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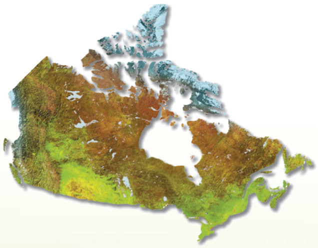

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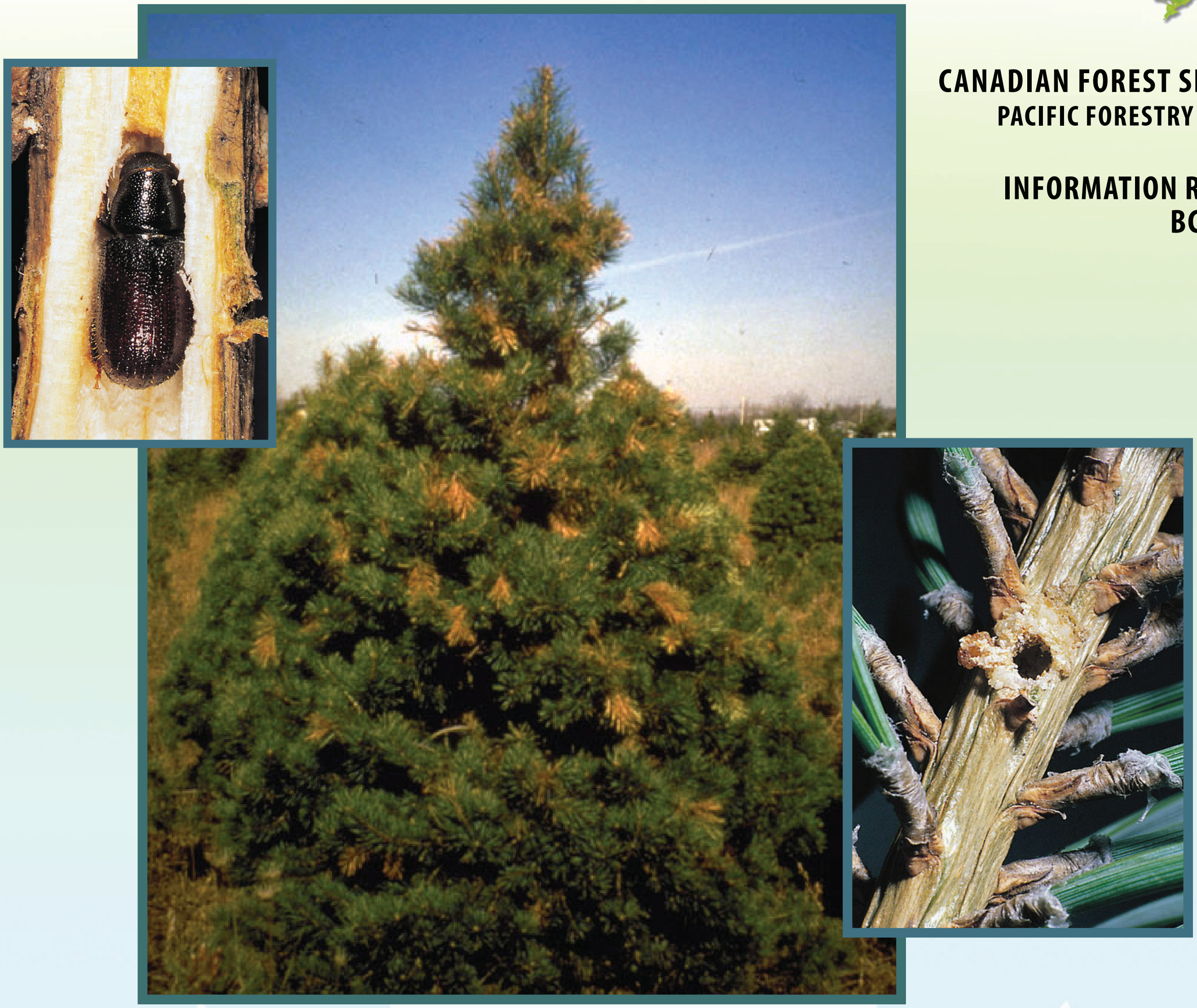

PINE SHOOT BEETLE, TOMICUS PINIPERDA (LINNAEUS): ANALYSIS OF REGULATORY OPTIONS FOR CANADA

Bogdanski, B.E.C., Corbett, L., Dyk, A., Grypma, D.

Canada

The Pacific Forestry Centre, Victoria, British Columbia

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Analysis of Regulatory Options for Canada

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Executive Summary

The pine shoot beetle (PSB), *Tomicus piniperda*, an invasive forest species introduced to Canada in the late 1980's or early 1990's, is a federally regulated species. Since 1994 a federal quarantine has been imposed to regulate the movement of at-risk pine commodities, including logs and firewood, and nursery stock.

Over the past 20 years, the pine shoot beetle has spread northward from its initial areas of detection and quarantine around the US-Canada border in Ontario and Quebec. Initial risk assessments raised concern that the beetle would spread from the existing areas of known occupation and damage valuable pine forests that are important for the forest sector across Canada. However, after 20 years of experience, little evidence has surfaced that the PSB has caused significant damage to native pine stands.

The purpose of this study was to evaluate the net benefits of current efforts to slow the spread of the pine shoot beetle from its current range of southern Ontario and Quebec. This study emulated a study conducted by the United States Department of Agriculture in 2015. We compared the expected economic losses from damaged pine trees under the current efforts to slow the spread of *T. piniperda* with the potential damages without regulations. The benefit of regulation is to push damage further into the future, assuming that the value of a loss in the future is less than the same loss incurred today. We compared the value of delayed damage to the on-going costs of regulation in the form of inspections and permitting the movement of regulated materials. We focussed on all merchantable pine forests in eastern Canada, i.e. east of Manitoba, regardless of geographical location. However, our study did not consider non-timber values such as carbon, biodiversity, or recreation nor did we try to account for damage to private residential property. These values may be locally important but, we found no evidence to suggest they were significant and so were not addressed in the analysis.

The findings of the study indicate that under conservative assumptions, it is very unlikely that the current regulatory program is beneficial. Assuming conservatively low cost estimates of regulation and high estimates of area that might be impacted by the PSB, we found only a 7.5%-17.4% chance that the program is generating a net benefit, depending on spread rates. Even with increased effective regulation (i.e. slower spread rate under regulation), there is only a small chance that the program might produce a net benefit. Break-even analysis indicated that a much higher mortality rate than supported by current scientific literature and expert opinion would be required for the program to pay for itself.

The results suggest there is likely little downside risk to deregulating the pine shoot beetle. The very low estimated mortality caused by *Tomicus piniperda* on native pine species in Canada underpins the analysis. A much higher mortality rate than is currently documented in available information would have to occur for the program to be an efficient use of public funds.

Introduction

The Canadian Forest Service (CFS), in partnership with the Canadian Food Inspection Agency (CFIA), conducted this analysis in response to a study by the Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA) of the effectiveness of domestic pest program to mitigate the economic impacts from the invasive species *Tomicus piniperda* (Fowler et al., 2015). The USDA-APHIS study analyzed a "slow-the-spread" program created to prevent further spread and infestation of the pine shoot beetle (*Tomicus piniperda*), hereafter known as PSB, in the United States. In this document, we provide a formal evaluation of the Canadian pest program that also aims to prevent the spread of PSB within Canada and utilizes the methods from the USDA-APHIS study.

PSB originated in Europe, North Africa and Asia and it is a serious pest in forests, particularly pines (NRCan / RNCan, 2015). The PSB is believed to have arrived on a cargo ship at a Great Lakes port via infested materials or dunnage (Haack and Lawrence, 1995) and established populations of PSB were first detected on a Christmas tree farm near Cleveland, Ohio in July 1992. This finding prompted PSB inspections in plantations and nurseries in surrounding states, which resulted in beetle detection in five new states: Indiana, Pennsylvania, Michigan, New York, and Illinois (Haack and Lawrence, 1995). Carter et al. (1996) noted that PSB populations were likely caused by two separate introductions, first in Ohio and later in Illinois. PSB was first discovered in Canada in southern Ontario in 1993 and southern Quebec in 1998 (NRCan / RNCan, 2015).

The USDA-APHIS and the CFIA recognized that the infestation of PSB could be problematic and, in an attempt to reduce the spread and potential damage by the species, the two countries imposed quarantines to prevent movement of affected pine across the landscape. In 1992, the USDA-APHIS implemented a "slow-the-spread program," which is a regulatory program and quarantine on at-risk pine commodities, such as logs and lumber with bark, Christmas trees, and nursery stock in known infested areas (Fowler et al., 2015). In 1994, the CFIA regulated US imports and the domestic movement of cut pine Christmas trees, pine nursey stock, pine forest products with bark attached, pine branches with or without foliage (fresh or dried), and pine bark greater than 25mm in diameter (CFIA, 2013). The regulations in Canada and US did not stop the spread of PSB; however, they did slow the speed at which PSB occupied new areas.

Within the United States, PSB has caused negligible direct economic damage in its current territory of analysis (Fowler et al., 2015). However, there is a high volume of susceptible pines and a favourable climate for the beetle in western and southwestern regions of the United States (Fowler and Borchert, 2006). As such, the USDA-APHIS conducted a full assessment of the economic benefits of existing regulation, taking into account the potential for further damage in currently unoccupied areas of the US.

In the USDA-APHIS analysis, the agency analyzed the effectiveness of the regulatory program by comparing two possible scenarios: with the “slow-the-spread” program and without. The results of the analysis indicated that the cost of the current program to slow-the-spread of the PSB in the US is greater than the avoided timber losses from the program. This finding is due to the low damage rate incurred by insect infestation. The study considered several sources of uncertainty, including damage rates, mortality rates, vulnerable pine stocks, and timber values. The analysis accounted for commercial timber damage, but did not consider environmental costs such as carbon emissions, damage to the Christmas tree industry, impacts to tourism and recreation, or impacts on trees on private residences. Moreover, the analysis did not attempt to determine if the timber killed would have commercial value and consequently may overestimate avoided damage due to the program.

The PSB impacts experienced in Canada over the past 20 years are similar to those in the United States (Dawson 2016). Specifically, little damage or tree mortality has been reported as a result of the PSB. As such, a study similar to the USDA-APHIS study for Canada seemed appropriate. Our analysis, therefore, aims to evaluate the costs and benefits of continued regulation focused on limiting PSB spread across Canada.

Biology of *Tomicus Piniperda* (Linnaeus) (Coleoptera Scolytidae)

The scientific name of the pine shoot beetle (PSB) is *Tomicus piniperda (*Linnaeus*) Coleoptera Scolytidae.* The PSB is part of the Scolytidae family and *Tomicus* genus and its general biology and behaviour is well-documented; however, there is little known of the biology of the pest in North America (Bakke, 1968; Salonen, 1973; Schroeder, 1988; Hui, 1991; Haack and Lawrence, 1995; Haack et al., 1998, 2001; Kauffman et al., 1998; Petrice et al., 2002, as cited by Haack and Poland, 2001). Its distribution globally is extensive; it is found in Europe, Asia and North Africa, with its northern extent beyond the Arctic Circle (CABI, 2013). PSB is a bark beetle that feeds on and reproduces in fresh pines. In the late winter and early spring, PSB leave their overwintering habitats and colonize weakened or stressed trees as well as cut pine stumps and logs for breeding, which they can locate using host volatiles such as alpha-pinene (Haack and Poland, 2001). Adults can fly for several kilometers to find a suitable host (Humphreys and Allen, 1999) and will then excavate under the bark to make egg galleries. After the adult finishes laying eggs, they emerge and die (Humphreys and Allen, 1999). In the early summer, new adults emerge and fly to nearby pine crowns, where they tunnel the young shoots on the outer parts of the branch (Långström et al, 1990). These adults will then overwinter either in the base of the pine bark if it is cold or the shoots themselves in milder temperatures (Haack and Poland, 2001). The tunnelling and shoot-feeding activity of the beetle results in tree growth loss and is the main reason why the PSB is a problematic pest (Carter et al., 1996).

PSB can feed on most pine species in North America; however, the pest prefers hard pines over soft pines for egg laying and brood production (CABI, 2013). The beetle may occasionally attack other conifer species such as spruce, larch and Douglas-fir (CABI, 2013). Internationally, PSB attacks various trees in different locations. In northern Europe, the principal host is Scots pine (*Pinus sylvestris*)

(Lombardero et al., 2008). In southern Europe, the beetle has been located in indigenous pines such as *Pinus pinaster*, *P. nigra* Arnold, and *P. radiatae* (Lombardero et al., 2008). In Canada, there are a large number of conifers available for the PSB to attack and all native pine species are potential hosts (Humphreys and Allen, 1999).

Damage Caused by *Tomicus Piniperda*

Research in Europe found that the PSB is a serious pest to several species of pine (*pinus*), especially Scots pine, due to their shoot-feeding activities (GISD 2017). The shoot-feeding results in reduced availability of photosynthates for growth, since the beetle tends to attack the uppermost section of a tree's crown and start with the outermost shoots (Långström et al., 1998). Attack causes 10-20 centimetres of the shoots to bend, turn yellow-red, and often break near the entry hole of the beetle (Humphreys and Allen, 1999). The beetle attacks the upper whorls of the tree crown, which are the most photosynthetic shoots (Ryall, 1997). Shoot feeding decreases forest productivity because the pest eats and destroys needles, shoots, and buds, which can lead to reductions in height and diameter growth (Humphreys and Allen, 1999).

Researchers have examined the impacts on trees of varying ages. Growth loss tends to be moderate in young stands (even at high attack densities) and damage is generally located in the top third of the trees (Ryall, 1997). Feeding can result in reduced needle mass and reduced tree height and diameter. Growth reductions will occur in young pine trees with more than twenty infested shoots or more than fifty infested shoots in old pine trees (Humphreys and Allen, 1999). It was found that simulated shoot-feeding resulted in greater growth reductions for older tree stands compared to younger tree stands (Långström et al., 1990). In Sweden, growth reductions last for several years but eventually most trees recover and in some cases, unaffected trees in a stand will add volume gains that offset volume losses of affected trees (Långström and Hellqvist 1991).

Other research has identified *Tomicus piniperda* as a secondary pest. Sikstrom et al. (2005) found that *Tomicus piniperda* was much more likely to kill trees that had significantly damaged crowns. Studies in southern Ontario (Morgan et al., 2004) and Michigan (Siegert and McCulluogh, 2001) showed similar results. Morgan et al. (2004) found that most shoot damage occurred in Scots pine that were already stressed, while Siegert and McCullough (2001) discovered that the most damage occurred in stressed Scots pine. In contrast, they showed that little shoot damage occurred in other pines. So while significant growth reductions and mortality can occur in stands with PSB present, it is highly unlikely that PSB directly causes tree mortality.

Pinus in North America

In Ontario, PSB has attacked native red (*Pinus resinosa*), white (*Pinus strobus* L.) and jack pine (*Pinus banksiana* Lamb.), which are all considered economically important timber tree species (Ryall, 1997). Jack pine is the most common of the three species, but white and red pines are common across southern and central Ontario and southwestern

Quebec. Various pine species are distributed across Canada with abundance hotspots in northern Alberta and central British Columbia (see Figure1).

As Scots pine is not a major commercial timber species in North America, the experience of damage from PSB in North America is very different than in Europe. In Europe, Scots pine is a major lumber source and is significantly more economically valuable than the North American Scots pine. In Southern Ontario and Quebec, Scots pine was planted in small stands to prevent erosion and re-stabilize the soil system, though it is not used for timber due to its poor stock quality (Ryall, 1997). Scots pine is, however, planted as a Christmas tree species in Canada (www.christmastrees.on.ca), although it is more popular for this use in the US, where it is the most common Christmas tree species (Koelling 2017). At the same time, Scots pine is also considered a weed species in United States forests (https://www.na.fs.fed.us/fhp/invasive_plants/weeds/scots-pine.pdf) and so economic damage from PSB on this pine species are questionable. While native pine species have not been extensively damaged in the United States, the PSB is a concern in the Great Lakes area of the US due to the region's temperate climate and the high occurrence of pine forests, Christmas tree plantations and nurseries (Haack et al., 1998).

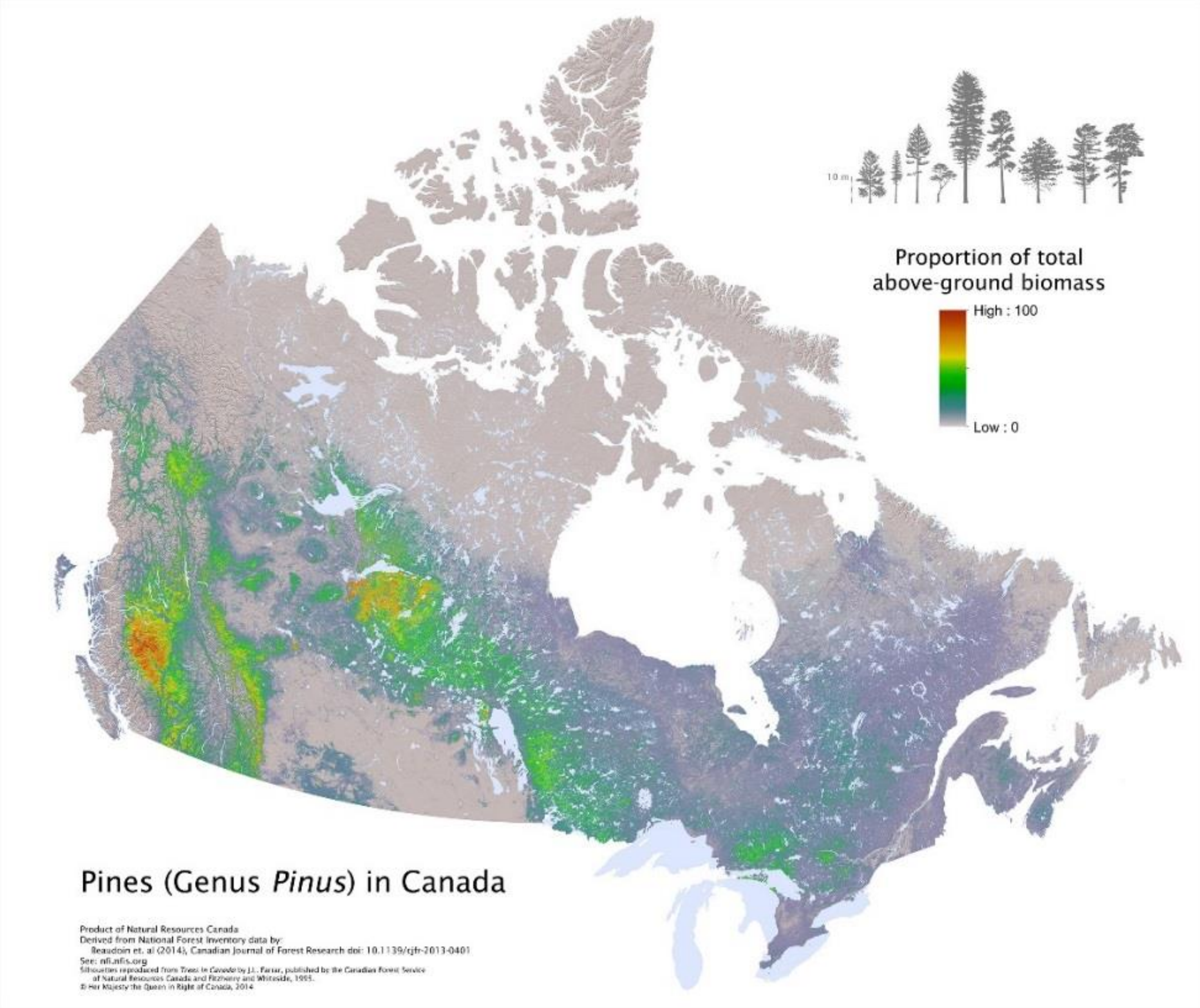

Figure 1 Distribution of pines across Canada. Source: National Forest Inventory of Canada.

Methods

Spread and Damage Model Overview

We developed a probabilistic model, similar to Fowler et al (2015), to create a distribution of estimates of the value of timber killed by PSB outside the current occupied area of southern Ontario and Quebec (Figure 2; Appendix 1).

We defined the occupied region as all areas with historical observations of PSB (Figure 3). Like the US study, we considered movement of the PSB via the transport of timber products into forested areas of Ontario, Quebec, and the Atlantic provinces. While there are large pine tracts across the Boreal plains and in the montane ecozones of Alberta and British Columbia (Figure1), we judged these areas to be at low PSB occupation risk and excluded them from our analysis. The westward spread of PSB from Ontario to Manitoba is highly unlikely given that the timber industry in Manitoba, which is connected to Ontario's industry through existing road networks, is located in the southern reaches, outside the boreal forest. Given that human activities are the main vector of PSB spread, it is very unlikely that infested material would be moved into southern Manitoba. It would also be improbable for a population to become established and for that population to move north-westward into the boreal forests of central Manitoba and Saskatchewan. Within the selected study area, we considered that all pine timber within and outside of commercial forest tenures to be at risk as did the USDA study. This produces a higher and thus conservative estimate of timber losses. Similar to the USDA study, we only considered timber losses from killed trees and did not account for commercial timber growth reductions. We also did not account for tree salvage, which would decrease economic losses.[1] We also did not consider aesthetic and ecological values nor did we take into account the costs of carbon sequestration or damage to private residential properties.

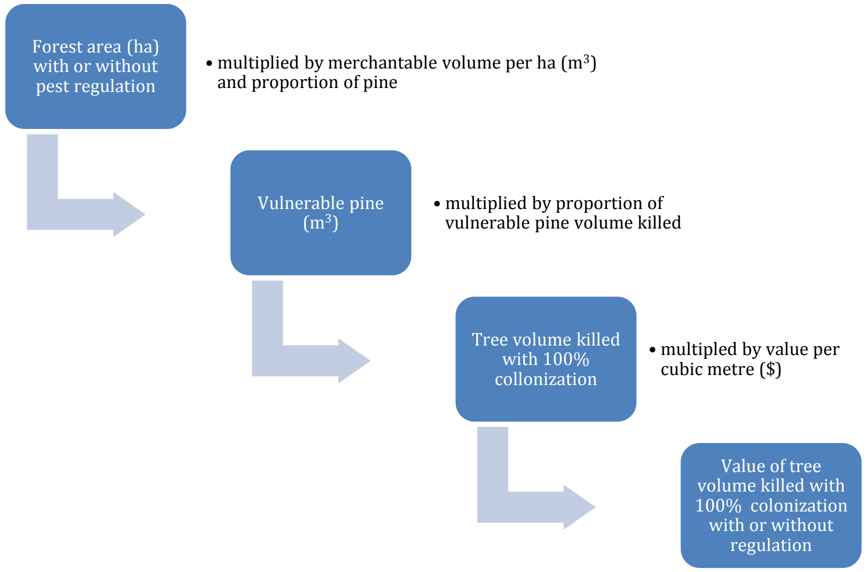

Figure 2 Schematic of a model to estimate the volume and value of timber losses from *Tomicus piniperda.*

Spread modelling

In our model, we evaluated the PSB timber regulatory program in terms of its effectiveness in slowing the spread and reducing timber losses over several years. We modelled the projected annual timber damage based on estimated spread rates with and without regulations until 100 percent of the at-risk timber was colonized within the study area. Like the USDA study, we assume a 10-year lag between colonization and tree mortality. Although we estimated the current spread of PSB (with regulation case) at 100km/yr., we also considered a slower rate of 40km/yr., similar to the rate used in the US study. For the without regulation spread rate,

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[1] It is important to note that because the PSB tends to move across the landscape with the aid of human activities, a more exact modelling effort would consider only the areas vulnerable to PSB along transportation corridors. Such a modeling effort would significantly decrease the area vulnerable to the PSB. Also, we included areas in northern Quebec and Ontario that have very little established industry and thus, our estimates produced larger values than would be otherwise derived. GIS technical challenges and time constraints did not permit more detailed analysis for this report.

we assume 300km/yr., which is greater than the 240km/yr. assumed by the USDA study. The faster spread rate is somewhat arbitrary but is consistent with some of the distances between mills in Ontario outside the present quarantine area. While mills within the spread zone in Quebec are much more closely spaced, the high spread rate offers a conservative (higher) estimate of PSB damage without regulation. For comparative purposes, we also considered a deregulated spread rate of 100 km/yr.

In estimating the amount of pine timber at risk, we used merchantable volume inventory data and species composition data from digital map files created by Beaudoin et al. (2014) from Canada's National Forest Inventory (NFI).

We assumed different discount rates (rates of time preference) and different program costs to capture a broad set of scenarios and conditions. We also modelled various aspects of uncertainty related to timber prices, merchantable volumes per hectare, proportion of pine volume per hectare, and mortality proportions.

The model was constructed with @Risk 7.5.1 Industrial (Palisades Corporation, 2016) and we ran 10 000 iterations using a random seed (Mersenne Twister) using Latin Hypercube sampling.

Spread and Damage Model Components

CFIA Detection Data

The CFIA surveyed the spread of the pine shoot beetle in Ontario, Quebec and eastern Canada starting in Ontario in 1996 up to 2014. The survey was set up to "target pine forests" (fencerows, woodlots, Christmas tree farms, greenbelt, etc.) adjacent or near (less than five kilometres) sawmills, pulp mills, pole producers, Christmas tree farms, firewood vendors, and nurseries that import pine from infested counties (Jill Dalton, Personal Communication, Nov 2016). An approximate distribution of detected PSB in Ontario and Quebec, starting in 1996 and ending in 2012, is shown in Figure3.

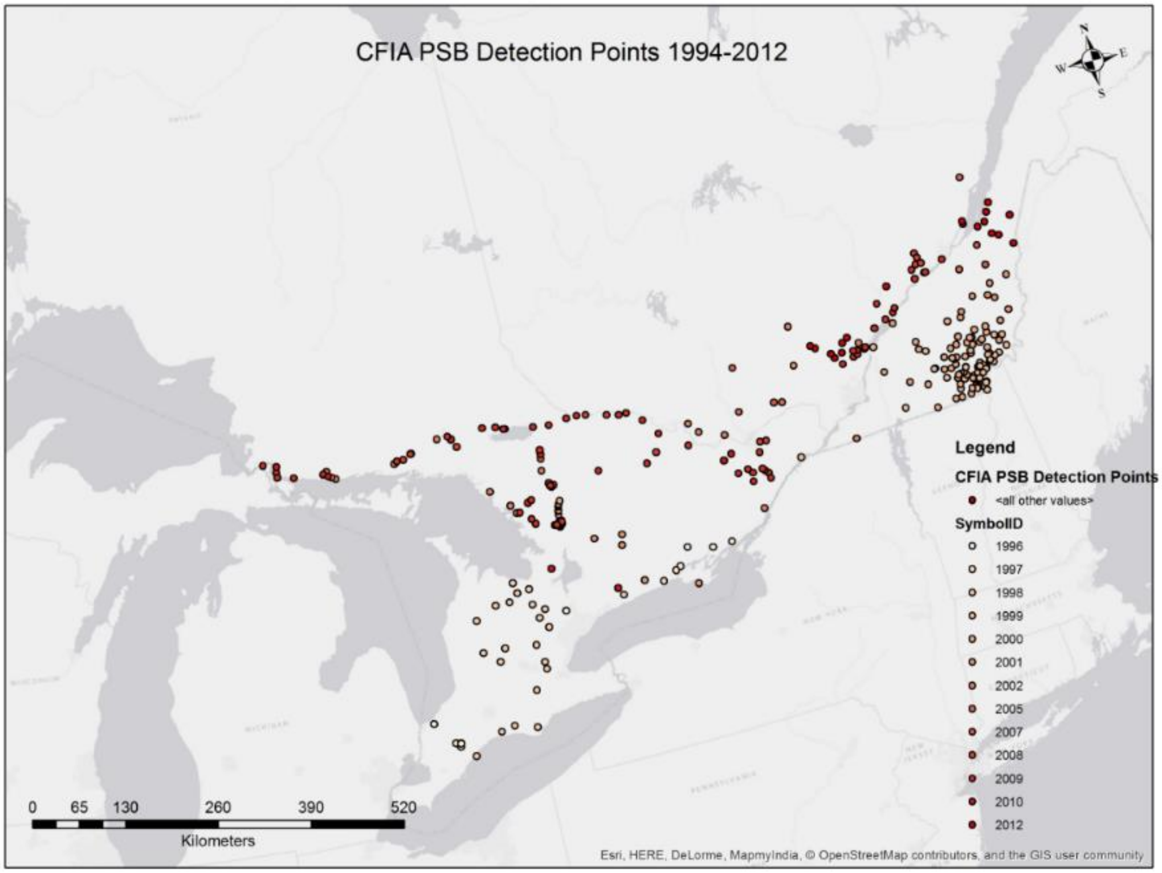

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Figure 3 Observed distribution of PSB, 1996-2014.

Dispersal Rate

To estimate the impact of the PSB, we estimated its dispersal rate with and without regulation. We modeled PSB dispersal with the regulatory program in place using the GPS coordinates of the CFIA detection sites. Before calculating spread rates, we grouped the data into three clusters based on year of first detection and general geographical location (Figure 4). We used the following steps to calculate the average spread distance per year for each cluster:

1. Calculate the distance from every detection point in year N-1 to every detection point in year N[2]
2. Calculate the average spread rate for each year by summing the total distance (in kilometres) calculated from Step 1 and dividing it by the number of unique distance calculations.
3. Complete the steps 1 and 2 for each cluster.
4. Calculate the weighted average for each cluster, where the weights are equivalent to the amount of detection points in year N multiplied by detection points in year N-1 for each year.

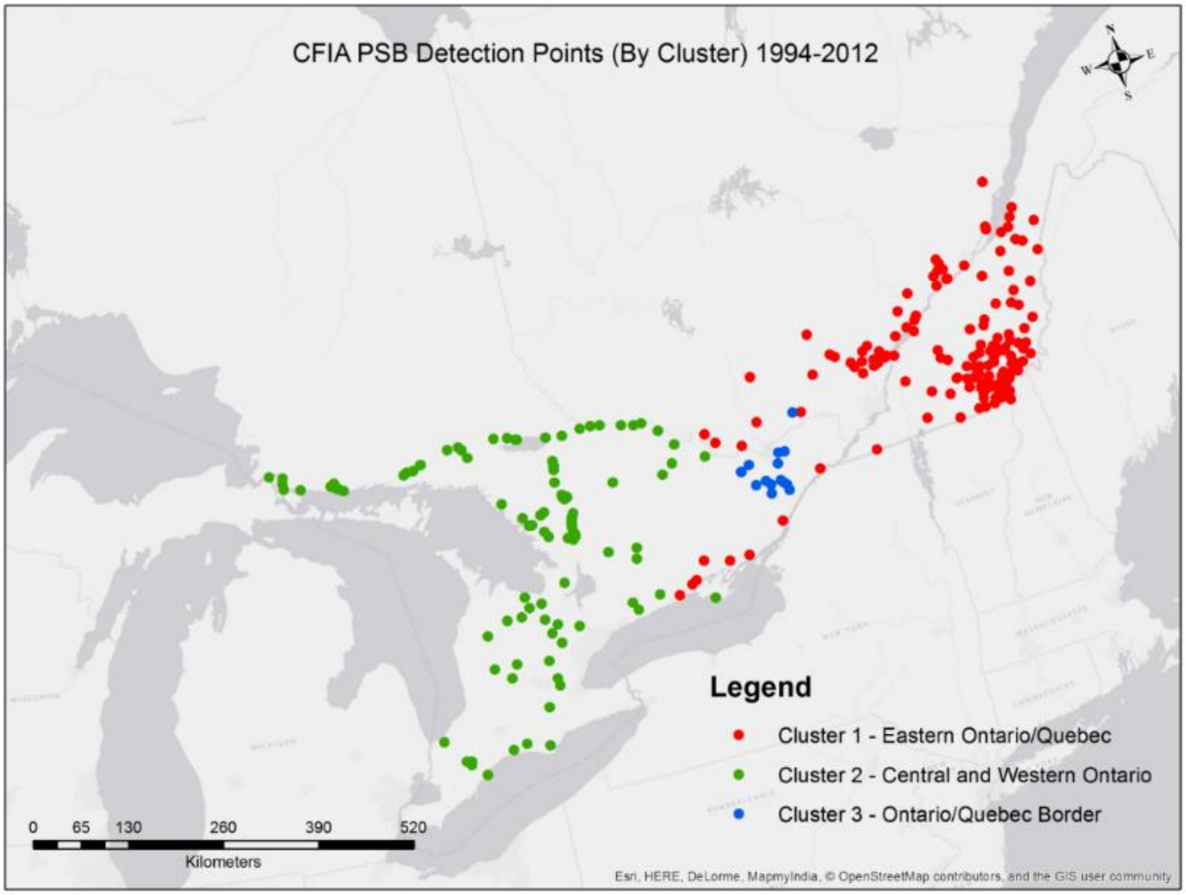

Figure 4 Clusters of Detection Points

We then averaged the three cluster averages to arrive at an estimated spread rate of 99.5 km/yr. For analysis, we rounded this estimate up to 100 km/yr. for the regulated scenario. As there is considerable uncertainty with the spread rate under regulation, we also

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[2] Distance is calculated using the distance formula from the Pythagorean Theorem: $d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$, where (x_1, y_1) are the geographic Cartesian coordinates for the detection point in year N-1 and (x_2, y_2) are the coordinates for the detection point in year N.

considered a spread rate similar to the USDA of 40km/yr. and a complete containment spread rate of 0 km/yr. The later spread rate of 0 km/yr. recognizes that little PSB spread has been observed between 2009 and 2014, the most recent years of data. All analysis was done using the GIS software ArcGIS (ESRI 2017).

The unregulated spread rate was assumed to be 300km/yr. which was adapted from the USDA-APHIS 2015 analysis. The US study used an unregulated spread rate of 240km/yr. based on an observed timber-buying radius for large mills in the northeast of the US (150 miles/yr. ≈ 240km/yr.) (Fowler et al., 2015). The timber-buying radius best represents the distance that infested timber can spread via shipment within a year. However, for our analysis, we did not have information on the average travel distance of logs to mills. We considered the distance between mills outside of the present quarantine area (area at risk of spread) as a measure of potential spread. The distances between mills are large in Ontario, often over 250km, but much less in Quebec and the Maritimes, often less than 100km. To be conservative in our estimation of damage, we chose an unregulated spread rate of 300 km/yr. This high spread rate means calculated damage were greater than the spread rate of 240km/yr. used in the US study. We also considered a lower spread rate of 100km/yr. for comparative purposes.

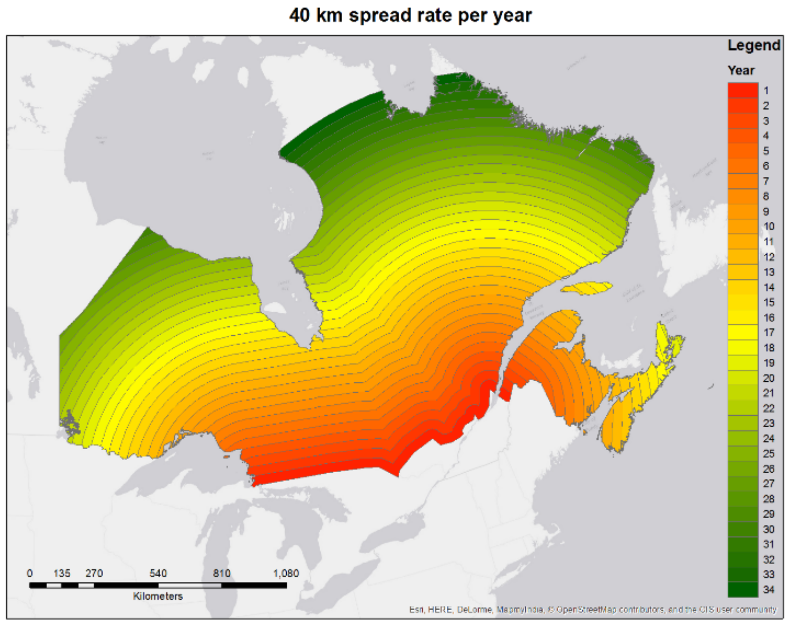
Estimating total and annual areas vulnerable to the pine shoot beetle

We considered all merchantable forest area within Ontario, Quebec and the Atlantic provinces, except Newfoundland, to be at risk for the PSB. This included merchantable timber in northern latitudes that are far from existing forest management and processing plants. While it is unclear how the PSB could move into northern areas of Ontario and Quebec, given the lack of industry and low density of merchantable pine timber, we made this assumption to simplify the GIS analysis and to keep the analysis conservative (i.e. estimating higher potential damages from PSB).

At the same time, we did not consider areas west of Ontario to be at risk because the wood industry is located in southern Manitoba outside the boreal forest. For the PSB to move westward through Manitoba, a population would need to move from eastern Ontario to southern Manitoba, to then establish itself in an area with very few pine trees. This new population would have to move northwestward to central Manitoba and Saskatchewan. Such a sequence of events seems highly improbable. We also ruled out the movement of the PSB from Minnesota, currently under US quarantine, into Manitoba. However, if the US discontinues its quarantine, it would be conceivable that the PSB could migrate northward into Manitoba from Minnesota or other U.S. states. Nevertheless, since much of the traded forest products would end up in Winnipeg, it is doubtful that the PSB would take hold in southern Manitoba and then migrate northwestward. As such, we did not extend the analysis west of Ontario.

We utilized the concept of buffer zones in the GIS analysis to represent new areas susceptible to PSB for each year into the future until all areas within the study scope were occupied. The initial area from which the buffer zones spread out was an area already containing pine shoot beetles. The spread used the outermost points of detection as the initial location (this can be considered t=0 area, where t is the year of analysis). A greater spread rate creates more area affected by the PSB each year. Figure 5 illustrates the buffer zones for each year for different spread rates of 40 km/yr., 100 km/yr., and 300 km/yr., respectively.

Digital data maps constructed by Beaudoin et al. (2014) using Canada's National Forest Inventory (NFI) were used to calculate forest area within the study area. Using ARCGIS, we tabulated the forest area for each buffer zone.


40 km spread rate per year

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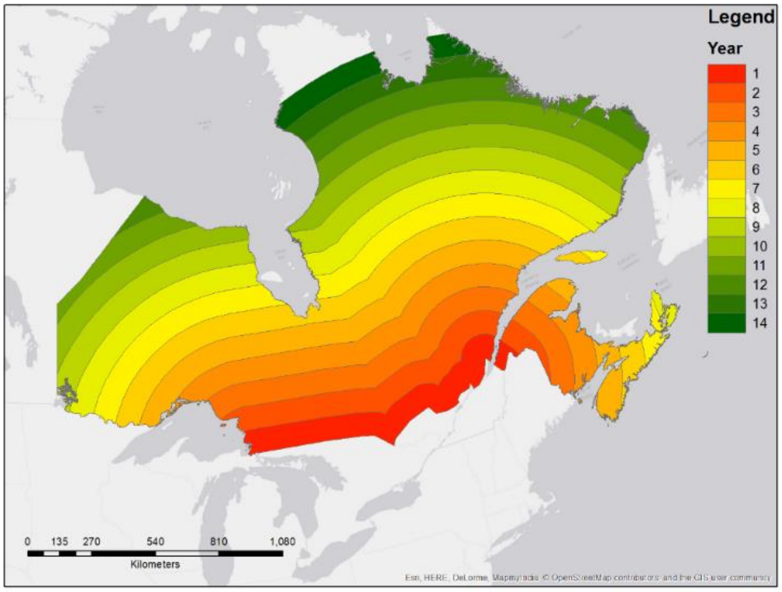
100 km spread rate per year

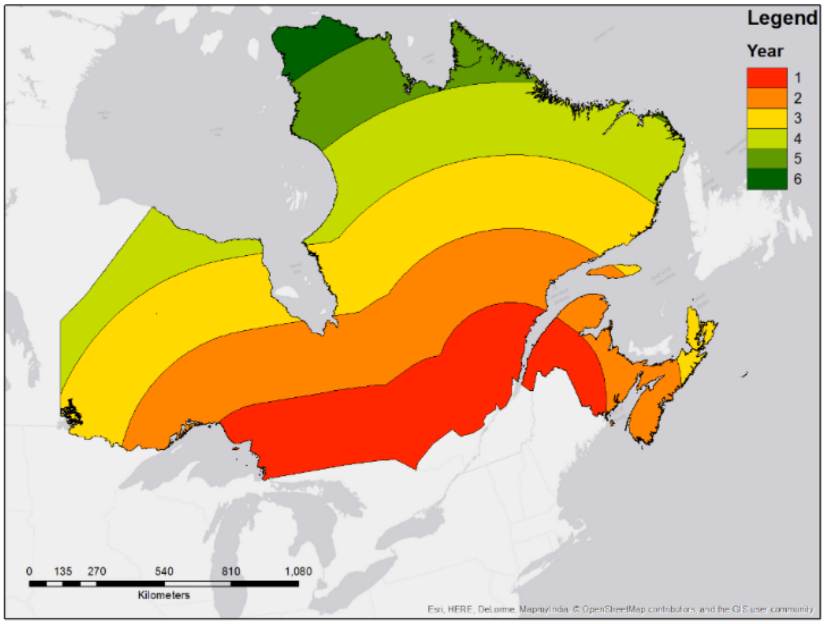
300 km spread rate per year

Figure 5 Buffer zones under expected spread rates under two alternative regulation rates (40/km/yr. and 100 km/yr.) and unregulated rate (300 km/yr.)

Merchantable Volume of Pine Vulnerable to PSB

The amount of potential merchantable volume threatened by PSB was estimated in three steps. Estimates of the average merchantable volume of timber (m^3/ha) per buffer were calculated using ARCGIS and the digital map data files created by Beaudoin et al. (2014) from National Forest Inventory photo plot data. Together with the estimated area (ha) of merchantable timber in each buffer zone, the product of the buffer area in hectares and per hectare estimates of merchantable volume (m^3/ha) in each buffer resulted in an estimate of the total merchantable volume (m^3) in each buffer zone.

Using the same digital map data (Beaudoin et al. 2014), an estimate of the proportion of pine trees (weighted by above-ground biomass) in each buffer zone was calculated. Multiplying the merchantable timber volume with the proportion of pine provided an estimate of the volume of merchantable pine vulnerable to the PSB in each buffer zone.

We assumed that merchantable timber volume per hectare and the proportion of pine for each buffer zone would be centralized between lower and upper estimates calculated from the Beaudoin et al (2014) digital map data files. As such, we modeled each of these values by buffer zone with a PERT distribution based on the minimum, maximum and mean (i.e. most likely value) estimates from Beaudoin et al (2014).

Annual Kill Rate of Pine Caused by PSB

Like Fowler et al. (2015), we drew from the European experience with PSB to estimate a mortality rate for pine areas occupied by the PSB, calculated from data reported in Grégoire and Evans (2004). However, unlike Fowler et al. (2015), we estimated the mortality of vulnerable pine volumes by multiplying our estimate of vulnerable pine by an estimate of the proportion of pine killed within the total area of vulnerable pine stands. Fowler et al. (2015), on the other hand, estimated pine mortality in three steps. First, they estimated the proportion of vulnerable pine area damaged using data from Grégoire and Evans (2004). They then multiplied this area by pine density per hectare taken from U.S. national forest data to estimate the amount of pine volume damaged. Finally, using an estimate of the proportion of pine killed within the area damaged in the European study, they calculated the pine volume killed by multiplying the damaged volume estimate by the mortality proportion. In contrast, our mortality proportion is simply the product of the two proportions used in the USDA-APHIS study. We summarize this in Table 1.

Table 1 Proportions of mortality and damage used in Fowler et al (2014) and in this study.

	USDA-APHIS (Fowler et al. 2014)*			Our estimates		
	Low	Most likely	High	Low	Most likely	High**
Proportion of area damaged	0	0.02847	0.0497			
Proportion of volume killed within damaged area	0	0	0.0042			
Proportion of volume killed within total area of vulnerable pine				0	0	0.00021

*Note proportion of area damaged estimated from Romanian data reported in Grégoire and Evans (2004) – 2 235 ha of area damaged divided by 45 000 ha of vulnerable pine (=0.0497). Mortality proportion calculated from cubic metres killed in the Romania case reported in Grégoire and Evans (2004), 2 028 m^3, divided by estimated vulnerable volume in the damaged area, which was calculated using average per hectare volume in Romania (217.55 m^3/ha) times area damaged (2 235 ha) (=2028/(217.55*2 235 = 0.0042).

**This proportion is the product of the proportion of area damaged and the proportion of volume killed within damaged area from Fowler et al. (2014) (=0.0497*0.0042=0.00021). This can also be calculated by dividing total volume killed in Romania (2 028 m^3) by total volume of vulnerable timber in Romania, which is equal to vulnerable area (45 000 ha) times average volume per hectare (217.55 m^3/ha) in Romania (=2 028/ (45 000*217.55) = 0.00021).

We assumed the proportion of pine killed was centralized between lower and upper estimates. Like the USDA-APHIS study, we assumed a PERT distribution with a value of zero for lower and most likely estimates of mortality. This is because the PSB primarily causes growth losses, which are often temporary (Långström and Hellqvist, 1991), and predominantly attacks on already stressed or weakened trees (CABI, 2014; Morgan et al. 2004). We assumed an upper estimate of 0.00021 of the proportion killed. This expected PERT distribution results in a mean mortality rate of 0.000035. For illustrative purposes, we also calculated the mean mortality proportions that are required for the program to break even.

As per expert opinion from the USDA-APHIS, we assumed there is a ten-year lag before PSB populations reach a critical level where tree mortality occurs (Fowler et al., 2015).

Annual Timber Volume and Value killed from PSB

To calculate the volume of pine trees killed in each buffer area by the PSB, we took the estimated volume of vulnerable trees and multiplied it by the proportion of pine killed by the PSB.

To calculate the value of timber killed, we multiplied the estimated volume of killed pine trees by an average value of the timber, or stumpage price. We used the Ontario crown timber charges for forestry companies as the proxy price for all pine timber values in the study area (OMNR 2017). In Ontario, forest companies pay for timber they harvest on Crown land by the cubic metre (Ghouri, 2016). The Ontario Ministry of Natural Resources' pricing system calculates the stumpage (timber price) based on timber species, area, and monthly market prices of pulp and lumber products. As reported mortality from PSB is very small, crown stumpage charges are a reasonable proxy for standing timber values.

We assumed that stumpage price was distributed around a central value between a minimum and maximum value. The minimum value is calculated by taking the monthly minimum price of Jack pine for 2016 assuming a 1:2 ratio of pulp to saw logs for each cubic metre. For the most likely value, we calculated the monthly average price of Jack pine for the same period and same pulp to saw log ratio. We use only Jack pine prices because most of the vulnerable pine outside of the current area occupied by the PSB is Jack pine. For the maximum stumpage value, we employed the average of the maximum monthly stumpage price for all pine, including white and red pine, observed in 2016. Again, we used a PERT distribution with a minimum value of \$11.24 per m^3, a most likely value of \$13.93 per m^3, and a maximum value of \$16.72 per m^3.

Impact Analysis

We estimated and compared the possible impact of PSB spread in Canada with and without regulatory programming by the Federal government. To do so, we estimated the costs and benefits of the regulated and unregulated scenarios, and compared the net benefits over time. For each regulated spread rate scenario, a time-period of 24 years was used for a spread rate of 100 km/yr. (14 years of spread plus 10 years for full occupation by the PSB while a time-period of

44 years was used for a 40km/yr. spread rate).

A. Discount rate

We discounted projected timber damage and program cost for both regulated and deregulated scenarios using a real discount rate to account for assumed time preference of current consumption over future consumption. Annual discount factor was calculated as:

Discount factor = $1/(1+r)^t$

Where r, the real discount rate, was 3, 4, or 5 percent. For comparison, the US study (Fowler et al. 2015) assumed a discount rate of 3.9%. These values align with estimates of 2.5-3.5% for long-term investments on public lands in Canada (Boardman et al. 2010).

B. Annual damage values with and without regulation

We calculated annual damage for the regulated and deregulated scenarios by multiplying estimated timber killed by stumpage value (timber price). This damage occurred ten years after initial occupation by the pine shoot beetle, which is consistent with the assumption that it takes 10 years for 100% occupation and for potential damage to come about. The time period of analysis was 24 years for a regulated spread rate of 100km/yr. and 44 years for a regulated spread rate of 40km/yr. We assumed a 44 year time period for a zero-spread-under-regulation scenario.

The difference between annual damages under the regulated spread scenario and the deregulated spread scenario is the estimated avoided losses from deregulation. The annual avoided losses are the benefits of regulation.

C. Annual costs of regulation

We estimated annual program costs from 2015/2016 data provided by the CFIA. Annual costs consist of expenses from conducting inspections, providing clearance certificates, and conducting lab test in federal labs associated with the movement of pine plants and products regulated under directive D-94-22: *"Plant Protection Requirements on Pine Plants and Pine Materials to Prevent the Entry and Spread of Pine Shoot Beetle"* (CFIA, 2013).

Specifically, the CFIA provided the number of inspections, clearance certificates and lab hours for Ontario, along with hours associated with each task. In the absence of data for Quebec, we doubled the Ontario data to provide the current costs of regulation for Canada.

Certificate data consisted of domestic, import and export shipments. Because it is unclear who bears the regulatory cost of importing shipments, we created two cost scenarios. The first and lowest cost scenario, excluded the costs of certificates for imported regulated pine plants and products into Canada. This scenario assumed the costs of regulation are borne by U.S. exporters and therefore outside the scope of our analysis. The second scenario includes import certificates. This was our high cost scenario, which assumed that all costs of importing regulated materials are borne by Canadians. As we only had one year of cost data, we assumed that the cost estimate would be constant throughout the analysis period. We calculate the low cost annual estimate to be $122 642 and the high cost annual estimate to be $423 012. In either scenario, annual costs only occurred for number of years it took for the PSB to spread under regulation to study area boundaries. Therefore, for the spread rate of 100 km/yr., costs occur over 14 years while for a 40km/yr. spread rate costs occur over 24 years. For the zero spread rate scenario, we only accounted for costs for 44 years, even though the program period is indefinite.

D. Net program benefits

We calculated the net program benefits by subtracting the annual program costs from the annual avoided losses (benefits), discounted by the relevant discount factor, and then summed over the total number of years, either 24 years or 44 years for a spread rate of 100 km/yr. or 40 km/yr., respectively.

Results and Discussion

A. Impact Analysis: Spread rate scenario I (100 km/yr.)

In spread rate scenario I (spread 100 km/yr. and 24 years of analysis) and low cost of regulation, the mean discounted net benefits of regulation were -$1.08 million, -$0.99 million, and -$0.92 million for discount rates of 3%, 4% and 5%, respectively (Table 2 and Figure 6). The net negative benefits from the regulation are due to mean costs of regulation exceeding the mean avoided damages (benefits) of regulation. There is an 11.5%, 11.4%, and 11.0% probability that the regulatory program would result in a net positive benefit for a 3%, 4%, and 5% discount rate, respectively.

The same spread scenario with higher costs of regulation resulted in much larger net negative benefits of regulation. Under these cost conditions, there is a 1.2%, 1.1%, and 0.9% chance the regulatory program would result in a net positive benefit for a 3%, 4%, and 5% discount rate, respectively.

Table 2 Impact analysis: damage scenario I, 100 km/yr. spread under regulation and 300 km/yr. spread under deregulation with low and high cost scenarios

	Discount Rate		
	3%	4%	5%
Loss with no Program	$1,480,061	$1,314,253	$1,168,452
Loss with Program	$1,175,895	$1,012,136	$873,137
Avoided Losses	$304,167	$302,117	$295,315
Low Program Costs	$1,385,373	$1,295,483	$1,213,989
Net Benefits with low costs	-$1,081,206	-$993,365	-$918,674
High Program Costs	$4,778,374	$4,468,328	$4,187,244
Net Benefits with high costs	-$4,474,208	-$4,166,210	-$3,891,929

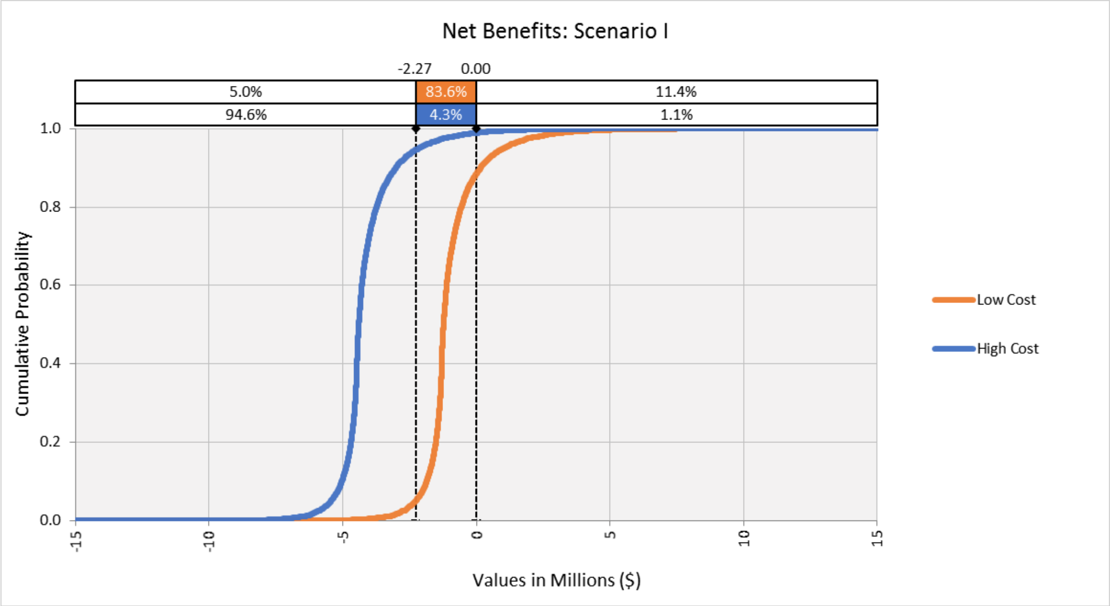

Figure 6 Cumulative distribution function for the damage scenario I impact analysis with a regulated spread rate of 100km/yr., a deregulated spread rate of 300km/yr., low and high costs of regulation, and a discount rate of 4%.

B. Impact Analysis: Spread rate scenario II (40 km/yr.)

In spread rate scenario II (spread 40 km/yr. and 44 years of analysis) and low cost of regulation, the mean discounted net benefits of regulation were -$1.95 million, -$1.63 million, and -$1.37 million for discount rates of 3%, 4% and 5%, respectively (Table 3 and Figure 7). The net negative benefits from the regulation were due to mean cost of regulation exceeding the mean avoided damage (benefits) from regulation. There is a 6.4%, 7.5%, and 8.3% probability the regulatory program results in a net positive benefit for a 3%, 4%, and 5% discount rate, respectively.

The same spread scenario with higher cost of regulation resulted in much larger net negative benefits of regulation. Under these cost conditions, there was a 0.2%, 0.2%, and 0.3% chance the regulatory program would result in a net positive benefit for a 3%, 4%, and 5% discount rate, respectively.

Table 3 Impact analysis: damage scenario II, 40 km/yr. spread under regulation and 300 km/yr. spread under deregulation with low and high cost scenarios

	Discount Rate		
	3%	4%	5%
Loss with no Program	$1,480,061	$1,314,253	$1,168,452
Loss with Program	$841,856	$682,159	$556,577
Avoided Losses	$637,851	$632,142	$612,177
Low Program Costs	$2,591,651	$2,257,986	$1,985,930
Net Benefits with low costs	-$1,953,800	-$1,625,844	-$1,373753
High Program Costs	$8,939,020	$7,788,158	$6,849,793
Net Benefits with high costs	-$8,301,170	-$7,156,015	-$6,237,616

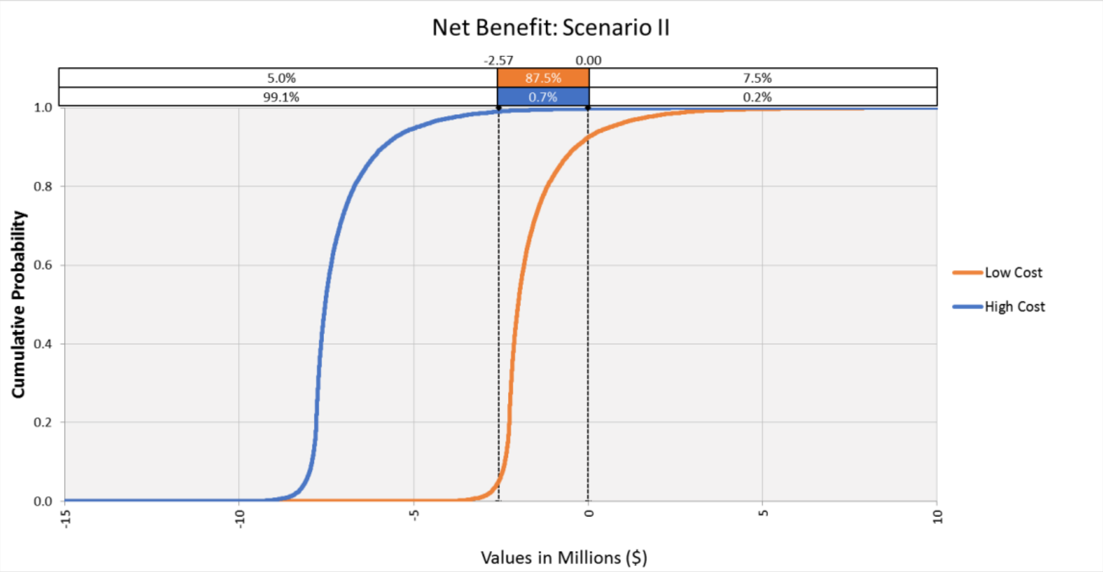

Figure 7 Cumulative distribution function for the damage scenario II impact analysis with a regulated spread rate of 40km/yr., a deregulated spread rate of 300km/yr., low and high costs of regulation, and a discount rate of 4%.

C. Impact Analysis: Spread rate scenario III (0 km/yr.)

In spread rate scenario III (spread of 0 km/yr. for the regulated scenario and 44 years of analysis) and low cost of regulation, the mean discounted net benefits of regulation were -$1.11 million, -$0.95 million, and -$0.82 million for discount rates of 3%, 4% and 5%, respectively (Table 4 and Figure 8). The negative net benefits from the regulation were due to the mean cost of regulation exceeding the mean avoided damage (benefits) from regulation. There was a 16.9%, 17.4%, and 17.7% probability that the regulatory program would result in a positive net benefit for a 3%, 4%, and 5% discount rate, respectively.

The same spread scenario with higher costs of regulation resulted in much larger negative net benefits of regulation. Under these cost conditions, there was a 0.6%, 0.7%, and 0.7% chance that the regulatory program would result in a positive net benefit for a 3%, 4%, and 5% discount rate, respectively.

Table 4. Impact analysis: damage scenario III, 0 km/yr. spread under regulation and 300 km/yr. spread under deregulation with low and high cost scenarios.

	Discount Rate		
	3%	4%	5%
Loss with no Program	$1,480,061	$1,314,253	$1,168,452
Loss with Program	$0	$0	$0
Avoided Losses	$1,480,061	$1,314,253	$1,168,452
Low Program Costs	$2,591,651	$2,257,986	$1,985,930
Net Benefits with low costs	-$1,114,322	-$946,138.60	-$819,599.10
High Program Costs	$8,939,020	$7,788,158	$6,849,793
Net Benefits with high costs	-$7,461,692	-$6,476,310	-$5,683,462

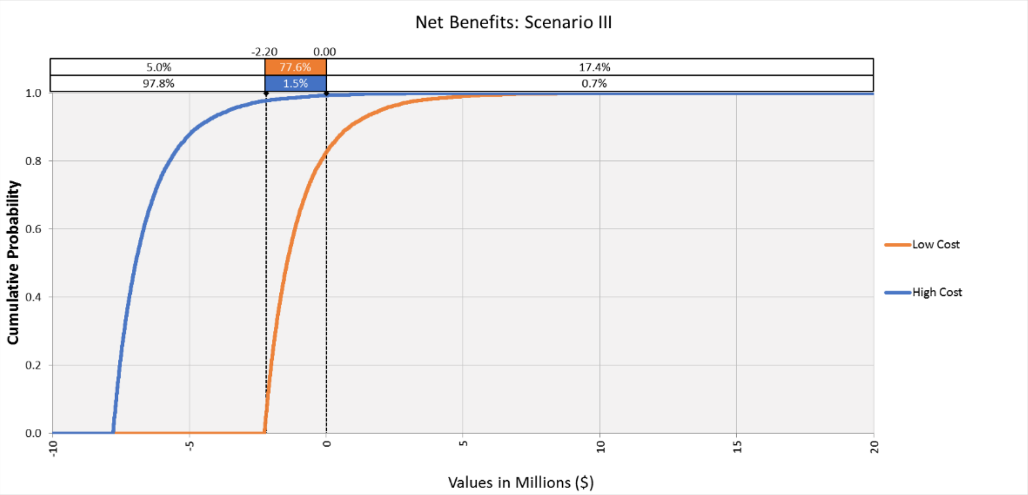

Figure 8 Cumulative distribution function for the damage Scenario III impact analysis with a regulated spread rate of 0km/yr, a deregulated spread rate of 300km/yr., low and high costs of regulation, and a discount rate of 4%.

D. Break even mortality scenario

Using the base case spread rates of 100 km/yr. under regulation and 300 km/yr. under deregulation, low program costs, and a discount rate of 4%, we estimated the mortality rate that would likely result in the PSB slow-the-spread program to break even. For this to occur, the program benefits (avoided damage) needed to be at least equal or greater to the program costs. Since we used a probabilistic model, we considered two measures. For the first measure, we calculated the mortality rate needed to result in the expected (mean) net present value to be zero. For the second measure, we calculated the mortality rate that resulted in a value of zero for the median net present value (NPV). In other words, we calculated the mortality rate that resulted in 50:50 odds of breaking even. Given that the underlying input and output distributions were not generally normally distributed (bell shaped), we did not expect the mean and median values to be the same.

We found the mortality rate needed to be 0.00016, or 460% higher than average mortality rate of the assumed mortality PERT distribution for the expected NPV to be zero (Figure 9). Moreover, we determined that the mortality rate had to be 0.00026, or 740% higher than the average mortality rate used in the impact analysis for median NPV to be zero (Figure 10).

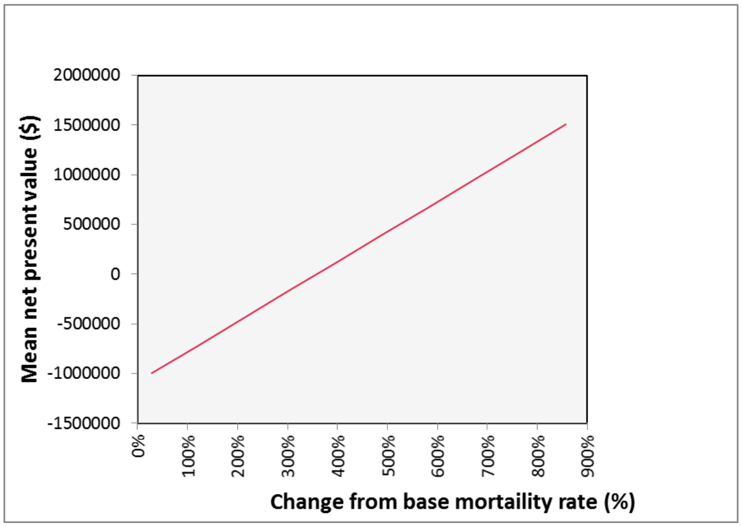

Figure 9 Relationship between mortality rates and mean net present value.

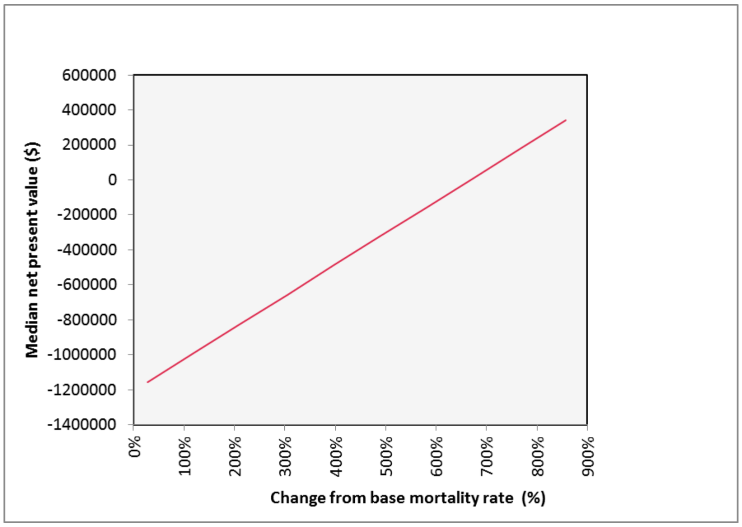

Figure 10 Relationship between mortality rates and median net present value.

E. Results of the Model

Our results indicated that the program to slow the spread of *Tomicus piniperda* from the existing occupied areas in Canada is inefficient. While there was a benefit in reducing damage from the pine shoot beetle, the avoided losses are less than the regulatory cost of the program. Our model predicted only about an 8%-17% chance that the program would avoid enough damage over the next few decades to justify the expense of the program. For the program to be beneficial, the mortality rate would have to be considerably higher than modelled in this study. Moreover, currently available information does not suggest higher mortality rates in the future, albeit there is scant information on mortality rates in Canada or elsewhere. However, the inclusion of other values, especially carbon, might increase the benefits of the program. At the same time, it is not clear, given the low mortality rates associated with the PSB, and the fact that PSB damages tend to be associated with stressed trees, that these additional values would have a considerable impact. Additionally, our analysis included a large area of forest and merchantable pine timber that is unlikely to be vulnerable to the PSB. If we considered a narrower and more realistic area of vulnerable timber land, such as only areas around mill sites or along transportation corridors, then the chances of the program generating a net benefit would be even smaller.

Summary and Conclusions

We constructed a probabilistic model that creates a distribution of the estimates of the value of timber killed by the pine shoot beetle, *Tomicus piniperda*, an alien invasive species, if it were to expand from its current range in southern Ontario and Quebec. Using a method developed by the USDA-APHIS, our goal was to evaluate the efficiency of the regulatory program to slow the spread of this pine shoot beetle (PSB). We modelled the annual pine timber damages based on the PSB's dispersal rate with and without a regulatory program to slow its spread. We considered two spread rates under regulation, one that involved a 24-year period of analysis and another that involved a 44-year period of analysis.

We reported the output of the impact analysis that evaluated the efficiency of the regulatory program to distribute tree mortality over a longer period than without such a program. The estimated impacts from pest damage with and without regulation were also compared to the cost of regulation. The regulatory program was judged beneficial if the avoided damage from regulation was greater than the cost of the regulation.

We found that the program is not beneficial since the avoided damage was less than the calculated cost of regulation. Moreover, we determined that even if the program is more effective in slowing the spread than calculated in this study, the net program benefits remain negative.

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References

ESRI, 2017. https://www.arcgis.com/features/index.html

Bakke, A., 1968. Ecological studies on bark beetles, Coleoptera: Scolytidae, associated with Scots pine (*Pinus sylvestris* L.) in Norway with particular reference to the influence of temperature. Vollebekk.

Beaudoin, A.; Bernier, P.Y.; Guindon, L.; Villemaire, P.; Guo, X.J.; Stinson, G.; Bergeron, T.; Magnussen, S.; Hall, R.J., 2014. Mapping attributes of Canada's forests at moderate resolution through kNN and MODIS imagery. Can. J. For. Res. 44:521-532.

Boardman, A.E., Moore, M.A., Vining A.R. 2010. The social discount rate for Canada based on future growth in consumption. Canadian Public Policy 36(3): 325–343. http://dx.doi.org/10.3138/cpp.36.3.325

CABI, 2013. "Tomicus piniperda (common pine shoot beetle)." At: http://www.cabi.org/isc/datasheet/54154

Carter, M.C., J.L. Robertson, R.A. Haack and J.L. Hayes, 1996. "Genetic relatedness of North American populations of Tomicus piniperda (Coleoptera: Scolytidae)." *Journal of Economic Entomology* 89: 1345-1353

CFIA, 2013. "D-94-22: Plant Protection Requirements on Pine Plants and Pine Materials to Prevent the Entry and Spread of Pine Shoot Beetle."

Dalton, Jill, 2016. Personal communication. CFIA; Plant Health Science Services Division.

Dawson, Marcel. 2016. Personal Communications. Canadian Food Inspection Agency.

ESRI, 2017. https://www.arcgis.com/features/index.html

Fowler, G. and D. Borchert, 2006. "Organism pest risk assessment: risks to the Continental United States associated with pine shoot beetle, Tomicus piniperda (Linnaeus), (coleopteran: Scolytidae)." 61pp. Raleigh, NC: USDA-APHIS-PPQ-CPHST-PERAL.

Fowler, G., Y. Takeuchi, T. Vo and L. Garret (2015) "Pine Shoot Beetle, *Tomicus piniperda* (Linnaeus): Analysis of Regulatory Options. *Analysis of Regulatory Options Rev. 01 20150219*. At: https://www.aphis.usda.gov/plant_health/plant_pest_info/psb/downloads/psb-analysis-regulatory-options.pdf

Ghouri, W., 2016. Personal communication. Ontario Ministry of Resources and Forestry.

GISD (Global Invasive Species Database). 2017. Species profile: Tomicus piniperda. Downloaded from http://www.iucngisd.org/gisd/speciesname/Tomicus+piniperda on 02-06-2017.

Grégoire, J.C. and H.F. Evans, 2004. "Damage and control of BAWBILT organisms, an overview" in *Bark and Wood Boring Insects in Living Trees in Europe, a Synthesis* (eds F. Lieutier, K. R. Day, A. Battisti, J. C. Gregoire & H. F. Evans). Kluwer, Dordrecht: 19-37.

Haack, R.A. and R.K. Lawrence, 1995. “Attack Densities of *Tomicus Piniperda* and *Ips pini* (Coleoptera: Scolytidae) on Scotch Pine Logs in Michigan in Relation to Felling Date,” *Journal of Entomological Science* 30(1): 17-28.

Haack, R.A. and T.M. Poland, 2001. “Evolving management strategies for a recently discovered exotic forest pest: the pine shoot beetle, Tomicus piniperda (Coleoptera), *Biological Invasions* 3: 307-322.

Haack R.A., T.M. Poland and W.E. Heilman, 1998. “Using historical temperature records to adjust the federal quarantine of the pine shoot beetle” in *Proceedings of the 13th Conference on Biometeorology and Aerobiology*: 319–322.

Hui, Y. 1991. “On the bionomy of *Tomicus piniperda* (L.) (Col.,Scolytidae) in the Kunming region of Chin,” *Journal of Applied Entomology* 112: 366–369.

Humphreys, N. and E.A. Allen, 1999. “The pine shoot beetle,” *Natural Resource Canada CFS: Exotic Forest Pest Advisory* 2.

Kauffman, W.C., R.D. Waltz and B.R. Cummings, 1998. “Shoot feeding and overwintering behavior of *Tomicus piniperda* (Coleoptera: Scolytidae): Implications for Management and Regulation,” *Journal of Economic Entomology* 91: 182–190

Koelling, M.R., 2017. “Scotch Pine.” Downloaded from http://www.realchristmastrees.org/dnn/Education/Tree-Varieties/Scotch-Pine on 02-06-2017.

Långström, B., H. Piene, R. Fleming, C. Hellqvist. 1998. “Shoot and Needle Losses in Scots Pine: Experimental Design and Techniques for Estimating Needle Biomass of Undamaged and Damaged Branches,” in *Proceedings: Population Dynamics, Impacts and Integrated Management of Forest Defoliating Insects, USDA Forest Service General Technical Report NE-247 (eds. M.L. McManus and A.M. Liebhold):* 230-246.

Långström, B. and C. Hellqvist, 1991. Shoot damage and growth losses following three years of *Tomicus*-attacks in Scots pine stands close to a timber storage site. Silva Fennica. Vol.25 No. 3: 133-145. Långström, B. and C. Hellqvist, 1993. “Induced and spontaneous attack by pine shoot beetles on young Scots pine trees: tree mortality and beetle performance” *Journal of Applied Entomology* 115, 25-36.

Långström, B., O. Tenow, A. Ericsson, C. Hellqvist and S. Larsson, 1990. “Effects of shoot pruning on stem growth, needle biomass, and dynamics of carbohydrates and nitrogen in Scots pine as related to season and tree age” *Canadian Journal of Forest Research* 1990 20, 514-523.

Lombardero, Maria J, Patricia Vazque-Mejuto and Matthew P. Ayres, 2008. “Role of Plant Enemies in the Forestry of Indigenous vs Non-Indigenous Pines,” *Ecological Applications* 18(5): 1171-1181.

Morgan, R.E., P. De Groot, and S.M. Smith, 2004. “Susceptibility of pine plantations to attack by the pine shoot beetle (Tomicus piniperda) in southern Ontario,” *Canadian Journal of Forest Research* 34: 2528-2540.

NRCan / RNCan, 2015. “Pine shoot beetle.” At: http://tidcf.nrcan.gc.ca/en/insects/factsheet/1000093

OMNR (Ontario Ministry of Natural Resources). 2017. Downloaded from https://www.ontario.ca/data/crown-timber-charges-forestry-companies on 05-03-2017.

Palisade Corporation. 2016. @Risk 7.5.1: Industrial Edition. http://www.palisade.com/risk/

Petrice, T.R., R.A. Haack and T.M. Poland T.M., 2002. “Selection of overwintering sites by *Tomicus piniperda* (Coleoptera: Scolytidae) during fall shoot departure,” *Journal of Entomological Science* 37: 48–59.

Ryall, Krista Lee, 1997. “Biology of the recently introduced pine shoot beetle Tomicus piniperda (L.) (Coleoptera, scolytidae) in Southern Ontario” (Master’s thesis) University of Toronto, Toronto, Canada.

Salonen, K., 1973. “On the life cycle, especially on the reproduction biology of *Blastophagus piniperda* L. (Col., Scolytidae).” *ActaForestalia Fennica* 127: 1–72.

Schroeder, L.M., 1988. “Attraction of the bark beetle *Tomicus piniperda* and some other bark- and wood-living beetles to the host volatiles alpha-pinene and ethanol” *Entomologia Experimentalis et Applicata* 46: 203–210.

Siegert, N.W., D.G. McCullough. 2001. Survey of shoot damage caused by the exotic pine shoot beetle in Michigan pine stands. Northern Journal of Applied Forestry 18(4):101-109.

Sikström, U., G. Jansson, J. Weslien. 2005. Predicting the mortality of Pinus sylvestris attacked by Gremmeniella abietina and occurrence of Tomicus piniperda colonization. *Canadian Journal of Forest Research* 35:860-867, https://doi.org/10.1139/x05-012

Appendix 1 – Calculations and data for the Pine Shoot Beetle timber damage model.

Component (N=number;P=proportion)	Unit	Distribution/Equation/Notes	Source(s)
N1. Merchantable forest area	Hectares	Annual area estimated from NFI GIS data with ARCGIS for each year of spread under Scenario 1: regulation with 100 km/yr. spread (14 years) and deregulation with 300 km/yr. spread (5 years) and Scenario 2: regulation with 40 km/yr. spread (24 years) and deregulation with 250 km/yr. spread (6 years)	Beaudoin et al (2014), National Forest Inventory (NFI), Fowler et al. (2015)
N2. Merchantable forest volume per hectare	Cubic metres per hectare	PERT(0,ML,Max) by year for regulated and deregulated areas	Beaudoin et al (2014), National Forest Inventory (NFI)
P1. Proportion of pine	Proportion	PERT(0,ML,Max) by year for regulated and deregulated areas	Beaudoin et al (2014), National Forest Inventory (NFI)
N.3 Vulnerable merchantable volume of pine	Cubic metres	N1*N2*P1	
P2. Proportion of damaged pine killed	Proportion	PERT(0,0,0.00021)	Grégoire and Evans (2004), Fowler et al. (2015)
N4. Volume of pine killed	Cubic metres	N3*P2	
N5. Value per cubic metre	Dollars per cubic metre	PERT(11.24,13.93,16.72)	OMNR (2017)
N6. Value of pine timber killed	Dollars	N4*N5	
P4. Interest rate	proportion	0.03, 0.04 or 0.05	
N7. Present value of pine killed under regulation and deregulation	Dollars	N6 divided by $(1+P4)^{t+10}$ where t is the year of spread summed for all years under regulation (24 years or 34 years) or deregulation (5 years), respectively. Note timber was killed ten years after year of occupation.	

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