United States Department of Agriculture

Pine Shoot Beetle, *Tomicus piniperda* (Linnaeus): Analysis of Regulatory Options

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United States Department of Agriculture
Animal and Plant Health Inspection Service
Plant Protection and Quarantine
Center for Plant Health Science and Technology
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Executive Summary

Tomicus piniperda, the pine shoot beetle, is a pest of pines in Africa, Asia, and Europe that was first detected in the United States in a Christmas tree farm near Cleveland, Ohio in 1992. Based on an earlier finding of a potentially high economic loss in 1992, APHIS implemented a regulatory program and quarantines on at-risk pine commodities, including logs and lumber with bark, Christmas trees, and nursery stock in known infested areas.

Despite the regulations, *T. piniperda* subsequently spread throughout the northeast and north central United States; however, to date, it has caused negligible direct damage. Nevertheless, some uninfested states remain concerned that the pest could cause damage if introduced into the western and southeastern United States due to factors including high concentrations of susceptible pine species, environmental stressors that increase availability of susceptible hosts, and generally favorable climates for the beetle.

Our objective in this analysis was to evaluate the *T. piniperda* regulatory program in terms of its effectiveness and efficiency in slowing spread and reducing losses. We estimated the value of slowing pest spread by applying the principle of time value of money which holds that the value of a dollar in loss in the future is less than the dollar loss today. Thus by deferring spread and associated losses, a dollar in avoided losses today can be invested so that it can grow to more than a dollar at a future time. In comparing two policies that yield the same stream of losses, the one that delays pest spread later in time generates larger returns in terms of avoided losses. The estimated impacts were judged against decision criteria for determining Federal response to pest events. The economic criterion suggests that response is warranted when the losses avoided with intervention exceeds its programmatic cost.

We constructed a probabilistic model that provides a distribution of estimates of the value of timber killed by *T. piniperda* if it is introduced into at-risk U.S. pine-producing areas located primarily in the Southeast. The use of distributions in the analysis captures uncertainties in the model inputs and outputs. We modeled the annual timber damage based on *T. piniperda*'s dispersal rate with and without a slow-the-spread program regulating timber until 100 percent colonization of the at-risk area occurred.

In addition to timber losses, we also estimated compliance costs incurred by Christmas tree growers in quarantined areas.

Two scenarios that differ in the assumed proportion of the area damaged were examined: scenario I - higher area damaged (most likely value = 2.48 percent) based primarily on a European experience with *T. piniperda;* and scenario II - lower area damaged (most likely value = zero) based primarily on observed conditions in the infested areas in the United States. The calculation of the mean annual dispersal rate under the program was based on the time when infested counties were placed under quarantine. The dispersal rate without the program was estimated based on the timber-buying radius for large mills as it represents a measure of the distance infested timber could be moved in a year. The time period of the analysis was 47 years, reflecting the length of time when full colonization would be reached.

Our analysis shows that the program is neither effective nor efficient with negative avoided losses (benefits) indicated under both scenarios. In the higher damage scenario, without slow-the-spread, the present value of losses at the mean was estimated at $1.2 million over 47 years, while with slow-the-spread losses was $1.6 million at the mean – higher than without the program by $457,000. When Federal program outlays were taken into account, the program was shown to be inefficient as indicated by an overall mean net loss of $4.4 million over the 47 year span of analysis.

In the lower damage scenario, with no program, the present value of losses was estimated at $393,000 at the mean. This contrasts with losses with the program that was estimated to be $1.1 million in present value, or $747,000 higher in losses with the program. When compared with program outlays, we

estimated a net loss of $4.7 million at the mean over 47 years indicating the operational inefficiency of the program.

These results appear to suggest that resources could be more effectively allocated to improve the efficiency of the slow-the-spread program and achieve a better return on investment. One suggestion may be to reduce survey activities in the western states since *T. piniperda* is unlikely to cross the Great Plains in timber shipments. These resources could then be redirected to other areas to reduce program costs or used to bolster regulatory activities along the leading edge of *T. piniperda*'s distribution to further decrease the rate of spread resulting from the program.

In reality, redirecting a portion of existing resources to trapping as suggested would likely be insufficient in improving program efficiency. Given the wide variability in current trapping efforts among states, additional funds beyond what is currently allocated would likely be needed to improve survey rigor in order to confidently establish the actual geographic range of *T. piniperda* and its rate of spread under quarantine in any given year.

We conclude that additional Federal outlays would not justify maintaining the *T. piniperda* program. Based on the little damage observed to date and the results of the analysis indicating that the program as currently funded is inefficient with mean negative net benefits under both scenarios, a change in strategy to the *T. piniperda* program should be considered.

Should the regulatory status of the pest be changed, exports of U.S. pine logs and lumber would unlikely be impacted because the importing countries either do not allow wood with bark, require phytosanitary treatments, e.g. fumigation, or have no requirements for the beetle. The exception is trade with Canada which could be affected if *T. piniperda* is deregulated because Canada – currently infested with the beetle - does not have restrictions on timber products from uninfested U.S. states. However, over the years Canada has indicated that it would follow the U.S. on changes to the *T. piniperda* regulations.

The methodology used here could be adopted for evaluating other regulatory pest programs. When data are available, this approach characterizes impacts in quantitative terms providing decision-makers with a transparent mechanism for evaluating the program's worth. Also, with the use of distributions, our approach captures uncertainty in the model inputs and results. Data needed to estimate spread and damage may not always be available. In such cases, expert opinions can serve as proxies.

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Introduction

The Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA) conducted this analysis as a result of USDA-APHIS discussions on the need for evaluating the effectiveness of domestic pest programs in achieving their intended goals. In this document we provide a mechanism for such evaluations using the pine shoot beetle (*Tomicus piniperda*) slow-the-spread program regulating timber as a case study.

Tomicus piniperda is a pest of pines in Africa, Asia, and Europe that was first detected in the United States in a Christmas tree farm near Cleveland, Ohio in 1992 (CABI, 2014; Haack and Poland, 2001). Based on an earlier finding of a potentially high economic loss of $742 million over 30 years due to the beetle (USDA-Forest Service, 1992a), APHIS implemented a regulatory program and quarantines on at-risk pine commodities, including logs and lumber with bark, Christmas trees, and nursery stock in known infested areas (7 CFR 301, 2009; Haack and Poland, 2001). Since inception, program expenditures for *T. piniperda* have been aggregated in a miscellaneous pest category, precluding the expenditures from being tracked in early years. Based on data between 2006 and 2011, APHIS spent an estimated average of $350,000 per year on controlling the pest (Austin, 2011; Elstun, 2011).

Despite the regulations, *T. piniperda* subsequently spread throughout the northeast and north central United States; however, it has caused negligible direct economic damage (Haack and Poland, 2001; USDA-APHIS, 2013). Nevertheless, the pest could cause damage if introduced into the western and southeastern United States due to factors including high concentrations of susceptible pine species, environmental stressors that increase host availability, and favorable climates for the beetle (Fowler and Borchert, 2006).

In this document we analyzed the effectiveness of the regulatory program in slowing the spread of the pest and reducing damages. The value of slowing pest spread is determined by applying the principle of time value of money which holds that the value of a dollar in loss in the future is less than the dollar loss today. Thus by deferring spread and associated losses, a dollar in avoided losses today can be invested so that it can grow to more than a dollar at a future time. In comparing two policies that yield the same stream of losses, the one that delays pest spread later in time generates larger returns in terms of avoided losses. The estimated impacts were judged against decision criteria for determining Federal response to pest events (Vo, 2014) (Figure 1). The economic criterion suggests that response is warranted when the losses avoided with intervention exceeds its programmatic cost.

We constructed a probabilistic model to estimate the annual timber damage that could occur with and without a slow-the-spread program regulating timber in place. We chose timber because, of the regulated commodities, it likely represents the highest risk pathway for *T. piniperda* introduction due to factors such as potential infestation levels (Fowler, 2007; Fowler and Borchert, 2006; Fowler et al., 2006; Haack and Poland, 2001). In addition to providing estimates on the effects of discontinuing the *T. piniperda* slow-the-spread program, our analysis could serve as method for evaluating other pest programs.

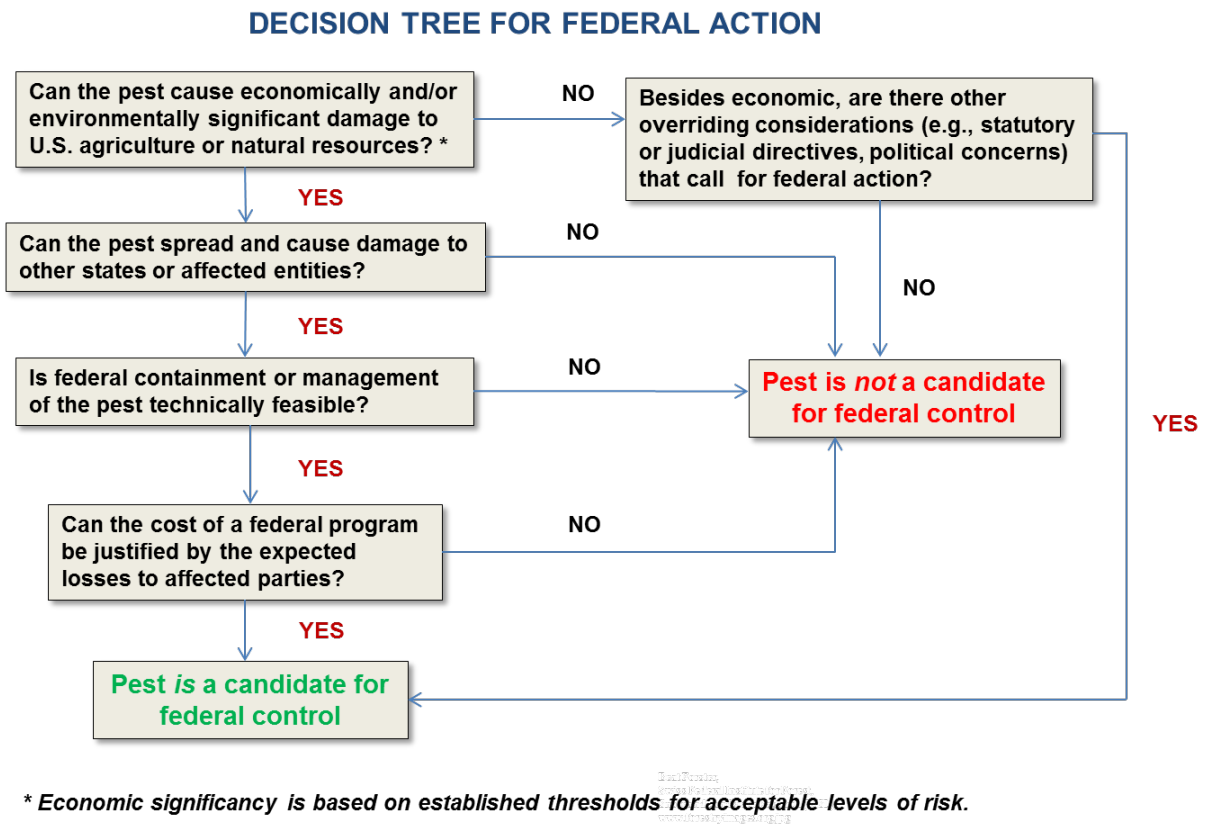

Figure 1. Schematic for determining if a pest is a candidate for Federal control (Vo, 2014).

Methods

I. Spread and Damage Model Overview

We constructed a probabilistic model that provides a distribution of estimates of the value of timber killed by *T. piniperda* if it is introduced into at-risk U.S. pine-producing areas (Figure 2, Appendix 1). To do this, we grouped states into regions based on geography, pine host prevalence, and quarantine status (Table 1, Figure 3). Pines are scarce in the Great Plains (Figure 4) and timber shipping distances [≈ 240 kilometers (Howell, 2005)] would likely not traverse the area into the west. Consequently, we did not model those regions and considered the at-risk area for *T. piniperda* introduction via timber products to be the southeast and the analyzed states in the quarantine area (Delaware, Illinois, Maryland, Missouri, and Virginia) (Table 1, Figure 3). The pine forests in Oklahoma and Texas are continuous with those in the southeast (Figure 4). Consequently, we included those forests in the at-risk area (Figure 4, Figure 6). Our model addresses timber losses and does not account for other types of tree damage, e.g., growth losses (ISSG, 2007), or damage associated with other affected commodities, e.g., Christmas trees (7 CFR 301, 2009). To characterize all *T. piniperda*-associated tree mortality, we modeled tree losses on all timber land, i.e., managed and unmanaged land. Consequently, our estimated values of timber subject to loss may be high since they include trees killed in natural settings that would not typically be harvested for sale, but do have aesthetic and ecological values that are harder to quantify.

Our objective was to evaluate the *T. piniperda* timber regulatory program in terms of its effectiveness in slowing spread and reducing losses. To do this, we modeled the annual timber damage based on *T. piniperda*'s dispersal rate with and without a slow-the-spread program regulating timber until 100 percent colonization, i.e., 37 years with slow-the-spread and 6 years without (see Methods Section II, Part E). Based on expert opinion (Haack, 2014d), we assumed there would be a 10-year lag before *T. piniperda* populations reached levels where tree mortality could occur. We then modeled the annual pine timber area that would be affected by *T. piniperda* with and without slow-the-spread under two damage scenarios (see Methods Section II, Part B).

We also modeled annual losses due to compliance costs to Christmas tree growers in the at-risk area with a slow-the-spread program. These losses were added to the annual value of killed timber with slow-the-spread to characterize the combined losses that *T. piniperda* could cause if introduced into the at-risk area.

We reported the outputs from an impact analysis evaluating the efficiency of the slow-the-spread program at preventing tree mortality along the leading edge of *T. piniperda*'s distribution.

The model was constructed with @Risk 5.7 Professional (Palisade Corporation, 2011) and we ran 10,000 iterations with an initial seed of 1 using Latin Hypercube sampling.

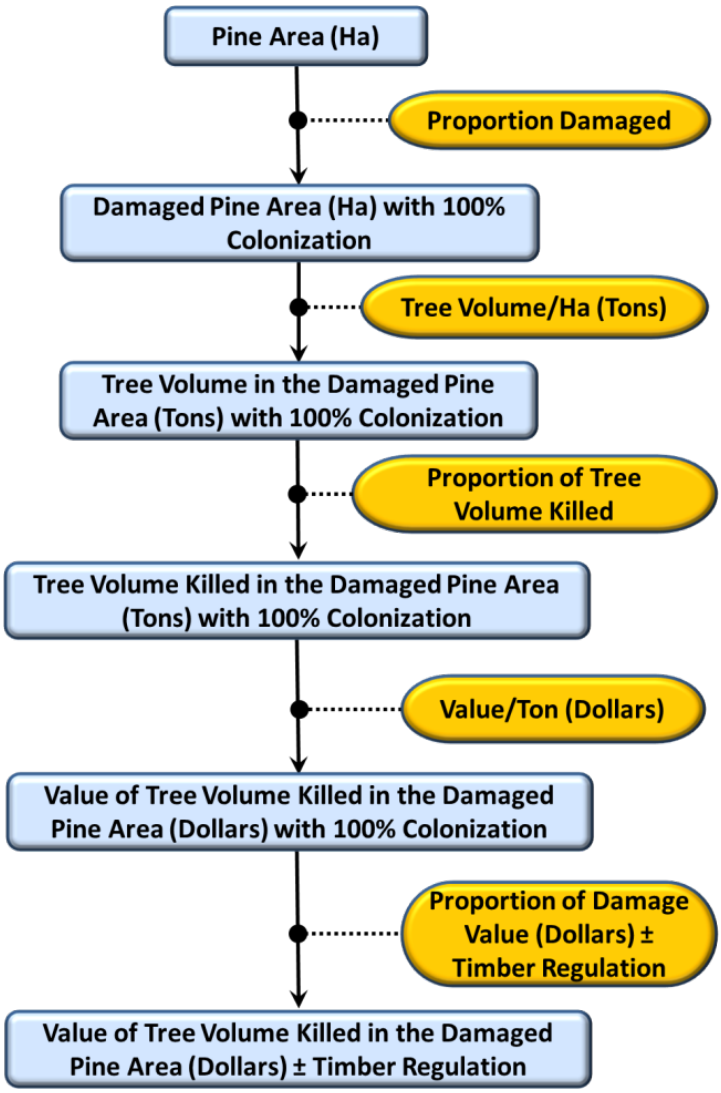

Figure 2. *Tomicus piniperda* pine timber volume and value damage model schematic.

Table 1. Regional classifications used in the *T. piniperda* pine timber damage model.

Region	Description
Unanalyzed States in the Quarantined Area	This region includes states that are either completely quarantined or located towards the northern edge of the quarantined area and partially quarantined, e.g., Maine (USDA-APHIS, 2013). This region is likely at less risk for *T. piniperda* damage than the southeastern and western United States due to the lower concentration of pines and large quantities of white pine, which is not a good host for the beetle (Fowler and Borchert, 2006; Ryall and Smith, 2000). To our knowledge, *T. piniperda* has caused negligible timber damage in this region and, consequently, it was not analyzed.
Analyzed States in the Quarantined Area	This region includes states that are either on the southern and/or western edge of the quarantined area and partially quarantined, e.g., Virginia, or contained within the quarantined area and uninfested, e.g., Delaware (USDA-APHIS, 2013).
Great Plains	This region includes non-quarantined states west of the quarantined area and east of the western United States. This region contains negligible quantities of pine and likely serves as a barrier preventing the natural spread of *T. piniperda* into the western United States (Fowler and Borchert, 2006).
Southeast	This region includes non-quarantined states south of the quarantined area and east of the Great Plains. This region may be at risk for *T. piniperda* damage due to factors including: 1) large quantities of at-risk pine species, 2) tropical storms and hurricanes that could produce large quantities of brood material, and 3) warmer temperatures that may increase beetle activity (CABI, 2014; Fowler, 2006; Långström et al., 1984; Ye, 1991).
West	This region includes non-quarantined states west of the Great Plains. This region may be at risk for *T. piniperda* damage due to factors including 1) large quantities of at-risk pine species and 2) fires and droughts that could increase tree susceptibility to beetle attack (Fowler and Borchert, 2006; ISSG, 2007; Swetnam, 2001; Ye, 1991).

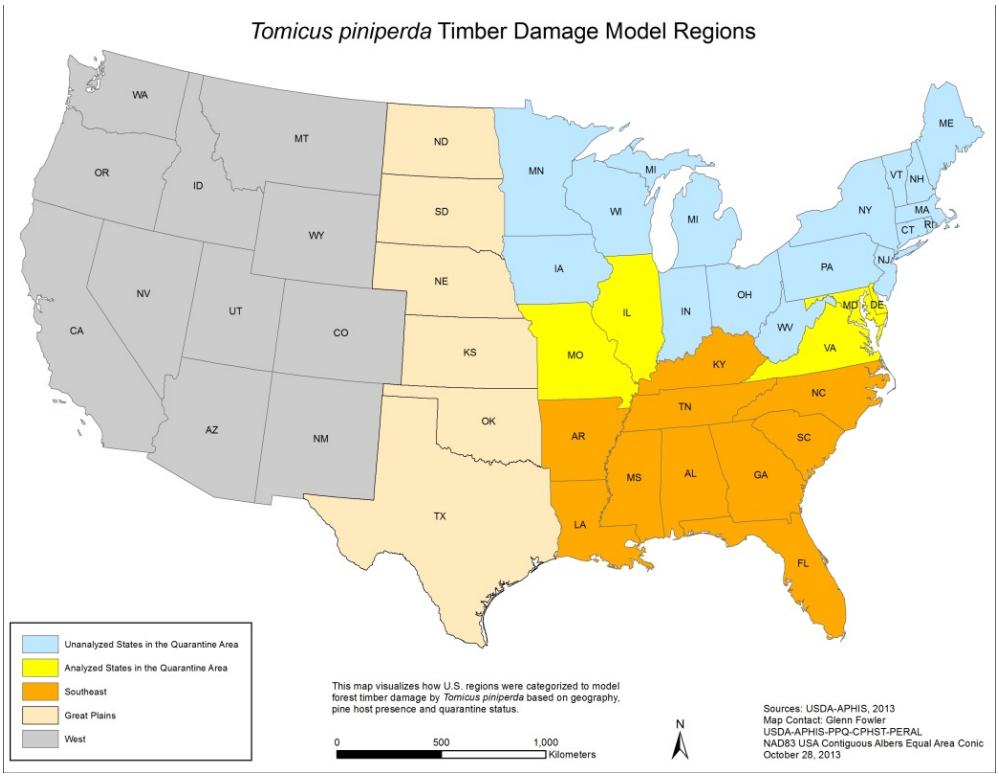

Figure 3. Regional classifications used in the *T. piniperda* pine timber damage model.

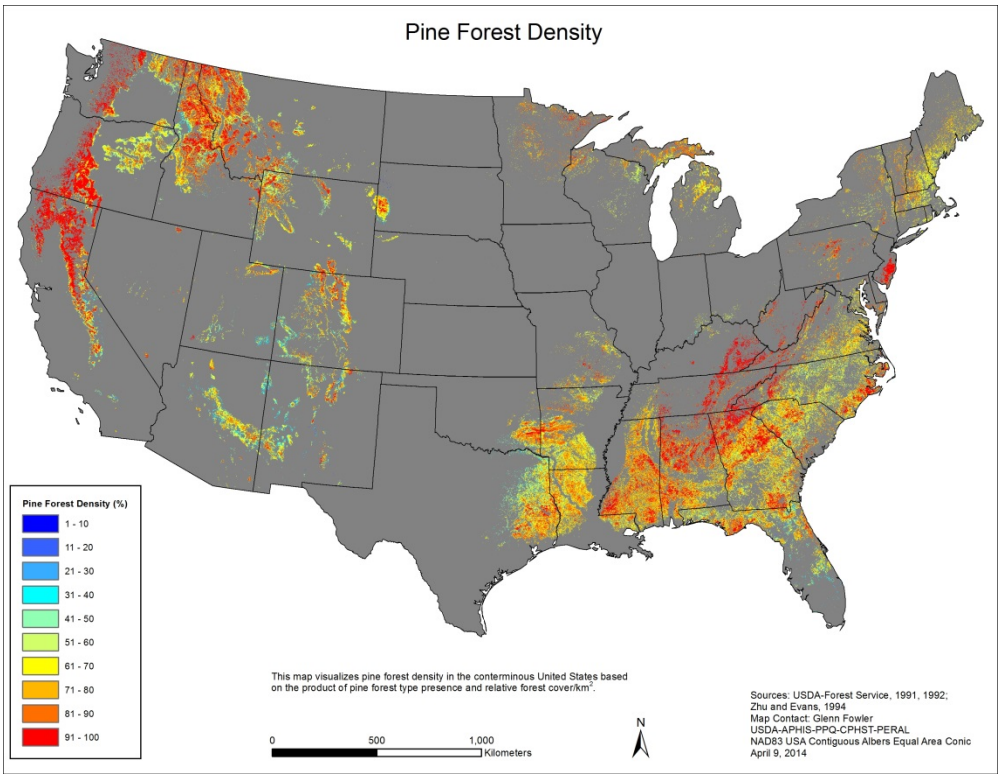

Figure 4. Pine host density in the conterminous United States (USDA-Forest Service, 1991, 1992b; Zhu and Evans, 1994).

II. Spread and Damage Model Components

A. Pine Area and Tree Volumes

For the at-risk area, we summed pine area (hectares) and volume (tons) in forest land and all ownerships by state using data from the Forest Inventory and Analysis (FIA) Database (USFS, 2013). We included all pine species in our analysis regardless of susceptibility to *T. piniperda*. Consequently, our timber damage estimates may be the upper bound because some pine species are more resistant to the beetle, possibly due to differences in stem structure and resin production (CABI, 2013; Eager et al., 2004). To account for variability in pine timber production, we queried the most recent year's data, the last available data within 10 years, and data for a year in between those time periods based on the survey years in each state. For the pine area we assumed 50 percent of mixed pine stands, e.g., oak/pine forests, would be pine. For the pine volumes we used data for trees in FIA categories ≥ 5 inches diameter at breast height (dbh). We used this threshold because smaller trees, i.e., < 6 inches dbh, are not used as timber products, e.g., pulpwood and sawtimber (SCFC, No Date), and would not fall under the purview of our analysis, i.e. volume and value loss. We further divided the volumes into pulpwood (FIA categories: 5 to 12.9 inches dbh) and sawtimber (FIA categories: ≥ 13 inches dbh) product classes (SCFC, No Date; USFS, 2013). We analyzed these two product classes separately due to the difference in their value, i.e., $7.20/ton for pine pulpwood vs. $51.33/ton for pine sawtimber (MFC, 2007; SCFC, No Date).

We assumed pine areas and volumes would usually be centralized between the lower and upper observed values and modeled them by state with a PERT distribution based on the minimum, mean, and maximum values from the FIA data. We then estimated the mean and standard deviation for tons of pine trees/hectare based on the quotient of the pine tree volume and area distributions.

B. Annual Pine Area Damaged by *T. piniperda* with 100 Percent Colonization

Tomicus piniperda has, to our knowledge, caused negligible timber damage in the United States despite being present since at least 1992 and having spread throughout the northeastern and north central states (Haack and Poland, 2001; USDA-APHIS, 2013). Consequently, we used zero as the minimum amount of area that would be damaged should it be introduced into other U.S. pine-producing regions.

In Europe, where *T. piniperda* is a forest pest, quantitative data for areas threatened and damaged by the beetle have been reported for Spain and Romania (Gregoire and Evans, 2004). The highest proportion of area damage (4.97 percent) occurred in Romania where 2,235 of 45,000 threatened hectares were damaged between 1991 and 2000. Europe experienced severe wind storms in 1990 that would have produced large quantities of brood material, i.e., fallen trees, for *T. piniperda* (CABI, 2013; Gregoire and Evans, 2004; Khater, 2008; Langstrom, 1984). *Tomicus piniperda* can heavily attack trees during the first two years following such storms due to high beetle populations, but these populations subsequently decline because of intraspecific competition (CABI, 2013). Consequently, most of the damage associated with *T. piniperda* in Romania likely occurred during the early 1990s. Based on that evidence we used 4.97 percent as the maximum amount of area that would be damaged annually should *T. piniperda* be introduced into other U.S. pine-producing regions. Our estimate is likely high since it assumes that this level of damage could all occur in a single year. However, since most of the *T. piniperda* damage likely occurred during the early 1990s we consider this estimate to be more reasonable than assuming equal levels of damage each year between 1991 and 2000.

Based on expert opinion (Haack, 2014a) we chose the mean between 0 and 4.97 percent, i.e., 2.48 percent, as a most likely amount of pine area that would be damaged annually by *T. piniperda* for the

higher damage scenario (scenario I). We then modeled the annual proportion of each state's pine area that would be damaged under scenario I with a PERT distribution based on these three parameters.

For the lower damage scenario (scenario II) we used 0 as the minimum and most likely values and 4.97 percent as the maximum value in a PERT distribution. We did this to simulate a situation where *T. piniperda* exhibits damage levels in the at-risk area similar to those in the quarantine area.

We then calculated the hectares of pine area by state that would be damaged if *T. piniperda* were introduced as the product of the pine area and the proportion of the pine area damaged for each damage scenario.

C. Annual Volume of Pine Trees Killed by *T. piniperda* with 100 Percent Colonization

To calculate the volume of trees killed we first needed to determine the volume of trees in the damaged area. We used the central limit theorem (Vose, 2000) and modeled this with a normal distribution based on the annual pine area damaged and the mean and standard deviation for tons of pines/hectare that was calculated in section A.

We then needed to determine the proportion of pine volume that would be killed by *T. piniperda*. The volume of *T. piniperda*-associated pine mortality was reported in Romania, where the beetle killed 2,028 m^3 of pines in 2,235 hectares from 1991 to 2000 (Gregoire and Evans, 2004), with most of this mortality likely occurring in the early 1990s (see Methods Section II, Part B). We used this value to inform the proportion estimate for the volume of trees killed. Our estimate may be high since we assumed the observed level of tree mortality could occur within a single year.

Next, we calculated the average forest density in Romania by dividing the forest volume (1,413,000,000 m^3) by the forest area (6,495,000 ha), which equaled 217.55 m^3/ha (Tucunel, No Date). This value was multiplied by the damaged area, 2,235 ha, to determine the pine volume, which equaled 486,224.25 m^3. We then calculated the proportion of pine volume killed by dividing the pine volume killed in the damaged area, 2028 m^3, by the pine volume in the damaged area, 486,224.25 m^3, which equaled 0.0042. Because *T. piniperda* primarily causes growth losses and only kills weakened trees (CABI, 2014), we used 0 as the minimum and most likely mortality rates in the affected areas. We modeled annual timber mortality using a PERT distribution with these three parameters. These mortality estimates were used in both damage scenarios.

We then calculated the tons of pines by state that would be killed if *T. piniperda* were introduced as the product of the pine volume in the damaged area and the proportion of the pine volume killed.

D. Annual Timber Volume and Value Damage from *T. piniperda* with 100 Percent Colonization

To model annual timber volume and value damage we first multiplied the tons of pines killed in each product class by the respective value/ton, i.e., $7.25/ton for pine pulpwood and $51.33/ton for pine sawtimber (MFC, 2007; SCFC, No Date) by state. The respective state values were then summed to model the annual damage for the at-risk region for damage scenarios I and II.

E. *Tomicus piniperda* Annual Dispersal Rate into the At-Risk Area with and without a Slow-the-Spread Program

To analyze the value of the *T. piniperda* slow-the-spread program regulating timber we needed to determine the rate at which the pest would move into the at-risk pine area with and without slow-the-spread until 100 percent colonization of the at-risk area was reached. This would allow us to determine the respective annual rate of damage over time along the leading edge of *T. piniperda*'s distribution.

To model *T. piniperda* dispersal with slow-the-spread, we first collected county data from 1992 to 2013, where the first year of detection was known (Figure 5). Since annual detection records were at the county level, we created a centroid for each county and assumed the distances between centroids represented *T. piniperda*'s annual movement. We also assumed that new infestations were introduced from the nearest quarantined county. The distance between centroids was then divided by the number of years the nearest infested county was quarantined to estimate the annual dispersal rate. In other words, if we determined county A infested county B and county A was infested 3 years prior to the detection in county B, then the distance between centroids in county A and B was divided by 3 to get an annual dispersal rate.

The first detection year was known for 423 county records. In 1992, 42 counties from Ohio, Indiana, Michigan, New York, Pennsylvania, and Illinois were reported as positive counties and placed under quarantine. The annual dispersal rate was determined by the detections in and after 1993 (381 counties). Based on that data, *T. piniperda*'s mean annual dispersal distance with slow-the-spread was 36.5 kilometers (Takeuchi, 2014) (Figure 6a). Using that rate, it would require 37 years for *T. piniperda* to fully colonize the at-risk area with slow-the-spread, i.e., time until 100 percent colonization (Figure 6a).

The timber-buying radius for large mills has been reported to be 150 miles (≈ 240 kilometers) (Fowler, 2007; Fowler et al., 2006; Howell, 2005). We used that value to model the annual dispersal rate for *T. piniperda* without slow-the-spread, since it represents a measure of how far infested timber could be shipped in a year (Figure 6b). Using that rate, it would require 6 years for *T. piniperda* to fully colonize the at-risk area without slow-the-spread (Figure 6b).

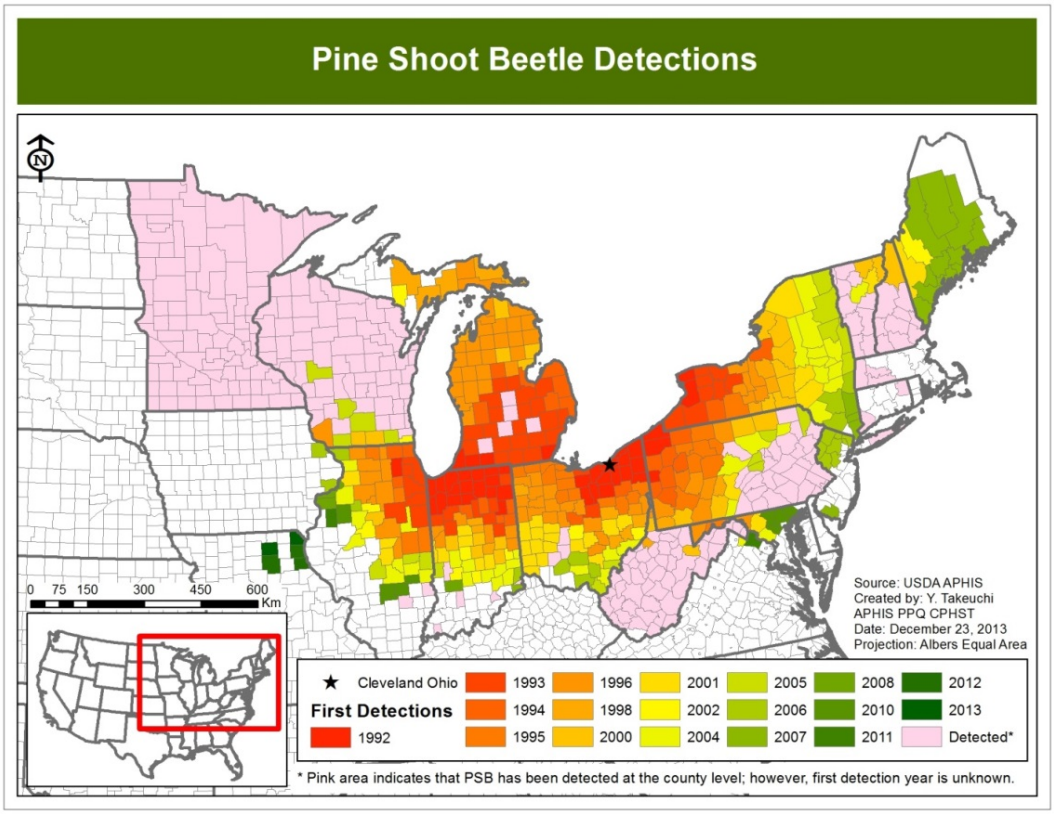

Figure 5. U.S. Counties where *T. piniperda* has been detected.

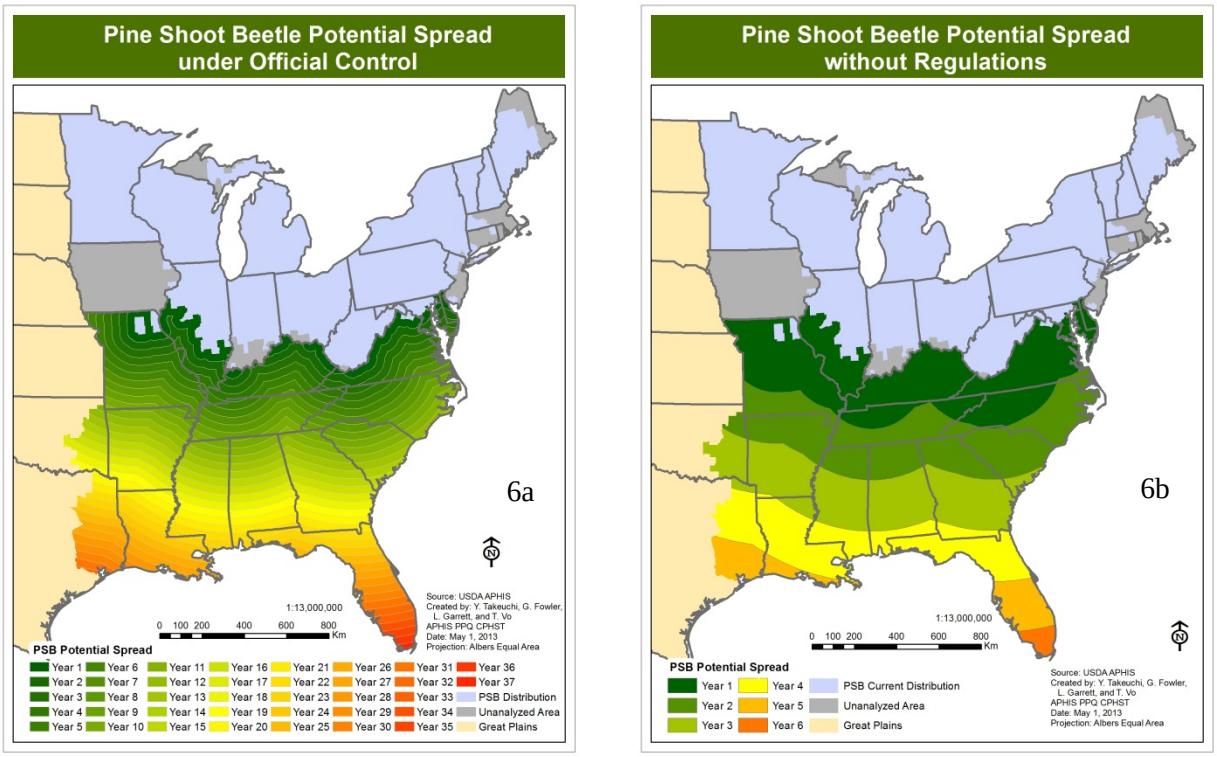

Figure 6. Predicted *T. piniperda* annual dispersal into the at-risk regions with (6a) and without (6b) slow-the-spread.

F. Annual Proportion of the At-Risk Area Colonized by *T. piniperda* with and without Slow-the-Spread

We modeled the annual proportion of the at-risk area colonized by *T. piniperda* by dividing the accumulated state area colonized per year under each regulatory scenario by the state's total area for the time until 100 percent colonization with slow-the-spread, i.e., 37 years (Figure 6a). We assumed these proportions were indicative of the proportion of pine area colonized each year.

G. Annual Timber Value Damage in the At-Risk Area Colonized by *T. piniperda* with and without Slow-the-Spread

We modeled the annual timber damage value (dollars) for each affected state with and without slow-the-spread as the product of the annual proportions colonized and the annual timber value damage with 100 percent colonization for damage scenarios I and II (see Methods Section II, Part D). We assumed these proportions were indicative of the proportion of the timber damage value each year. Based on expert opinion (Haack, 2014d), we assumed there would be a 10-year lag before *T. piniperda* populations reached levels where tree mortality could occur. For each regulatory and damage scenario we kept a running tally of the annual timber damage in the at-risk area over the 47-year analysis period.

H. Annual Christmas Tree Compliance Costs with Slow-the-Spread

We also projected annual compliance costs that would be experienced by Christmas tree growers in the at-risk states for 47 years (Appendix 3). To do this we first calculated the proportion of Christmas trees produced in the at-risk states that were pines based on the number of trees on operations as of January 1, 2010 (NASS, 2010). To account for variation in pine Christmas tree production we modeled the lower and upper 95th confidence intervals around that proportion for the twelve at-risk states where data was available and used the three values as the minimum, most likely and maximum proportions (Caton, 2007; Cochran, 1977). For five of the at-risk states some data was not reported. We estimated their minimum, most likely and maximum pine Christmas tree proportions using the mean ± two standard deviations, i.e., 95 percent of the distribution assuming its normal (Vose, 2000), from the 12 at-risk states, which was 0.24 ± 0.31. We note that two standard deviations below the mean yielded a negative value and, consequently, we used 0 as the minimum proportion. We then multiplied these proportions by the harvested acres of Christmas trees in each at-risk state in 2007 to calculate the acres of pine Christmas trees under compliance. Next we assumed a compliance cost of $20/acre based on estimates from Michigan Christmas tree growers (Haack, 2014c) and multiplied this value by the acres under compliance for each at-risk state (Appendix 3). These values were used to model annual compliance costs for each at-risk state with a PERT distribution. These distributions were then multiplied by the proportion of each state colonized by *T. piniperda* each year and summed to model the annual compliance costs to Christmas tree growers in the at-risk area. These totals were then added to the annual timber damage values with slow-the-spread to characterize the combined economic losses.

III. Impact Analysis

Next we estimated and compared the timber damage caused by *T. piniperda* along the leading edge of its distribution with and without slow-the-spread to evaluate the benefit of maintaining the regulatory program. To do this we calculated the tree damage in each annual dispersal band until 100 percent colonization with and without slow-the-spread for damage scenarios I and II.

With slow-the-spread this required 47 years [37 years to colonize the at-risk area (Figure 6a) and 10 years for *T. piniperda* populations to attain levels capable of causing mortality in each dispersal band].

Without slow-the-spread 16 years were required for 100 percent colonization [6 years to colonize the at-risk area (Figure 6b) and 10 years for *T. piniperda* populations to attain levels capable of causing mortality in each dispersal band]. For each analyzed year after 16, i.e., years 17 to 47, the calculated damage without slow-the-spread was zero because additional dispersal was no longer possible.

A. Annual Damage Values with and without Slow-the-Spread

We first needed to adjust the annual damage values with and without slow-the-spread for current dollars over the 47-year period of analysis. The annual discount rate was calculated as:

$$Discount\ Rate = 1/(1 + r)^t$$

Where the rate (r) = 3.9% (OMB, 2013) and time (t) = the year and (t) at year 1 = 0.

The respective discount rate and annual damage value were then multiplied to get the adjusted damage values.

B. Annual Avoided Losses

The annual avoided losses, i.e., benefits of the program, were calculated by subtracting the adjusted damage with slow-the-spread from the adjusted damage without.

C. Annual Federal Program Costs

Next we projected the annual Federal program costs of the *T. piniperda* slow-the-spread program 47 years into the future based on data from 2006 to 2011 (Austin, 2011; Elstun, 2011) (Appendix 2). Linear regression analysis revealed a significant negative trend in program spending ($p = 0.049$) (JMP®, 2012). Consequently, we modeled the annual program cost using the predicted value for the next year, i.e., 2012, and the lower and upper 95 percent confidence intervals as the most likely, minimum, and maximum values in a PERT distribution (minimum = 0; most likely = 150,181; maximum = 467,550) (Appendix 2). These values were then adjusted for the annual discount rate over the 47 year analysis period. We note that the lower 95 percent confidence interval was negative and so we used 0 as the minimum value for annual program costs. This reflects a situation where the program was in place but no money was spent that year.

D. Annual Net Program Benefits

The annual net program benefits were calculated by subtracting the annual Federal program costs from the annual avoided losses.

Results and Discussion

I. Impact Analysis: Damage Scenario I

In damage scenario I, without slow-the-spread, total mean losses at the leading edge were estimated at $1.2 million over 47 years; while with slow-the-spread total mean losses were estimated to be $1.6 million at the leading edge (Table 2, Figure 7). The greater losses with the program were due to the Christmas tree compliance costs. This yields a mean net avoided loss with slow-the-spread of -$457,000. When Federal program outlays were taken into account, there was an overall mean net loss of $4.4 million over the 47 year span of analysis.

Table 2. Impact analysis: damage scenario I results.

	47 Year Total Damage (1,000 Dollars)		
Parameter	5th Percentile	Mean	95th Percentile
Losses with No Program	726	1,177	1,736
Losses with Program	1,347	1,635	1,988
Avoided Losses (Benefits)	-643	-457	-225
Program Costs	3,452	3,958	4,477
Net Benefits	-4,973	-4,415	-3,863

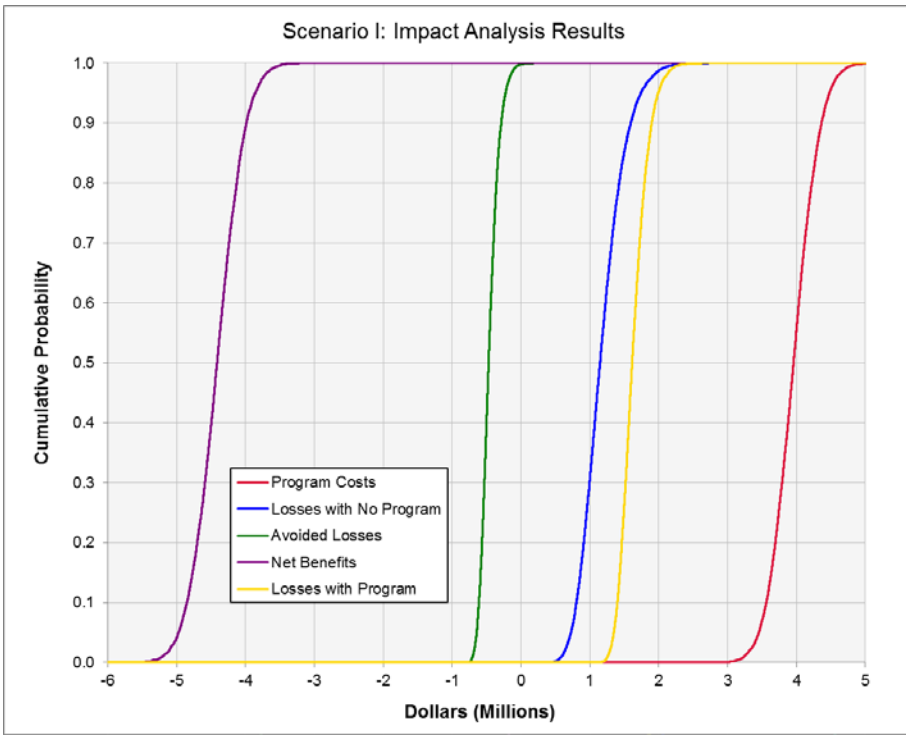

Figure 7. Cumulative distribution functions for the damage scenario I impact analysis after 47 years.

II. Impact Analysis: Damage Scenario II

In damage scenario II, with no program, total mean losses were estimated at $393,000 (Table 3, Figure 8). Losses were higher at $1.1 million with slow-the-spread in effect due to the Christmas tree compliance costs, yielding a net avoided loss of -$747,000 with the program. When the program costs were accounted for, the model estimated a mean net loss of $4.7 million over the period of analysis.

Table 3. Impact analysis: damage scenario II results.

Parameter	47 Year Total Damage (1,000 Dollars)		
	5th Percentile	Mean	95th Percentile
Losses with No Program	187	393	679
Losses with Program	1,002	1,139	1,327
Avoided Losses (Benefits)	-842	-747	-627
Program Costs	3,452	3,958	4,477
Net Benefits	-5,238	-4,704	-4,184

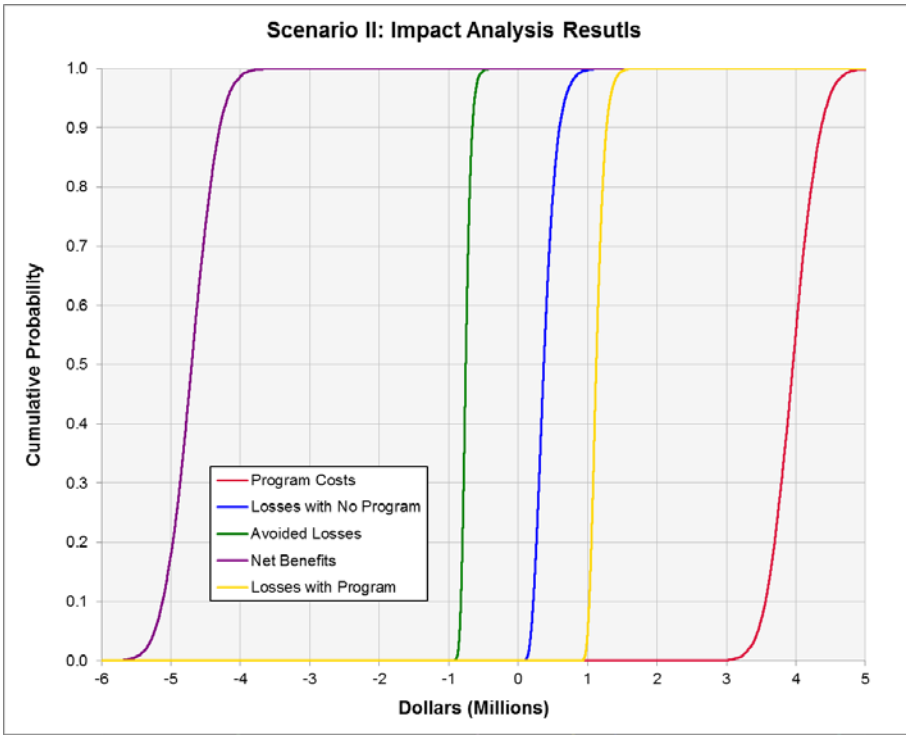

Figure 8. Cumulative distribution functions for the damage scenario II impact analysis after 47 years.

III. Results of the Model

Our results indicate that the program is not efficient or effective when compared to the Federal outlay, with negative mean total net benefits after 47 years for both scenarios. For example, the model predicted mean net losses of $4.4 and $4.7 million after 47 years under damage scenarios I and II (Table 2, Table 3). Even without the Federal outlay, the avoided losses (benefits) of the slow-the-spread program were negative for both scenarios due to the Christmas tree compliance costs. These results indicate that the cost of the program, as currently funded, does not appear to justify the savings in terms of avoided timber losses.

These results appear to suggest that resources could be more effectively allocated to improve the efficiency of the slow-the-spread program and achieve a better return on investment. One suggestion may be to reduce survey activities in the western states since *T. piniperda* is unlikely to cross the Great Plains in timber shipments. These resources could then be redirected to other areas to reduce program costs or used to bolster regulatory activities along the leading edge of *T. piniperda*'s distribution to further decrease the rate of spread resulting from the program.

In reality, redirecting a portion of existing resources to trapping as suggested would likely be insufficient in improving program efficiency. Given the wide variability in current trapping efforts among states (Beckwith, 2013), additional funds beyond what is currently allocated would likely be needed to improve survey rigor in order to confidently establish the actual geographic range of *T. piniperda* and its rate of spread under quarantine in any given year.

We conclude that additional Federal outlays would not justify maintaining the *T. piniperda* program. Based on the little damage observed to date and the results of the analysis indicating that the program as currently funded is inefficient with mean negative net benefits under both scenarios, a change in strategy to the *T. piniperda* program should be considered.

In 2013, 45 percent (or $244 million) of U.S. pine logs and lumber exports were sent to nine countries that consider *T. piniperda* a harmful organism (FAS, 2014; PExD, 2014b). Should the regulatory status of the pest be changed, the volume of U.S. exports of pine logs and lumber would unlikely be affected for all these countries except Canada because they either do not allow wood with bark, require phytosanitary treatments, e.g., fumigation, or have no requirements for the beetle (PExD, 2014a). Trade with Canada, which received 21 percent of U.S. pine logs and lumber exports in 2013 ($114 million), could be affected if *T. piniperda* is deregulated because they do not currently have restrictions on timber products from uninfested U.S. states (PExD, 2014a). Another possibility is that Canada would deregulate *T. piniperda* if the United States does (Haack, 2014b) which would likely leave trade unaffected.

The methodology used here could be adopted for evaluating other regulatory pest programs. When data are available, this approach characterizes impacts in quantitative terms providing decision-makers with a transparent mechanism for evaluating the program's worth that is arguably less sensitive to subjective interpretation than qualitative estimates. Also, with the use of distributions, our approach captures uncertainty in the model inputs and results. Data needed to estimate spread and damage may not always be available. In such cases, expert opinions can serve as proxies.

Summary and Conclusions

We constructed a probabilistic model that provides a distribution of estimates of the value of timber killed by *T. piniperda* if it is introduced into at-risk U.S. pine producing areas. Our objective was to evaluate the *T. piniperda* timber regulatory program in terms of its effectiveness in slowing the spread and reducing losses. To do this, we modeled the annual timber damage based on *T. piniperda*'s dispersal rate with and without a slow-the-spread program regulating timber until 100 percent colonization of the at-risk area under higher and lower area damaged scenarios. The time period of analysis was 47 years, reflecting the length of time when colonization would be reached and damage would occur in each scenario.

We reported the outputs of an impact analysis evaluating the efficiency of the slow-the-spread program at preventing tree mortality along the leading edge of *T. piniperda*'s distribution. The estimated impacts were judged against decision criteria for determining Federal response to pest events. The economic criterion suggests that response is warranted when the losses avoided with intervention exceeds its programmatic cost.

Our results indicate that the program is not effective or efficient, with negative mean total net benefits after 47 years for both scenarios. In sum, the cost of the program, as currently funded, does not appear to justify the savings in terms of avoided timber losses.

The methodology used here could be adopted for evaluating other regulatory pest programs.

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Appendices

Appendix 1. Data table for the *T. piniperda* timber damage model.

Component (N = number; P = proportion)	Unit	Distribution/Equation	Source(s)
N1. Pine Area	Ha	PERT(Min,ML,Max) by State	USFS (2013)
P1. Proportion Damaged	Proportion	Scenario I: PERT(0,0.02845,0.0497) Scenario II: PERT(0,0,0.0497)	Gregoire and Evans (2004); Haack pers. comm. (2014a)
N2. Damaged Area	Ha	N1*P1	
N3. Tree Volume/Ha	Tons/Ha	Mean and SD based of PERT(Min,ML,Max) volume/PERT(Min,ML,Max) area by State	USFS (2013)
N4. Damaged Volume	Tons	Normal(N2*Mean of N3, Sqrt(N2)*SD of N3)	Vose (2000)
P2. Proportion of Volume Killed	Proportion	PERT(0,0,0.0042)	Caton (2007); Cochran (1977); Gregoire and Evans (2004), Tucunel (No Date)
N5. Volume Killed	Tons	N4*P2	
N6. Value/Ton	Dollars/Ton	Pulpwood = $7.20; Sawtimber = $51.33	MFC (2007); SCFC (No Date)
N7. Value of Volume Killed	Dollars	N5*N6	
P3. Proportion of Damage Value ± Regulation	Proportion	annual proportion by State based on regulation dispersal ≈ 37 km and deregulation dispersal ≈ 240 km	Howell pers. comm. (2005); Takeuchi (2014)
N8. Value of Volume Killed ± Regulation	Dollars	N7*P3	

Appendix 2. Program costs data (Austin, 2011; Elstun, 2011; JMP®, 2012).

Year	Expenditures	Predicted Expenditures	Lower 95% Individual Expenditures	Upper 95% Individual Expenditures
2006	596,984	485,760	199,015	772,505
2007	341,990	429,830	165,464	694,196
2008	313,648	373,900	121,467	626,334
2009	281,675	317,970	65,537	570,404
2010	310,627	262,041	-2,325	526,407
2011	230,688	206,111	-80,634	492,856
2012	NA	150,181	-167,188	467,550

Appendix 3. Christmas tree compliance costs data (Haack, 2014c; NASS, 2010, 2014).

At-Risk State	Total Xmas Trees (1,000)	Scotch Pine (1,000)	White Pine (1,000)	Pines Xmas Trees (1,000)	Lower 95th Confidence Interval/-2 SD Xmas Tree Proportion*	Mean or Actual Pine Xmas Tree proportion	Upper 95th Confidence Interval/+2 SD Xmas Tree Proportion	Xmas Tree Acres	Minimum Pine Xmas Tree Acres	Most Likely Pine Xmas Tree Acres	Maximum Pine Xmas Tree Acres	Costs per Acre	Minimum Compliance Costs	Most Likely Compliance Costs	Maximum Compliance Costs
Alabama	104	0	23	23	0.1414	0.221	0.301	738	104.3	163.2	222.1	20	2,087	3,264	4,442
Arkansas	57	D	D	NA	0.0000	0.235	0.847	562	0.0	131.8	476.1	20	0	2,636	9,522
Delaware	698	0	d	NA	0.0000	0.235	0.847	385	0.0	90.3	326.2	20	0	1,806	6,523
Florida	44	0	0	0	0.0000	0.000	0.000	747	0.0	0.0	0.0	20	0	0	0
Georgia	355	D	12	NA	0.0000	0.235	0.847	2,359	0.0	553.2	1,998.4	20	0	11,064	39,968
Illinois	1,397	573	272	845	0.5792	0.605	0.631	3,843	2,226.0	2,324.5	2,423.0	20	44,520	46,490	48,461
Kentucky	111	15	49	64	0.4847	0.577	0.668	988	478.8	569.7	660.5	20	9,577	11,393	13,209
Louisiana	100	0	0	0	0.0000	0.000	0.000	590	0.0	0.0	0.0	20	0	0	0
Maryland	911	26	123	149	0.1395	0.164	0.188	2,978	415.5	487.1	558.6	20	8,311	9,741	11,172
Mississippi	29	0	0	0	0.0000	0.000	0.000	1,188	0.0	0.0	0.0	20	0	0	0
Missouri	276	204	48	252	0.8798	0.913	0.946	1,596	1,404.2	1,457.2	1,510.3	20	28,083	29,144	30,205
North Carolina	37,161	10	78	88	0.0019	0.002	0.003	37,653	70.6	89.2	107.8	20	1,411	1,783	2,155
Oklahoma	55	D	0	NA	0.0000	0.235	0.847	415	0.0	97.3	351.6	20	0	1,946	7,031
South Carolina	223	0	64	64	0.2276	0.287	0.346	1,707	388.6	489.9	591.3	20	7,771	9,798	11,825
Tennessee	459	D	64	NA	0.0000	0.235	0.847	2,262	0.0	530.4	1,916.2	20	0	10,609	38,325
Texas	129	0	0	0	0.0000	0.000	0.000	2,425	0.0	0.0	0.0	20	0	0	0
Virginia	3,891	71	106	177	0.0389	0.045	0.052	9,414	366.6	428.2	489.9	20	7,332	8,565	9,798
Mean						0.235									
Standard Deviation (SD)						0.306									
Sum													109,092	148,240	232,636

*Since -2 standard deviations below the mean was a negative value, we used 0 as the minimum proportion of Christmas trees that were pines.

D = data withheld (NASS, 2010); NA = not applicable