where habitat exists and the populations have been through at least one outbreak episode, to low level populations where zero to light defoliation occurs. The Transition Zone is adjacent to the Generally Infested Zone, male moth captures are discontinuous, and outbreaks have not yet occurred. The Uninfested Zone contains only isolated spots.

Slow-The-Spread would be implemented in the Transition Zone. Detection efforts would be intensified by using one kilometer pheromone baited trap grids and and supplementing them with 500 and 250 m intensive grids if initial results indicated the likely presence of gypsy moth. The plan is to discover small, low density infestations which now go undiscovered.

An intensive treatment program would be implemented concurrently. Any detected infestation above a threshold level is treated or intensively monitored. Existing spraying techniques using diflubenzuron and *Bacillus thuringiensis* var. *kurstaki* are used. In addition, Gypchek (virus), mating disruption phermones, sterile male mating, and mass trapping techniques, which are all gypsy moth specific, are available for environmentally sensitive areas. Slow-The-Spread will not affect the moth in the Generally Infested Zone nor will it eliminate its spread.

The fundamental benefit of Slow-The-Spread is to slow the rate at which land enters the Generally Infested Zone from the Transition Zone. This strategy can be likened to that in human medicine where death is not prevented, only postponed. Eradication programs for isolated infestations in the Uninfested Zone, ahead of the Transition Zone, will

NOTE: This study was performed in 1990-91 while the author was on the faculty in the Department of Forestry, VPI & SU under a Cooperative Agreement with the USDA-Forest Service Northeastern Forest Experiment Station. We gratefully acknowledge the many contributions of numerous colleagues.

continue as before and are not considered part of Slow-The-Spread

This assessment is based on a series of spread rates simulated for a 25 yr period Only spread to the south and west which is contiguous to the current Generally Infested Zone is analyzed Lake States and other infestations are excluded. Damages are calculated for each rate from the base year, 1990, for the next 25 yr The difference between the damages for the rate without Slow-The-Spread and with Slow-The-Spread is the estimated program benefit.

Spread Simulation Model

Gypsy moth spread was simulated using a GIS model (ARC/INFO) that overlaid county maps on all states which might enter the Generally Infested Zone in the next 25 yr. The base year (1990) Generally Infested Zone was obtained from APHIS, the North Carolina Department of Agriculture, and the Entomology Department at Virginia Polytechnic Institute & State University Whole county units within the Generally Infested Zone (APHIS Zone I) were identified on the GIS for the base year The whole county was included if greater than 50% of its land area was infested

Six rates of spread were chosen ranging from 2 5 to 15.0 miles/yr in 2.5 mile increments These bounded the likely spread rates both without and with Slow-The-Spread Spread was simulated for each of the six rates The internal borders of the Generally Infested Zone counties were dissolved each year to create a single polygon which was then buffered by the rate of spread to create lines of equal distance representing the Generally Infested Zone's frontal movement. County boundaries were reimposed each year, and the proportion of a county's area entering the Generally Infested Zone in that year was calculated creating a matrix:

$$PC_{ijt} \tag{1}$$

where

PC = proportion of county i entering the Generally Infested Zone at rate of spread j in year t; $0.0 <= PC <= 1.0$

i = county (identified by FIPS code), $i = 1, \ldots, n$

j = rate of spread; $j = 1, \ldots, 6$; $1 = 2.5, \ldots, 6 = 15.0$

t = time period (year), $t = 1, \ldots, 25$.

Economic Model

An economic impact has been defined as "... any impact occurring to a socially useful forest product, any change in socially useful items needed to produce the product, or any change in the distribution among society of either the product (or the income derived from it) or its production cost" (Leuschner and Berck 1985). These economic impacts are considered damages when they are negative. Major potential economic impacts from the gypsy moth in the rural and urban forests were identified as occurring in: (1) gypsy moth management activities; (2) timber production, (3) high density recreation, (4) residential infestations, (5) scenic beauty/esthetics, (6) water quality; and (7) wildlife.

Distributional impacts were beyond the scope of this study. Impacts on the production and cost of categories 5, 6, and 7 above were also not estimated because data were not available to do so. In general, the remaining impacts were estimated by estimating the area of each county which entered the Generally Infested Zone in each year and multiplying it by that impact's value per unit of area and also the probability of being infested

Once in the Generally Infested Zone, an acre has a nonzero probability of being infested every year thereafter These subsequent infestations were modeled by making the simplifying assumption that, on average, a stand would be just as suseptible in the years following its entrance as the year of entrance and then merely accumulating the impacts. The difference between the present value of the accumulated impacts without and with the Slow-The-Spread program, summed over 25 yr, is the potential program benefit.

Management Activities

Pest management experts confirmed that management activities in the Generally Infested Zone will increase as spread increases the number of acres in the Generally Infested Zone Slow-The-Spread may reduce the rate of increase in the Generally Infested Zone thus management costs may be less with Slow-The-Spread than without it. The decreased cost is a program benefit

Management activity costs (MA) are estimated by

$$MA_{jt} = \sum_{i=1}^{n} PC_{ijt} * A_i * C \tag{2}$$

where

A = acres in county i

C = average cost per acre = \$0 18239

and all other variables are as previously defined.

The average cost per acre, C, is the average cost for 1988–1989 in the state of Pennsylvania (personal communication). Pennsylvania's cost was used because the entire state was in the Generally Infested Zone and the state was experienced in gypsy moth management activities and thus more likely to reflect costs which would occur in other states over time.

Timber Impacts

Timber impacts occur because defoliation results in reduced stand growth and possibly increased mortality Timber impacts occur as decreased yield and/or stumpage price *when the stand is harvested* and are reflected in a lower present value than if the stand had not been attacked. There is no economic impact at the year of infestation, the impact occurs at harvest time and is the difference between what would have been harvested without an infestation and what is harvested with an infestation.

Timber impacts theoretically include decreases in quality or log grade and changes in species composition These changes would be reflected in a changed stumpage price if they occurred. Impacts could also occur if an infestation reduces the regenerated stand's value, perhaps due to species composition changes. Information was not available to estimate log grade/species composition/ regenerated stand impacts.

Timber benefits accrue with Slow-The-Spread because individual stands are attacked later in their life or, in some cases, are harvested before attack and replaced by stands too young to be susceptible. The younger a stand when attacked, the greater the yield lost. Thus, the longer attack is postponed, the greater the timber yield and hence total revenue.

However, the economic criterion is the present value of a stand. In general, the present value is greater the older the stand because revenues are received sooner and hence worth more The present value of the yield lost to attack from a younger stand is "worth" less in present value because it is discounted more years, even though the volume lost is greater than in an older stand This phenomenon is seen in Table 1 and occurs until the last decade or two before rotation.

Estimating Acres Attacked.—Forest area in each county was obtained from the Eastwide Data Base (Hansen et al. 1992) The study included only the following cover types because they are the ones suseptible to defoliation· Oak–Pine, Oak–Hickory (except Yellow-poplar–Oak), Yellow-poplar–Oak, Oak–Gum–Cypress (except nonsusceptible types), and Maple–Birch–Beech (Eyre 1980 and Hansen et al. 1992).

The acres in each county were summed for each of the above cover types. Only poletimber and sawtimber size classes were included This formed a variable, acres of susceptible type *(AST)* for county *i* and cover type *k*. However, not all acres of susceptible host types are infested in any one year, even though an area is generally infested. Thus, a probability of timber becoming infested *(PTI)* in any one year was estimated as 0.097 based on a report by Ketron, Inc. (1978). The Ketron estimate was based on the acres defoliated, as reported in various USDA evironmental statements, and the acres of susceptible host type in New England, New York, New Jersey, and Pennsylvania.

Commercial forestland which is not harvested has zero value for timber and thus would incur no timber impact There are several reasons why land may not be harvested, such as private landowners with nontimber objectives or public lands reserved from timber management. Therefore, the proportion of land available for cut (PAC) should also be estimated. This was done by assuming the PACs by ownership were: National Forest = 0.25; Other Public = 0.00; Forest Industry = 1 00, Farmer = 0 75, Corporate = 1.00; and Other Individual = 0.50. These proportions were weighted by acres in the above ownership categories in the southeast region (USDA Forest Service 1988) in Pine–Hardwood, Upland Hardwood, and Bottomland Hardwood types to obtain PAC = 0 6585

Estimating Damages per Acre—Timber impacts can occur if (1) yield is changed, (2) the rotation is changed, (3) wood quality or species composition, as reflected in a different stumpage price, is changed, (4) some combination of 1–3 occurs, or (5) the regenerated stand is changed by one or a combination of 1–3. Literature on moth damage (Campbell and Sloan 1977, Gansner and Herrick 1984 and 1987, Gansner et al. 1983) leads to the following conclusions:

1. There are insufficient data to directly estimate changes in yield at rotation.
2. Stand volume and basal area generally recovers to preattack levels in about 10 yr.
3. Species composition shifts out of oak are relatively small (5% of BA). Shifts between oak species are not documented

We conclude from this that the major impact of an average infestation is about 10 yr growth loss Growth loss for 10 yr can be reflected in at least one of two ways in even-aged management: (1) the rotation may be extended 10 yr to regain the lost growth or (2) the stand may be harvested at its regular rotation with decreased growth. Other combinations are possible

Table 1. Estimated timber damages in dollars per acre, present value at stand age at attack

	Cover type				
Age at attack	O–P	O–H	YP–O	O–G–C	M–B–B
20	15 32	10 18	33 87	22 93	6 43
25	17 29	11 61	39 70	27 02	7 82
30	19 46	13 17	46 00	31 44	9 36
35	21 93	14 94	53 04	36 38	11 09
40	24 78	16 97	61 04	41 99	13 06
45	28 10	19 33	70 27	48 44	15 33
50	31 97	22 07	40 48	27 96	17 96
55	36 52	25 28	23 35	16 16	21 03
60	20 91	14 52	0 01	0 01	24 61
65	12 02	8 36			28 81
70	0 01	0 01			16 86
75					9 88
80					0 01

Note O–P = Oak–Pine, O–H = Oak–Hickory, YP–O = Yellow-poplar–Oak, O-G-C = Oak–Gum–Cypress, and M–B–B = Maple–Birch–Beech

Simulations of these two alternatives show that extending the rotation consistently results in greater losses of net present value as compared to maintaining the regular rotation and accepting 10 years growth loss. The rational forest manager who is managing for timber would choose the alternative resulting in the smallest loss. Therefore, the second alternative, unattacked rotation age with reduced yield was used to estimate the impacts

Stand age must be estimated to use yield functions Existing stand age was taken as the weighted mean for all acres in a stand size class and cover type in a Survey Unit The acre weighted mean of all Survey Units for a cover type is used if data are missing. Rotation age is based on expert opinion of what occurs in practice in the cover types rather than what is optimal Rotation ages used in the analysis were: Oak–Pine = 70; Oak–Hickory = 70; Yellow-poplar–Oak = 60; Oak–Gum–Cypress = 60; and Maple–Birch–Beech = 80

A single timber yield function was calculated for each of the five forest types using published yield tables (Beck and Della-Bianca 1970, Gevorkiantz and Duerr 1937, McClure and Knight 1984, and Schnur 1937) and a standard functional form (ln Yield $= a + b * 1/\text{Age}$) to which the tables were fitted. The Yellow-poplar–Oak function was estimated by weighting yield 0.5 from each yield table. Doolittle (1958) was used to estimate site index equivalents.

Yields for stands without attack are estimated using the above functions and rotation ages. Yield at rotation for a one-time attack was reduced by $10 * PAI$ if a stand is attacked more than 10 yr before its rotation age. Yield at rotation is reduced $5 \times PAI$ if a stand is attacked within 10 yr of rotation PAI is calculated as the difference between yield at rotation and age of attack divided by the number of years between rotation and age of attack

Stumpage prices were the 1990 average prices taken from Timber Mart-South (Norris various) and converted to dollars per cunit. Prices are weighted 25%/75% for saw-timber/pulpwood Oak–Pine was weighted 50%/50% for hardwood/softwood within these products Species groups were matched as closely as data permitted. Prices used were Oak–Pine = \$26.84, Oak–Hickory = \$17.25; Yellow-poplar–Oak = \$18.64; Oak–Gum–Cypress = \$17.25; and Maple–Birch–Beech = \$15 13

Timber damages are the difference between the present value of the stand without attack and the present value of the stand with attack Under the assumptions in this model, they are the present value of the decreased yield valued at the stumpage price and discounted the number of years between the age at attack and the rotation age (Table 1).

Timber Impact Summary.—Timber impact estimates may be summarized in terms of the basic model of acres attacked multiplied by damages per acre:

$$AA_{jkt} = \sum_{i=1}^{n} PC_{ijt} * AST_{ikt} * PTI * PAC \qquad (3)$$

where

AA_{jkt} = acres attacked for rate of spread j in cover type k in time period t

AST_{ikt} = acres of susceptible type in county i and cover type k in time period t

PTI = probablity of timber becoming infested

PAC = proportion of timber cut

k = cover type k, $k = 1, \ldots, 5$

and all other variables are as previously defined.

The timber damages for any rate of spread and year are:

$$TD_{jt} = \sum_{k=1}^{5} AA_{jkt} * DA_{kt} \qquad (4)$$

where

TD_{jt} = timber damages for rate of spread j in year t

DA_{kt} = timber damages per acre for cover type k (Table 1)

and all other variables are as previously defined and it is understood that DA is for the stand age at time of attack.

High Density Recreation Impacts

High density recreation impacts occur because the moth defoliates a recreation area and makes the area less desirable (causes a nuisance through droppings, hairs, larvae, etc.). Persons either stop visiting the recreation area, postpone visits, substitute visits to other areas, or use the same area with less enjoyment during the infestation In addition, management costs for suppression before and during the infestation and cleanup, removal, and replacement costs during and after the infestation may increase Only impacts from stopped and substituted visits are estimated.

The basic model of estimating the number of visitor days impacted and the value per visitor day is followed. However, the estimates for days stopped and substituted and their values are made separately.

Estimating Visitor Days.—The recreation areas in a county *(RA)* were estimated from the National Outdoor Recreation Supply Information System (NORSIS) by summing the number of campgrounds and picnic areas in all ownership categories in each county. The mean visitor days per area *(VD)* were estimated from USDA Southern Region Recreation Information Management high density recreation attendance data However, gypsy moth impacts occur only in the spring and summer, thus the proportion of visits in season *(PSE)* was also estimated. Finally, not all recreation areas will be attacked, just as not all timber stands will be attacked, hence *PTI* derived above was also used as a multiplier This model may be summarized as:

$$V_{jt} = \sum_{i=1}^{n} PC_{ijt} * RA_i * VD * PSE * PTI \qquad (5)$$

where

V_{jt} = visitor days to infested recreation areas for rate of spread j in time period t

RA_i = number of recreation areas in county i

VD = average visitor days per area per year = 13,500

PSE = proportion of visitor days during season when impacts are possible = 0 7123

and all other variables are as previously defined.

The proportion of visitor days where people stop recreating *(PST)* and the proportion where people substitute other areas *(PSU)* were estimated from Leuschner and Young's (1977) study of Southern Pine Beetle impacts on East Texas reservoir recreation Then

$$VST_{jt} = V_{jt} * PST \quad (6)$$

and

$$VSU_{jt} = V_{jt} * PSU \quad (7)$$

where

VST_{jt} = visitor days stopped for rate of spread j in time period t

VSU_{jt} = visitor days substituted at another site for rate of spread j in time period t

PST = proportion of visitor days stopped = 0.1715

PSU = proportion of visitor days substituted at another site = 0.3908

and all other variables are as previously defined

The damages per visitor day are estimated by using USDA Forest Service (1984) estimates of participant willingness-to-pay for a visitor day of camping and picnicing in the Southern Region. These estimates are inflated to 1990 price levels at a rate which approximates the inflation rates in the Gross Domestic Product Implicit Price Deflator and the Consumer Price Index-All Items during the same time period. This is the damage per visitor day of stopped recreation

The damage from substituting another recreation site for the attacked site is the proportion of value loss on substituted recreation sites found by Leuschner and Young (1977) applied to the damage per visitor day of stopped recreation. The loss from substitution is small because recreationists simply travel to a different, uninfested recreation site. The benefit of the recreation is still received but is less valuable because a less preferred site is now visited

Recreation damages *(RD)* for any rate of spread are then estimated by:

$$RD_{jt} = VST_{jt} * DST + VSU_{jt} * DSU \quad (8)$$

where

RD_{jt} = recreation damages for rate of spread j in time period t

DST = damages per visitor day of stopped recreation = \$13.58

DSU = damages per visitor day of substituted recreation = \$0.19

and all other variables are as previously defined

Residential Impacts

Residential impacts occur because trees are defoliated and a nuisance is caused as explained above. Householders may make a private suppression expenditure over and above those made in the public sector; may make a cleanup, removal and replacement expenditure; and/or may be willing to pay over and above these amounts to avoid the impacts.

Number of households in each county *(HH)* were obtained from a CD ROM of the County and City Data Book (USDC Bureau of the Census 1988) No adjustment was made for changes in households either to the 1990 base year or for future years Number of households impacted in each county and year is estimated by multiplying number of households by the *PC* matrix and *PTI* estimate. Value of the damage was obtained from a University of Maryland (1988) contingent valuation study which estimated the willingness to pay for gypsy moth control. The mean of the two control scenarios was taken and inflated forward to 1990 This willingness to pay to avoid the damage is taken as the value of the damage *(DR)* and equals \$41.07 per household

In formula form

$$HD_{tj} = \sum_{i=1}^{n} PC_{ijt} * HH_i * PTI * DR \quad (9)$$

where

HD_{tj} = residential household damages for rate of spread j in time period t

HH_i = number of households in county i

DR = damages per household infested = \$41.07

and all other variables are as previously defined. The University of Maryland (1988) estimated DR as the average for *all* households in the area thus PTI was set equal to zero in the actual calculations.

The preceding models were used to estimate damages for each impact for the year in which an acre of land first entered the Generally Infested Zone with any of the six rates of spread Recall the simplifying assumption was made that, on average, an acre would be just as suseptible in the years following its entrance as the year of entrance. This allows accumulating damages for any one rate of spread from the base year, 1990, forward to the 25 yr of the analysis before taking their present value.

For example, HD_{jt} is the residential household damage in year t for rate of spread j Then, the present value of the cumulative residential household damage, CHD, is:

$$CHD_j = \sum_{t=1}^{25} \{HD_{jt} + HD_{jt-1}\} * (1+d)^{-t} \qquad (10)$$

where

CHD = the present value of cumulative residential household damages

d = the real discount rate = 0 04

and all other variables are as previously defined. The discount rate is the one used by the USDA Forest Service (Row et al. 1981) The difference between the present value of the cumulative damages for the rates of spread without and with Slow-The-Spread is the potential benefit of the program for that impact

What, then, are possible rates of spread without and with the program? Liebhold et al. (1992) have estimated that the gypsy moth's average rate of spread for 1966–1990 in "warm counties" was 12.88 miles/yr. Other experts quoted estimates of around 9.0 miles/yr. Based on these indicators, we assigned the 10 0, 12.5, and 15.0 miles/yr rates of spread as the "without" Slow-The-Spread rates The remaining rates of spread were considered "with" Slow-The-Spread rates.

Results

The gypsy moth Generally Infested Zone expansion may range from a front running from Ohio through West Virginia and Virginia into northeast North Carolina (Figure 1) over a 25 yr period if a 2.5 mile/yr rate of spread is experienced to a front running from Illinois through Indiana, Kentucky, and Tennessee into north Georgia (Figure 2) if a 15.0 mile/yr rate of spread is experienced.

The estimated impacts in each category and rate of spead are summarized in Table 2 These are the estimated damages if STS is *not* implemented or if it is implemented and is completely unsuccessful If STS is completely unsuccessful, the total negative impact of gypsy moth would be the damages for whatever rate of spread was actually experienced (Table 2) plus the cost of the unsuccessful program.

Potential program benefits (Table 3) are simply the difference between the impacts (Table 2) for these rates of spread. For example, the potential benefit is $774.8 million, present value, for the 10 0 miles per year – 7 5 miles per year rate of spread combination ($3,005 1 – $2,230.3). Benefits generated by individual impact categories can be calculated similarly.

Potential program benefits range from $774.8 to $3,801 5 million, present value, and are somewhat uniformly distributed over the pairs For ease of discussion, we designate the (10.0 miles per year – 7.5 miles per year), (12 5 miles per year – 5.0 miles per year), and (15.0 miles per year – 2 5 miles per year) pairs as the Least, Medium, and Greatest benefit scenarios, respectively. These are the two extreme and the median values The reader may choose any combination desired

Discussion

The present values of the potential Slow-The-Spread benefits are dominated by the residential impacts although the remaining benefit level in the other impacts is still quite large, ranging from about $130 to $660 million (Table 4). Two traditional forest outputs, timber and recreation, account for approximately 13% of the potential benefits About 83% of the potential benefits are caused by residential impacts, which are essentially aesthetic impacts and are likely to be generated outside of commercial forest acreage.

Some readers may be uncomfortable that continguent valuation and willingness to pay values have been used to estimate residential and recreation benefits. Recreation valuation has been so frequently replicated in the last decade or so that we are comfortable with the general level of the value per visitor day

This replication is not present for the willingness to pay for gypsy moth control Miller and Lindsay (1993) recently found a willingness to pay ranging from $27 to $83 per household Jakus and Smith (1991) in an unpublished discussion paper found a range of $238 to $394 per household to protect only the individual's residence site and a range of $295 to $494 per household to protect ". . . private neighborhoods, and the parks and rural areas. " The Jakus and Smith estimates varied by whether a linear or nonlinear model was used and by the specific variables included in the model

This wide variation is disconcerting, and the willingness to pay evidence is not yet, in our opinion, conclusive. We therefore chose the more conservative estimate which falls within the range of Miller and Lindsay's (1993) published estimates.

Another concern is that the households were considered willing to pay each and every year to prevent damage in that year. This is consistent with other calculations in the model. However, we felt that the contingent market descriptions in all the studies did not unequivocally establish whether the respondents were willing to make a payment each year (our interpretation) or a single payment that would prevent infestations for years or decades

This ambiguity is important because residential benefits are so large. When a single residential payment is estimated, the potential benefits estimates change to $2,834, $1,756, and $580 million for the Greatest, Medium, and Least Benefit scenarios and the proportions shift to about 77% residential and 17% timber and recreation combined

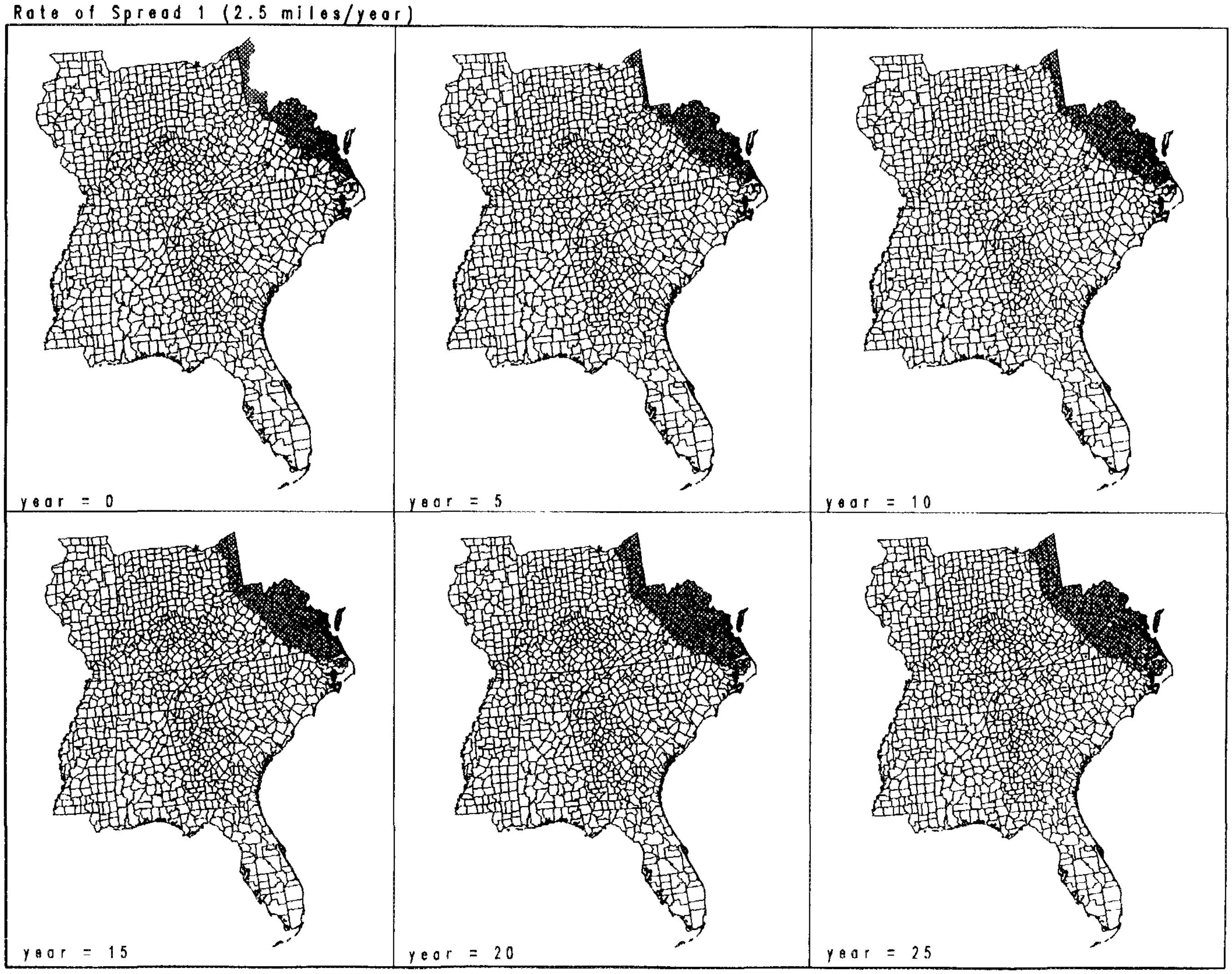

Figure 1 Location of Generally Infested Zone by year of projection when rate of spread is 2 5 miles/yr.

The absolute and relative residential benefits may appear inordinately large, but they are the best estimates possible, given the available evidence and the logic of the model However, readers may second-guess our estimates if they choose. Note that all the models are multiplicative [Equations (2)–(9)] This means variables may be re-estimated (except for *d*, the discount rate) and substituted for our estimates A ratio of the new estimate to our estimate is formed and multiplied by our estimated potential benefits.

For example, suppose residential willingness to pay is thought to be $20.00 instead of $41 07 per household. Then, 20.00/41 07 = 0 48697, and the potential residential benefits (Table 4) become $1,529 0, $938 6, and $313.0 million, present value, for the Greatest, Medium, and Least Benefit scenarios. Other variables, such as Probability of Timber being Infested, may be similarly re-estimated

One could argue that Management Activity benefits should not be included because these funds are controlled by government and that expenditures could (or should) be reduced in light of the relatively small commodity impacts. Although logical, this view ignores the political reality of gypsy moth control which is at least partly reflected in the large number of households impacted We believe management activity funds would continue to be expended based on a political rationale and that, hence, an economic benefit exists.

Table 2. Negative impacts of gypsy moth spread over 25 yr in millions of 1990 dollars, present value.

	Rate of spread — miles/yr					
Impact	2 5	5 0	7 5	10 0	12 5	15 0
Manage act	32 2	62 0	92 9	125 0	158 5	193 6
Timber	66 4	122 8	173 6	221 6	267 5	324 4
Recreation	46 9	94 7	143 0	195 0	241 7	389 3
Residentia	649 7	1203 6	1820 7	2463 6	3131 1	3789 6
Total	795 4	1483 1	2230 3	3005 1	3798 9	4597 0

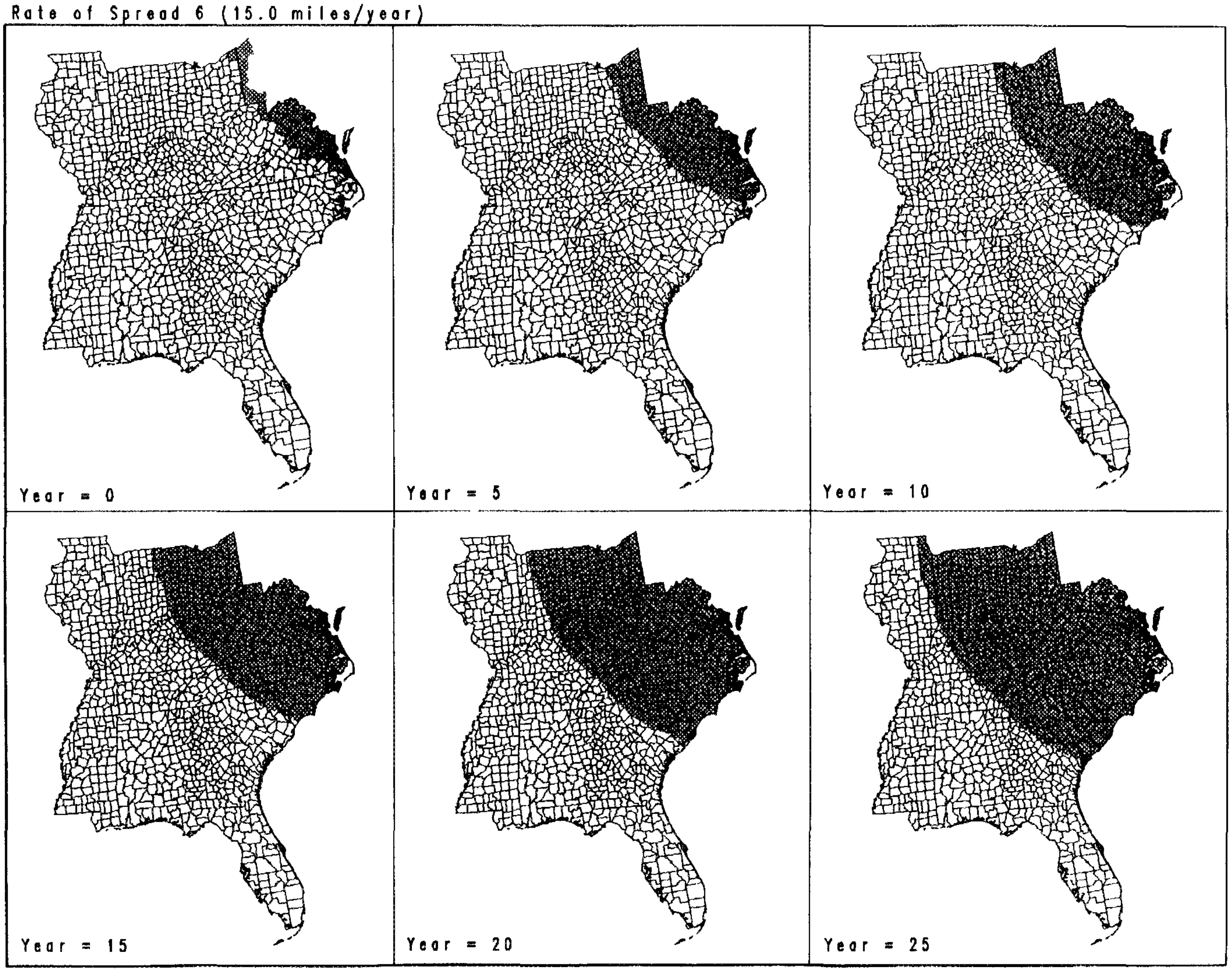

Figure 2. Location of Generally Infested Zone by year of projection when rate of spread is 15 0 miles/yr

The study contains some imprecisions. One is that the projected infested acreage does not initially increase constantly as would be expected along a growing front This is caused by adhering to whole counties in the initial GIS polygon. The county line configuration caused indented places on the polygon (e g., a right angle) which when buffered equal distances caused an acerage decrease This imprecision decreases as the rate of spread and year of the projection increases.

A second imprecision is that growth of existing premerchantable stands into the susceptible poletimber size class was not included. A rerun of Virginia data indicated that state's timber impact would have been 18% higher had ingrowth been included. This imprecision seems of a lesser consequence in light of the relatively small place of timber impacts in the overall result

Third, the study aggregates estimates over wide geographic areas and many different variables. The possibility of aggregation error exists, but its investigation was beyond the scope of the study However, Rastetter et al. (1992) state "Not all aggregations produce errors No error will result from the aggregation of components with only linear properties." We note that most of our estimates are linear

The benefit estimates can be used to calculate a cost guideline to indicate how much could be spent on Slow-The-

Table 3 Potential benefits of the Slow-The -Spread (STS) program over 25 yr in millions of 1990 dollars, present value

Spread with STS (miles/yr)	Spread without STS (miles/yr) 10 0	12 5	15 0
2 5	2209 7	3003 4	3801 5
5 0	1522 0	2315 8	3113 9
7 5	774 8	1568 6	2366 7

Table 4 Potential benefits of Slow-The-Spread over 25 yr by impact category and scenario in millions of 1990 dollars, present value.

	Scenario		
Impact	Greatest (15 0–2 5 miles/yr)	Medium (12 5–5 0 miles/yr)	Least (10 0-7 5 miles/yr)
Manage act	161 2	96 5	32 1
Timber	258 0	144 8	47 9
Recreation	242 4	147 1	52 0
Residential	3139 9	1927 5	642 8
Total	3801 5	2315 8	774 8

Spread and still have the program benefits equal its costs. We used the Equivalent Annual Income. Equivalent Annual Income is the constant amount of annual income or expenditure which is the equivalent of the stated present value. It is the amount which, if spent each year for the 25 yr, would have a present value exactly equal to the potential Slow-The-Spread benefits at the 4% discount rate

The Equivalent Annual Incomes are

Potential benefit	Equivalent annual income
$3,800 million	$243 2 million
$2,300 million	$147 2 million
$800 million	$51 2 million

Thus, $51 2 million a year could be spent for 25 yr on Slow-The-Spread in the least benefit scenario and the program would break even. Parallel Equivalent Annual Income for the nonresidential benefits, which ranged from $130 to $660 million, are $8 3 and $42.2 million/yr for 25 yr.

Conclusions

We believe the general regional impact of Slow-The-Spread is indicated by this analysis and that a program slowing the rate of spread of the gypsy moth could be economically feasible. The study also indicates that programs seeking only to *slow* the spread of pests, as opposed to eradicating the pest, are worthy of consideration and analysis by pest control practitioners In addition, we believe the study demonstrates GIS techniques which may be useful to practitioners who are developing epidemiological spread models and economic models which could be useful in assessing the impact of that spread.

Literature Cited

BECK, D E AND L DELLA-BIANCA 1970 Yield of unthinned yellow-poplar USDA For Serv RP-SE-58

CAMPBELL, R W, AND R J SLOAN 1977 Forest stand responses to defoliation by the gypsy moth For Sci Monogr 19

DOOLITTLE, W T 1958 Site index comparisons for several forest species in the southern Appalachians Soil Sci Soc Am Proc 22(5) 455-458

EYRE, F H, ED 1980 Forest cover types of the United States and Canada Soc Am For, Washington, DC

GANSNER, D A, AND O W HERRICK 1987 Impact of gypsy moth on the timber resource In Fosbroke, S and R R Hicks, Jr Proceedings of coping with the gypsy moth in the new frontier West Va Univ Books, Morgantown, WV

GANSNER, D A, AND O W HERRICK 1984 Guides for estimating stand losses to gypsy moth North J Appl For 1(2) 21–23

GANSNER, D A, O W HERRICK, P S DEBALD, AND R E ACCIAVATTI 1983 Changes in forest condition associated with gypsy moth J For 81(3) 155–157

GEVORKIANTZ, S R, AND W A DUERR 1937 A yield table for northern hardwood in the lake states J For 35 340–343

HANSEN, M H, T FRIESWYK, J F GLOVER, AND J F KELLY 1992 The eastwide forest inventory data base Data base description and user's manual USDA For Serv GTR-NC-151

JAKUS, P, AND V K SMITH 1991 Measuring use and nonuse values for landscape amenities A contingent behavior analysis of gypsy moth control Resour for the Future, Discuss Pap QE92-07 Washington, DC

KETRON, INC 1978 Final report A cost/benefit analysis for gypsy moth containment Ketron, Inc Arlington, VA Unpublished report

LEUSCHNER, W A, AND P BERCK 1985 Impacts on forest uses and values *In* Integrated pest management in pine-bark beetle ecosystems Waters, W W, et al (eds) Wiley, NY

LEUSCHNER, W A, AND R L YOUNG 1978 Estimating the southern pine beetle's impact on reservoir campsites For Sci 24(4) 527–537

LIEBHOLD, A M, J A HALVERSON, AND G A ELMES 1992 Gypsy moth invasion in North America A quantitative analysis J Biogeog 19 513–520

MCCLURE, J P, AND H A KNIGHT 1984 Empirical yields of timber and forest biomass in the southeast USDA For Serv RP-SE-245

MILLER, J D, AND B S LINDSAY 1993 Willingness to pay for a state gypsy moth control program in New Hampshire A contingent valuation case study J Econ Entomol 86(3) 828–837

MCMANUS, M L, AND T MCINTYRE 1981 *In* The gypsy moth Research toward integrated pest management, Doane, C C, and M L McManus (eds) USDA For Serv Tech Bull 1584, Washington, DC

NORRIS, F Various Timber Mart-South Box 1278, Highlands, NC

RASTETTER, E B, ET AL 1992 Aggregating fine-scale ecological knowledge to model coarser-scale attributes of ecosystems Ecol Appl 2(1) 55 70

ROW, C, H F KAISER, AND J SESSIONS 1981 Discount rate for long-term Forest Service investments J For 79 367–369

SCHNUR, G L 1937 Yield, stand, and volume tables for even-aged upland oak forests USDA Tech Bull 560 Washington, DC

UNIVERSITY OF MARYLAND 1988 Benefit-cost analysis of the Maryland integrated pest management pilot project Final Report, 1988 Unpublished office report

USDA FOREST SERVICE 1988 The South's fourth forest Alternatives for the future USDA For Serv FRP No 24, Washington, DC

USDA FOREST SERVICE 1984 Draft environmental impact statement 1985–2030 resources planning act program USDA For Serv, Washington, DC

USDC Bureau of the Census 1988 County and city data book Washington, DC